WAREHOUSE AUTOMATION SOLUTIONS

PPG Tikkurila

Lappeenranta–Lahti University of Technology LUT

Master's degree programme in Industrial Engineering and Management

2022

Risto Keskinen

Examiner(s): Professor Timo Pirttilä

ABSTRACT

Lappeenranta–Lahti University of Technology LUT

LUT School of Engineering Sciences

Industrial Engineering and Management

Risto Keskinen

Warehouse automation solutions

PPG Tikkurila

Master's thesis

2022

71 pages, 27 figures, 9 tables and 3 appendices

Examiner: Professor Timo Pirttilä

Keywords: Warehouse automatization, Pick by Voice, Automated Guided Vehicle, Automated Storage and Retrieval System, Automated Warehouse, Semi Automated Warehouse, Manual Warehouse.

This thesis introduces the reader to PPG Tikkurila as a company and how its warehousing and logistics are handled currently. The aim of the thesis is to find automation solutions that could improve the efficiency of warehousing processes in PPG Tikkurila.

At the beginning of the work, the principles of warehousing and logistics in business are reviewed and various warehousing solutions, such as manual warehousing, semi-automatic warehousing, and automatic warehousing, are introduced in more detail. Nowadays automatization can be found almost everywhere, and the warehousing industry is no exception. The thesis provides a general overview of the automation technologies used in logistics companies and how these technologies can be utilized in warehousing today.

After introducing the reader to existing technologies, different automation solutions, their advantages and how they could be implemented into the PPG Tikkurila warehouse are evaluated. Finally, the most suitable solution for PPG Tikkurila is selected and more detailed investment payback calculations and requirements for efficiency improvements are presented based on a preliminary offer received from a selected supplier.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

LUT School Of Engineering Sciences

Tuotantotalouden koulutusohjelma

Risto Keskinen

Varaston automaatioratkaisut

PPG Tikkurila

Master’s thesis

2022

71 sivua, 27 kuvaa, 9 taulukkoa ja 3 liitettä

Tarkastaja: Professori Timo Pirttilä

Avainsanat: Varastoautomaatio, Äänikeräily, AGV, AS/RS, Automaattinen varasto, Puoliautomaattinen varasto, Manuaalinen varasto

Tämä opinnäytetyö esittelee lukijalle PPG Tikkurilan yrityksenä ja miten sen varastointi ja logistiikka hoidetaan tällä hetkellä. Opinnäytetyön tavoitteena on löytää automaatioratkaisuja, jotka voisivat parantaa PPG Tikkurilan varastoprosessien tehokkuutta.

Työn alussa käydään läpi liiketoiminnan varastoinnin ja logistiikan periaatteet ja esitellään tarkemmin erilaisia varastointiratkaisuja, kuten manuaalinen varastointi, puoliautomaattinen varastointi ja automaattinen varastointi. Nykyään automatisointia löytyy lähes kaikkialta, eikä varastoteollisuus ole poikkeus. Opinnäytetyö tarjoaa yleiskatsauksen logistiikka-alan yrityksissä käytössä olevista automaatioteknologioista ja siitä, miten näitä teknologioita voidaan hyödyntää varastoinnissa tänä päivänä.

Sen jälkeen, kun lukijalle on esitelty olemassa olevia teknologioita, arvioidaan erilaisia automaatioratkaisuja, niiden etuja ja miten ne voitaisiin toteuttaa PPG Tikkurilan varastokäytössä. Lopuksi valitaan PPG Tikkurilan kannalta sopivin ratkaisu ja esitetään tarkemmat investointien takaisinmaksulaskelmat ja tehostamisvaatimukset valitulta toimittajalta saadun ennakkotarjouksen perusteella.

ABBREVIATIONS

AGV	Automated guided Vehicle
AIDC	Automatic Identification and Data Capture
AMR	Automated Mobile Robot
AS/RS	Automated Storage and Retrieval System
ERP	Enterprise Resource Planning
RFID	Radio Frequency Identification

Table of contents

1. Introduction

Words like “digitalization” and “automatization” are nowadays linked to almost everything and this is also the case in warehousing. Today's modern warehouses are full of automation and automation has taken big leaps forward in the last ten years, for instance. Automatization has become a more reliable and cost-effective solution, which has increased the attraction of these applications in different areas of industry. This raised the question of whether it would be possible to increase the number of automated warehousing solutions at my current employer, Tikkurila Vantaa.

1.1. Background

Nowadays new warehouses are full of automatization. The warehousing sector that once heavily depended on manual work force can now move large numbers of items and pallets with relatively small amount of human work. Automatization does not always mean automated machines and robots that replace humans and take care of all the work people did in the past. Automatization can also be used as a part of the existing work process by automating some of the processes that take time from operational work and slows down the process.

At current, the Tikkurila Vantaa warehouse is a combination of old and new: Some of the processes, such as wrapping of the pallets, are already automated. In addition, a modern enterprise resource planning system is in use. Nevertheless, all material transactions inside the warehouse are still performed in a somewhat old-fashioned way with manual forklifts and standard pallet racks. Also, the employees move between different warehouse locations and pick the items, which is also known as “person-to-goods" way of material handling.

1.2. Aims and limitations of the thesis

The aims of this thesis are twofold: First, the thesis presents the best known and most used technologies and automation solutions on today's warehousing industry in the form a literature review and evaluates the probability of their implementation in Tikkurila Vantaa's warehousing processes. Second, the thesis aims to find suitable solutions among the introduced technologies that can help increase the overall productivity of Tikkurila Vantaa's warehouse. It must be borne in mind that these solutions need to have realistic payback calculations and be feasible to implement in to action.

In summary, these two aims form two separate research questions:

1. What are the main technologies used in warehouses to automate processes?
2. Which of these technologies could be applied in use at the Tikkurila Vantaa warehouse?

This thesis focuses on presenting different automation solutions, but the actual implementation of the solutions is excluded from the thesis. The feasibility of the solutions is based on existing literature reviews and case studies and the solutions' effectiveness and functionality in practice cannot be verified. Although numerous automation technologies exist, this thesis focuses on the best-known technologies that are most used in warehouse environments.

1.3. Research methodology

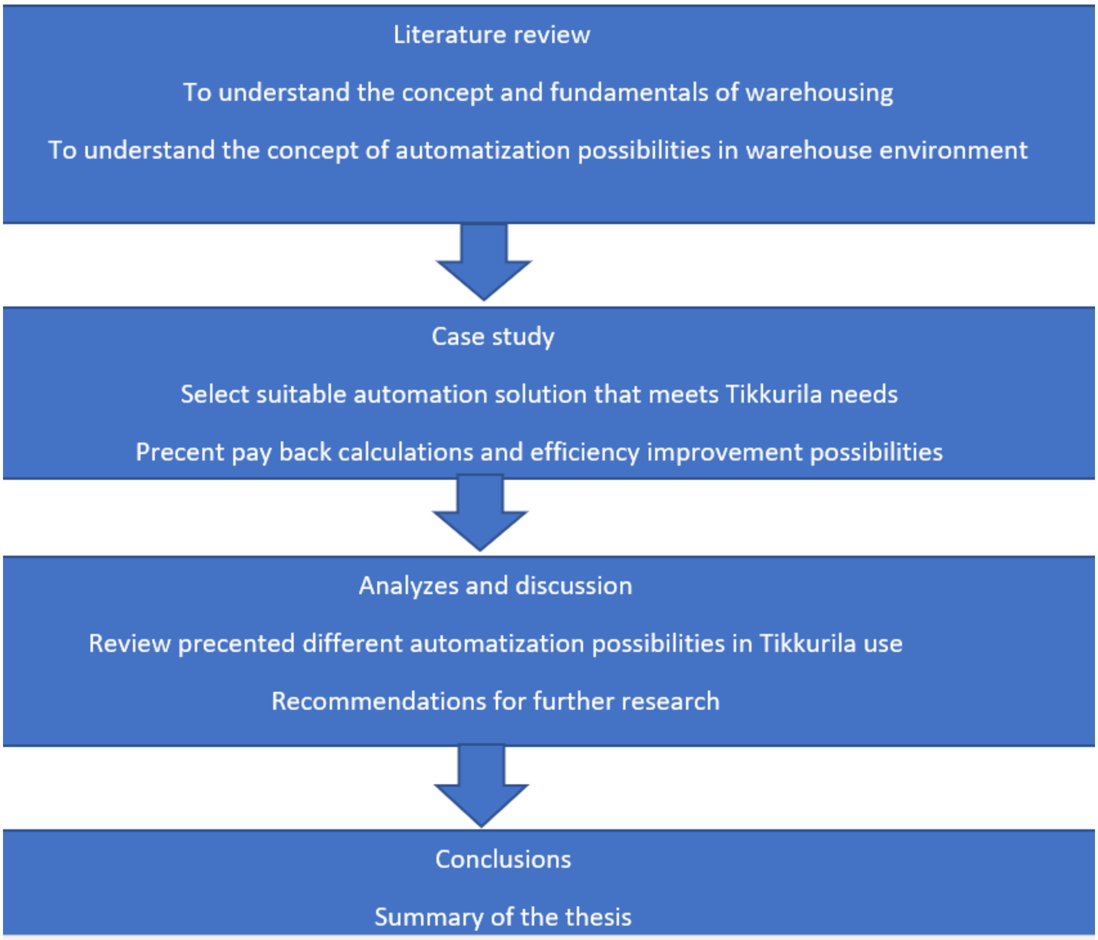
This thesis consists of two different sections, the theoretical part and the case study part. The theoretical part is based on existing scientific literature on warehousing and warehouse automation solutions. The aim of the theory part is to provide the reader with basic knowledge of different ways of warehousing and modern automation solutions that are developed specially for warehousing use. The case study part aims at finding a suitable automation solution for the warehouse use of Tikkurila Vantaa from the automation solutions presented in the literature review.

The scientific publications utilized in the literature review are chosen based on the time of publication and scientific reliability.

1.4. Structure of the thesis

The structure of the thesis is presented in Table 1.

Table 1. The structure of the thesis.



2. Tikkurila Oyj

Tikkurila is a Nordic paint company that manufactures a wide range of decorative paints and surface treatment products for both consumer and professional use (Tikkurila Oyj 2018). Tikkurila's own paint production operates in six different countries with seven paint factories employing around 2600 dedicated professionals. The Tikkurila brand is available in over 40 countries. (Tikkurila Oyj 2018.)

2.1. Customers and products

Tikkurila's main customer base consists of consumers, professionals and industrial customers (Tikkurila Oyj 2018). According to Tikkurila's own estimations, sales are divided between the three groups in the following market shares: consumer sales 47 percent, professional sales 35 percent and industrial sales 18 percent.

Tikkurila's production portfolio consists of interior paints, lacquers and effect products as well as exterior products for wood, masonry and metal surfaces. Although most of the current market share consists of consumer products, Tikkurila also offers products, such as paints and coatings, for the metal and wood industries. In addition, Tikkurila also provides different services related to painting. The highlights of Tikkurila's business are working with strong brands, high quality and long-term product development. The best-known Tikkurila brands for decorative products are, among others, Tikkurila, Alcro, Teks, Vivacolor and Beckers. (Tikkurila Oyj 2018.)

Tikkurila's main distribution network for decorative paints consists mainly of hardware or home improvement stores, various paint store chains and independent paint retailers, through which consumers and professionals are usually served. In Scandinavia, Tikkurila also has its own paint stores to provide products directly to customers. Tikkurila industrial products are sold either directly to customers or through the Tikkurila Industrial Paint Service retailer network. (Tikkurila Oyj 2018.)

2.2. Tikkurila's history

Tikkurila Oyj has a long and multi-stage history, during which it has grown its position as a paint producer.

2.2.1. From the early stages to the 21st century

Tikkurila Oyj was established in Finland on the 14th of August in 1862 by the name of Dickursby Oljeslageri to produce linseed oil and varnish. During its first years, the company and business kept growing and, in 1885, the Dickursby Oljeslageri was acquired by the Schildt & Hallberg in Helsinki. In 1919 Schildt & Hallberg Oy expanded their production portfolio and business to paint production. From that point on, the Schildt & Hallberg Oy continued expanding on the domestic paint markets and rising to the position of the largest paint manufacturer in Finland.

The success on the paint markets was not left unnoticed by other companies and in 1972, the Finnish chemical conglomerate Kemira acquired the Schildt & Hallberg Oy and started the expansion and modernization of the production plant. In 1975, the company was renamed as Tikkurila Väritehtaat Oy (Tikkurila Paint Factories), and eleven years later the name was shortened to Tikkurila Oy. In 2010, Tikkurila Oy's former sole owner Kemira decided to relinquish Tikkurila and on the 17th of February 2010 Tikkurila Oy changed its name to Tikkurila Oyj. Tikkurila Oyj was listed on NASDAQ OMX Helsinki Oy in March 2010. (Tikkurila Oyj 2018.)

2.2.2. PPG acquisition in 2020

During this thesis process, on the 18th of December 2020, PPG Industries, Inc. announced that it had made an agreement to acquire Tikkurila in an all-cash transaction. Pursuant to the terms of the agreement, PPG commenced acquiring all the issued and outstanding stock of Tikkurila. (Business wire 2021). In October 2021, PPG Industries, Inc. announced to have acquired 100 percent of Tikkurila's shares and that Tikkurila Oyj was delisted from the Nasdaq Helsinki stock exchange. (PPG Industries Inc, 2021.)

2.3. PPG Industries, Inc.

Captain John B. Ford and John Pitcairn started the first commercially successful plate glass factory Pittsburgh Plate Glass Company in 1883 in the northeast of Pittsburgh, Pennsylvania (PPG 2021). Pittsburgh Plate Glass Company became the United States' first successful commercial producer of high quality thick flat glass. In the early 20th century, the company was looking for a way to expand their business. Paints and brushes were distributed through the same channels as glass, and that made them a logical addition to the company. By the end of 1900, the company had acquired a major interest in Milwaukee, Wisconsin based Patton Paint Company, which can be considered as a precursor to PPG's current coatings and resins group today. During the following decades, the Pittsburg Plate Glass company continued to expand on the glass and coatings market with several acquisitions. The company also expanded its portfolio to other industries, such as automotive, military and aerospace. In 1968, the Pittsburgh Plate Glass Company changed its name to PPG Industries, Inc. (PPG 2021.)

As of today, the PPG Industries, Inc. is an American Fortune 500 company and global supplier of flat glass, fiber glass, fabricated glass products, coatings and resins, and industrial and specialty chemicals (PPG 2021). Its headquarters is still located in Pittsburgh, Pennsylvania, United States. Nowadays PPG Industries, Inc. operates in more than 70 countries around the globe with more than 150 different production facilities. (PPG 2021.)

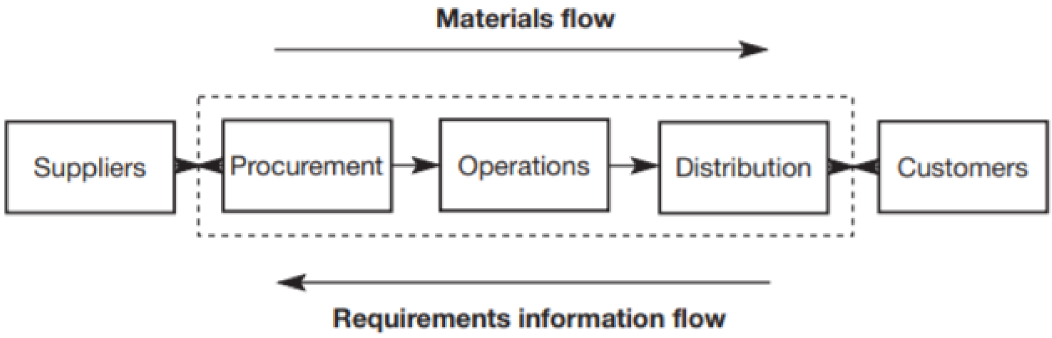
3. Warehousing in companies

Generally, warehousing is considered as a mandatory obligation for companies to keep their business running and customers happy, but it also has a greater meaning. In this chapter I will introduce the definitions for logistics, material handling and warehousing and clarify why companies use warehouses.

3.1. Logistics

There are many ways of defining logistics. According to Christopher Martin (2011, 2) logistics is managing the procurement, movement and storage of materials, parts and finished inventory strategically through the organization and its marketing channels in manner that allows for the current and future profitability to be maximized through cost-effectively fulfilling orders. Groover (2013, 280), on the other hand, defines the term “logistics” as the “acquisition, movement, storage, and distribution of materials and products, as well as the planning and control of these operations in order to satisfy customer demand”. In a more detailed view logistics can be divided into two different categories: internal logistics and external logistics. Internal logistics, also known as material handling, includes all movements and warehousing of materials inside a given facility. External logistics is usually considered as all transportation related activities outside of a facility, such as transporting materials between different geographical locations. (Groover 2013, 280-281)

The scope of logistics spans the organization, from the management of raw materials to the delivery of the final product. The main function of logistics is to help enterprises to increase the overall value of their whole supply chain by providing fast deliveries to customers and cost-effective warehousing solutions for the enterprises (Christopher 2011, 11). According to Hokkanen, Karhunen and Luukkainen (2010, 57), all resources used for material handling, purchasing and other logistics functions need to have positive productivity for the overall logistics function to have a positive effect on enterprise’s business. Basic logistics process is presented in Picture 1.



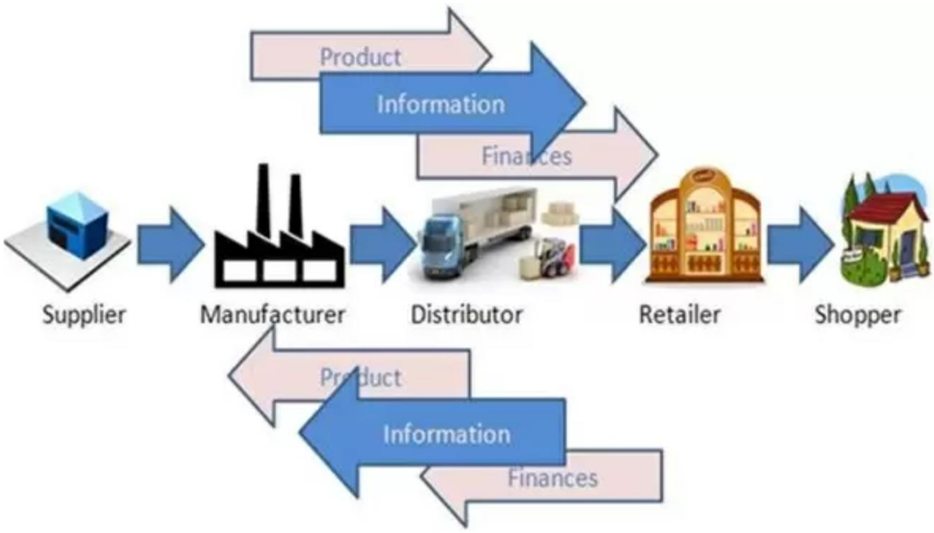
Picture 1. Logistics management process. Christopher (2011, 11)

How successful logistics are is usually viewed from a financial perspective. According to Hokkanen et al. (2010, 57), logistics costs are generally divided into four different categories: transportation, warehousing, capital and management expenses. Most of the costs related to logistics functions are indirect costs, i.e., not directly related to the actual product or its value but instead indirectly affect the product or service. Direct warehousing costs and transportation costs are usually easy to show, and these are quite well recognized in companies. However, all other indirect costs are more difficult to show, and therefore those expenses are quite often allocated under some general overhead costs which results in difficulties in solving the overall logistics expenses accurately. (Hokkanen et al. 2010, 57.)

3.2. Material handling

Material handling can be defined in multiple ways. As a definition, material handling is not bound to size or complexity. It can be either small or large, yet the same definition of material handling applies. According to Vasili, Tang and Vasili (2012) material handling is as simple as moving material. A broader definition is provided by Stephens and Meyers (2019, 209), who stated that “material handling is the function of moving the right materials to the right place at right time, at the right amount, in sequence, and in the right position or condition to minimize production cost”. In addition, Groover (2013, 279) argued that material handling is moving, protecting, storing and controlling of the materials and products from manufacturing to warehouses and distribution to consumption and, finally, disposal.

In the end material handling is a process that combines a wide range of manual, semi-automated and automated equipment and systems that support logistics and make the overall supply chain work efficiently like presented in Picture 2. (Groover, 2013, 279; Vasili et al, 2012.)



Picture 2. Logistics as an interface for business operations. Hebergemetnwebs. 2020.

3.3. Warehousing

Hompel and Schmidt (2006, 2) state that efficient warehouse management represents expert knowledge that compares information about the required processes, technically and operationally feasible and successful implementation to a functioning overall system. There are, however, no clear rules on how warehouse management should be organized to achieve these targets and a multitude of different variables can affect how a warehouse should be operated. For example, customer ordering patterns and volumes and warehouse layouts and automatization rates can influence warehouse management processes. (Hompel and Schmidt 2006, 2.)

3.3.1. Reasons for warehousing

Although the term warehousing quite often raises negative mental images like non-value-adding times and high costs, in practice most companies have various reasons to store goods. Here are the three main reasons why companies use warehousing to support their business, as seen by Hompel & Schmidt (2006, 2-3).

Optimizing logistics performance: When a customer makes an order, he/she expects it to be fulfilled quickly. A basic customer requirement is the immediate fulfilment of an order. Since predicting customer order quantities and ordering times and frequency exactly right is nearly impossible, companies prepare for incoming orders by keeping materials in stock. Then, when a customer makes an order, the company is prepared and can send out the ordered quantity right away and this way ensure a fast and good customer experience. According to Hompel and Schmidt (2006, 2-3) fast deliveries straight from the warehouse can be thought as a competition advantage to other competitors.

Ensuring productivity: One of the key reasons for keeping stock in production is to ensure the supply of raw materials for production purposes (Hompel & Schmidt 2006, 2-3). Raw material supply chains may have disturbances from time to time which may influence delivery times. Raw materials used for production are kept in stock to give more flexibility for the raw material supply chain. Productions that work with just-in-time deliveries and minimized stock levels are vulnerable to supply chain disturbances. This might have a negative effect on production. (Hompel & Schmidt 2006, 2-3.)

Balancing required and delivered quantities: Many business fields are subject to considerable seasonal fluctuations which cannot be absorbed by just adapting to the production capacities. Also, in some cases, production volumes need to be produced with appropriate lot sizes which can be higher than demand at that time. This creates a need to store excessive production materials. (Hompel & Schmidt, 2006, 3.)

As argued by Hompel and Schmidt (2006, 4), optimization of production lot sizes or discounts for purchase quantities are not the only reasons for companies to keep stocks. Instead, there are multiple reasons for stock keeping. Each case should be evaluated separately by considering the whole supply chain and what kind of effects warehouse levels may have on it.

3.3.2. Warehousing types

When automating warehouse operations, the goal is usually to lower operation costs and increase warehousing productivity (Hokkanen et al. 2010, 140). By automating warehouse operations, warehouses can reduce the number of employees and perform tasks that are hard or even impossible to execute by humans, for example moving heavy items or working under extreme conditions like hot or cold temperatures. Warehousing can be roughly divided into three different types: manual warehousing, semiautomated warehousing and fully automated warehousing (Hokkanen et al. 2010, 140).

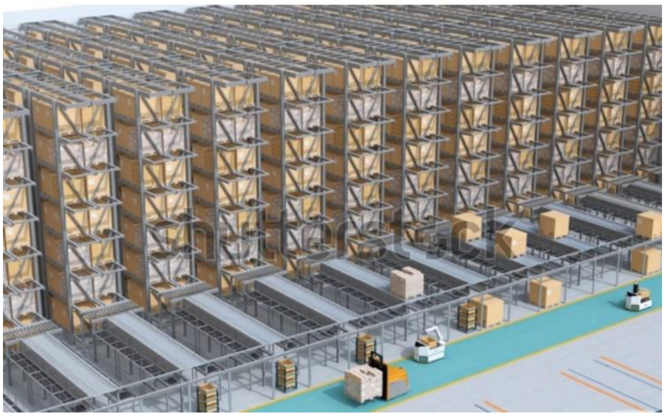
Manual or mechanical warehousing usually refers to a traditional warehousing type, like shown in Picture 3, where all material handling is done manually using human workforce and manually operated material handling machines like forklifts. Pallet racks are designed in the way that they can be operated by a manual forklift. Most common pallet rack types are standard pallet racks and very narrow pallet racks. (Hokkanen et al. 2010, 140.)

Picture 3. A manual warehouse. The stellar group. 2021

When traditional mechanical warehousing is combined with automated solutions, the warehouse is called a semiautomated warehouse. An example of a semiautomated warehouse solution is a high-speed load carrier that works in specialized racking and carries out all handling operations inside the rack, like seen in Picture 4. They can be guided with a remote control while the placement and retrieval of the pallets can be done by a reach truck or counterbalanced truck. The load carriers enable high-density storage and a maximized number of pallet locations hence saving space and cost (Hokkanen et al. 2010, 146).

Picture 4. A semi-automated warehouse. Toyota material handling. 2021.

A fully automated warehouse, as the name implies, is fully automated and does not need a human operator to execute tasks within the warehouse. In a fully automated warehouse, automation is usually based on different kinds of sensor technology and robotics. Fully automated warehouses are called AS/RS systems (automated storing/retrieving system). These systems are usually built and designed to handle full pallet movements inbound and outbound from the warehouse. In AS/RS systems pallet movements are handled using automated robots or cranes that move between the shelves on their own and pick or shelf the pallets. AS/RS systems always need a connection to the warehouse management system, which tells the system which actions need to be done and is working as the brains of the operation. The warehouse management system also keeps the storage inventory up to date. In fully automated warehouses operating is possible only through an automated system and it is not possible to convert the system to work manually in the case of a machine failure, for example. (Hokkanen et al. 2010, 148.)



Picture 5. A fully automated warehouse. Shutterstock 2021.

4. Automation in warehousing

During the last few decades material handling systems and warehouses have developed quite rapidly. According to Ghelichi and Kilaru (2021, 1), especially the rapid growth of ecommerce fulfillment centers has changed the way warehouses operate. Today, warehouses and logistics centers are highly automated facilities with complex processes to provide customers with the level of service they want.

Groover (2013, 71) defines automation as technology, in which a process is accomplished without humans. In automation a process is implemented using a program of instructions combined as well as a control system that executes the given instructions. An automated system usually consists of three basic elements: 1) the power to execute processes and to operate the system, 2) a program of instructions to direct the process and 3) a control system to actuate the instructions. To automate a process, an external power source is required to operate these three basic functions. (Groover 2013, 71.)

4.1. Issues and advantages associated with automation in warehouses

According to Park (2012, 8) there are two kinds of automation issues in a warehouse: one with the physical handling systems and another with the information handling systems. Automation issues in physical handling systems include the automation and integration of physical storage and retrieval operations and material flows together with information flows. Both the physical handling system and information handling system need to be considered when planning the automation of warehouse operations. (Park 2012, 8.)

The overall impression of warehouse operations can typically be that it requires quite a lot of manual labor. Especially order picking is recognized as one of the most time-consuming activities in the warehouse, especially on warehouses that work on person-to-goods basis (Ghelichi & Kilaru 2021, 1). The picking process requires a worker to spend most of his/her working time moving from one location to another, all the while carrying the picked materials with him/her. The time spent moving between picking locations leads to loss of throughput rate and, in worst case, failure to stick to tight schedules. Therefore, any improvements made to reduce the time spent moving between locations can improve warehouse productivity and create cost savings. (Ghelichi and Kilaru 2021, 1.)

High speed and accuracy are key elements in successful warehouse operations in today's markets. One way to increase productivity and reduce picking mistakes is to present the materials or information to the picker (Park 2012, 8). This way the picker does not move from the picking station but instead materials are fetched with automation solutions to the picking location. The picker does not have to use time to move from storage location to another, which reduces inefficient work like search and travel, which is the most time consuming and costly operation in picking work. This technology is becoming more important than ever, since it can significantly improve both picking productivity and accuracy. (Park 2012, 8-9)

According to Park (2012, 10) automatic presentation of information to picker is also becoming increasingly popular. The main goal with this automation technology is to provide hands-free and paperless information flow to warehouse worker to reduce the time used to finding the right picking location, right products and entering the product codes to the ERP system and therefore increasing the overall warehouse productivity. Examples of such technology are pick-by-light, pick-by-voice and other virtual displays. In picking operations, the biggest benefit of presenting information presentation to pickers is to increase hands-free way of working and facilitate efficient retrieval and fast registering of picked materials with fewer picking errors. (Park 2012, 10.)

Proper automation has several advantages. It can greatly reduce labor costs, increase inventory and picking accuracy, and shorten order cycle time. However, there are also some disadvantages. Firstly, automation usually requires a substantial investment. Adapting automated warehouse operations to changing business environment can also be challenging because automatic solutions are not as flexible in adapting to changing circumstances like normal nonautomated warehouse solutions are. According to Park (2012, 9-10), to make automation functions work properly and reliably, they should be well integrated, designed and combined with work simplification processes and standardization.

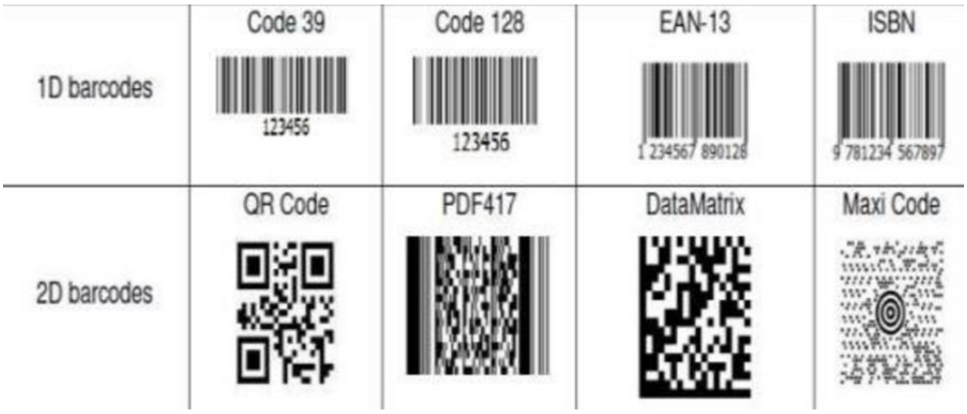
4.2. Picking

One of the most critical and labor requiring activities in warehouse operations is picking. Thus, simplifying and increasing the productivity of picking operations has been one of the main objectives of automation in warehouse environment. Different kinds of AIDC (automated identification and data capture) technologies, like barcode scanners and RFID scanners, have been utilized in material handling to reduce the time and increase accuracy of picking. Also, different kinds of paperless and hands-free innovations, such as voice picking, have been introduced to material handling to develop productivity even further. (Battini, Calzavara, Persona & Sgarbossa 2015, 485.)

In the following subchapters, I will concentrate a little more on the technologies described earlier and introduce the reader to some of the possibilities technology development has brought to warehouse logistics.

4.2.1. One-dimensional and two-dimensional barcodes

A barcode was initially invented by Norman Joseph Woodland and Bernard Silver in 1948 to make reading product information much easier during checkout processes. (Su, Chu, Prabhu & Gadh 2007, 1). As defined by Kato, Tan and Chai (2010, 1) a barcode is a "machine-readable presentation on information that is formed by combination of high and low reflectance regions of the surface of an object, which are converted to 1s and 0s". Barcodes can be divided into two different categories, one-dimensional (1D) and two-dimensional (2D) barcodes. In two-dimensional barcodes, bars and spaces are replaced with dots and spaces arranged in an array or a matrix. By using the 2D method, the density of data within a given space can be increased, which enables storing larger quantities of data compared to a one-dimensional barcode. The definition of barcode implies for both types. (Kato et al. 2010, 1.) Different kinds of barcodes are presented in Picture 6.



Picture 6. Examples of 1D and 2D barcodes. Z. Zainal Abidin. 2019

A symbology is a coding scheme that barcodes use to encode data. Symbology defies how to encode and decode the specific barcode data. There are several kinds of symbologies, of which some can only encode numbers, some letters and some can encode both. Generally, a symbology is designed for certain use and application. (Su et al. 2007, 4) Commonly used symbologies, their information storing capacities and applications where they are most often used are shown in tables 2 and 3.

Table 2. Commonly used 1D-barcode symbologies. (Modified from Su et al. 2007, 4-5)

1D-barcodes		
Symbology	Capacity	End use
CODE 2 and 5	8 digits	Distribution
UPC A	12 digits	Retail stores
UPC E	8 digits	Retail stores
EAN 8	8 digits	Retail stores

EAN 13	13 digits	Retail stores
CODE 39	43 characters	Logistics, libraries etc.
CODE 93	48 characters	Industrial use
CODE 128	48 characters	Logistics
GSI-128	48 characters	Logistics and wholesale

Table 3. Commonly used 2D-barcodes. (Modified. Su et al. 2007, 4-5)

2D-barcodes		
Symbology	Capasity	End use
PDF 417	2725 markings	Shipping, automotive, defense
GS1 DATA MATRIX	3116 markings	Automotive
MAXICODE	93–138 markings	Shipping
AZTEC CODE	3750 markings	Retail, consumer markets
QR-CODE	1000–7000 markings. Depens on the QR-code size and model	Advertaising

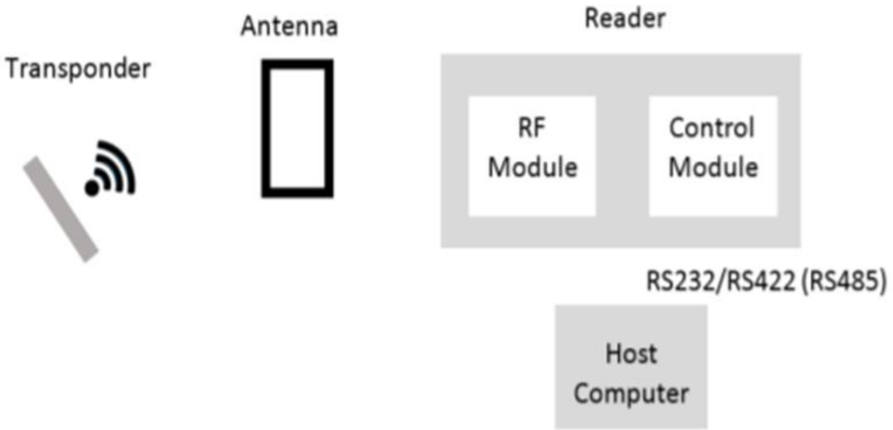
One-dimensional and two-dimensional barcode technologies have differences, and both technologies have their own advantages and disadvantages. Table 4 shows some of the most common advantages and disadvantages related to barcode technology. For instance, one-dimensional barcodes can be read using a special optical scanner that sweeps a beam of light across the barcode. Two-dimensional barcode symbologies, on the other hand, need a scanning device that is capable of simultaneous reading of two dimensions, vertical and horizontal. (Kato et al. 2010, 1.)

Table 4. Advantages and disadvantages of barcode technology. (Modified from Kato et al. 2010, 5)

Advantages +	Disadvantages -
Fast, accurate and reliable data reading	Needs a clear line of sight to read the barcode
Technology is versatile and inexpensive	Only one barcode at the time can be read
Printed tags last long	Reading distance is small
Secure: Once data is in barcode format, the data cannot be changed without physical alteration	

4.2.2. RFID-technology

RFID (radio frequency identification) technology is a part of the AIDC technologies referred to in the earlier chapter. In AIDC technology, the information from the identifier is transferred automatically to a specified computer software with a special reader without manual work. Since reading is done mechanically, information stays intact, and the risk of human error is reduced. (Su et al. 2007, 5-7.) The basic elements that are needed to a a RFID solution are presented in Picture 7.



Picture 7. What is needed for the passive RFID to work. Z. Zainal Abidin. 2019

RFID’s first applications can be traced back to World War II and to the British Air Force. During the World War II, the British Air Force had problems in identifying incoming aircrafts, i.e., which of them were their own and which enemy aircrafts. The solution to this identifying problem was RFID technology. Utilizing this technology, a transmitter that could identify allies’ aircrafts from enemy ones was invented. (Su et al. 2007, 5.)

There are many types of RFID technologies available, but according to Want (2006, 25-26), RFID devices are to be divided into active and passive devices. Active RFID tags require an external power source, so they need to be always connected to powered infrastructure or to an external battery. Because of the external power source, active RFID tags can store larger quantities of data. Additionally, their reading distance can be longer than that on passive RFID tags. Active RFID technology can be used for various forms of asset location management and real-time location systems (RTLS systems). (Su et al. 2007, 5–7).

Passive RFID uses high-power readers that send out a low-frequency, high-power RF signal to battery-free tags. Passive RFID tags do not need any external power to be read. The antenna in the tag is woken up by the amount of energy flowing to it, which wakes up its circuit. The tag then transmits a coded message back to the reader at a different frequency. Because the electricity generated in the passive tag from the RFID signal is small, the transferred maximum data size is also quite small compared to active tags. Also, the reader must be close to the tag for the reading and data transfer to be successful. Passive RFID technology is often used for inventory tracking and to deter theft. The range of the passive RFID tag depends on the antenna size of both the tag and the reader as well as the power level of the radio wave. (Su et al. 2007, 5–7.). Differences of the barcode and RFID technologies are compared in Table 5.

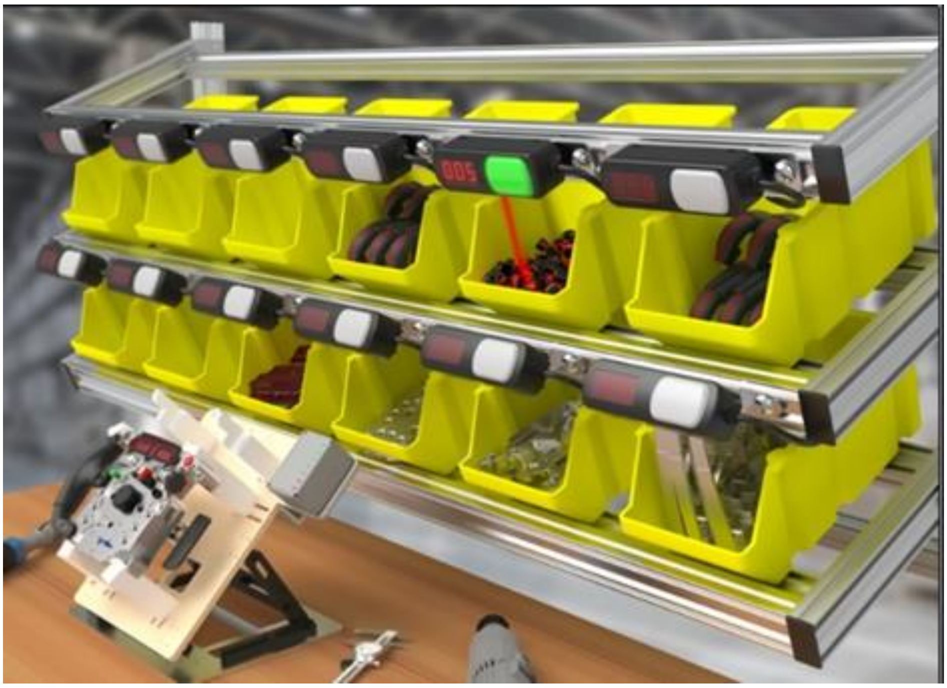
Table 5. Comparison of barcodes and RFID. (Modified from. Gligorije et al. 2019, 549)

	1D-code	2D-code	RFID
Required visibility for reading	Yes	Yes	No

Multiple tag reading	No	No	Yes
Distance from the reader	Up to 4 meters	Up to 4 meters	30 cm above 100 meters
Ability to save and update data	No	No	Yes
Amount of data that can be saved	20 digits	Up to 3 Kb	Up to 128 Kb
Sources of interference	Dirt, physical batteries	Dirt, physical batteries	Magnetic fields
Price	Low	Low	Medium

4.3. Pick by light

Generally, a pick-to-light, or a pick by light, system is a picking system that combines indicator lights and displays at the storage locations. The picking operation is performed following light indicators in storage places and picking the materials from the indicated locations. Typically, the light indicator also has a display that shows how many items need to be picked from one location. After picking from this location, the picker accepts the quantity from a display located at the picking location. After that, the pick by light system indicates the next picking location in the warehouse with a light indicator. (Park 2012, 9.) The pick by light system is the most popular system for picking a high volume of small items located in a small storage area, like presented in Pictures 8 and 9.



Picture 8. Pick by light system in production. (Banner engineering corp. 2021)

Picture 9. Pick by light system in a warehouse. (Turck GmbH. 2021)

4.3.1. Voice picking

In recent years the technology for voice picking has improved greatly and nowadays it is one of the viable solutions for different picking tasks, such as piece pick, case pick, pallet pick and high-volume pick operations (Battini et al. 2015, 485-486). A voice picking system is basically a voice-directed device that uses speech recognition to allow warehouse operators to communicate in real time with the warehouse management system. The system is operated by using a headset or a speaker vest to receive information from the ERP-system that communicates with the pickers by a synthetic voice. Microphones are then used to communicate back to the ERP and confirm instructions and executed tasks given by the ERP-system. The warehouse operator can also interact with the voice picking system in real time and confirm that items from the picking list are picked from wanted locations by verifying the item code and location by voice commands to the microphone (Battini et al. 2015, 485-486; Park 2012, 9), like presented in Picture 10.

Picture 10. Voice picking in use. Brilliant WMS 2021.

According to Battini et al. (2015. 485-486), one of the biggest advantages of voice picking, and one of the reasons why voice picking is proven to be an effective tool in warehouse picking operations, is the possibility to operate hands- and eyes-free. In addition, with a voice picking solution the warehouse operator is constantly interacting with the ERP system and receiving information about the next location and product without having to stop and check the manual or electronic picking list. When the warehouse operator’s hands and eyes are free from manually checking the picking list and confirming every move to the ERP system (since the operator simply hears an instruction and executes it), the picker will be able to perform the picking task more efficiently. This also allows the operator to handle heavier items while guaranteeing a safer way of working. Another favorable thing in voice picking is the training required for the technology, which is relatively simple and quick.

Voice picking, however, also has some disadvantages. For instance, implementing voice picking to warehouse operations requires investing in software and equipment like headsets and microphones, which may break down or need maintenance from time to time. This increases the warehouse operation costs, as argued by Azanha, Vivaldini, Pires and Batista de Camargo Junior (2016, 727).

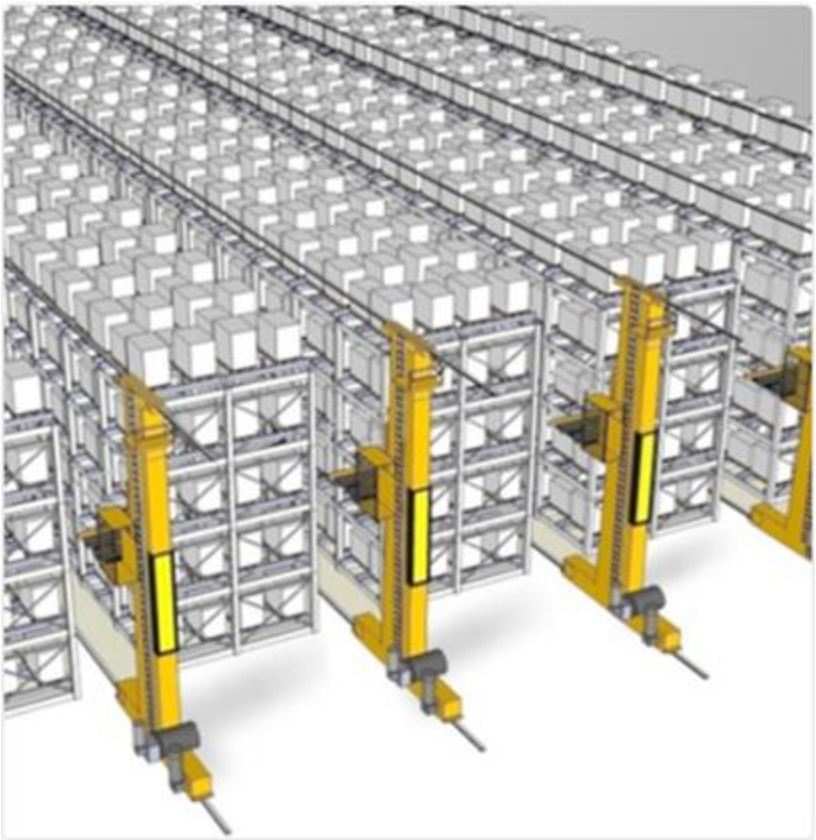
According to Honeywell International Inc. (2017, 3), pick by voice operation can increase the picking productivity by 10- 35 percent, depending on the former picking method. Picker productivity is gained from the hands-free, eyes-up capability with voice directed technology. Workers avoid the need to handle paper or devices multiple times during each pick, resulting in work being accomplished with fewer motions and steps. With the pick by voice operation, picking mistakes can be reduced by 50-90 percent compared to paper-based operations. Furthermore, accuracy can be improved by up to 15 percent compared to pick by light operation and work environments that use radio frequency scanning in picking operations can be improved anywhere between 8-25 percent. (Honeywell International Inc. 2017, 3.)

Improved picking efficiency and the reduced number of picking mistakes are one of the key reasons why companies are interested in pick by voice solutions and why pick by voice solutions are becoming more common among the logistics and distribution centers.

4.4. Automated warehouses

The first applications of AS/RS systems became available around the 1950s. Since then, they have been a widely used solution for automating material handling and inventory control tasks in distribution centers and automated production sites. With an AS/RS system distribution centers and factories can automate inventory control, increase warehouse productivity, and reduce the amount of human labor needed. According to Vasili et al. (2012, 162) all these together result in better profitability.

The definition of an automated warehouse covers a wide range of systems with varying degrees of complexity and size. Still, usually when referring to automated warehousing the model is specific AS/RS (automated storage/retrieval system) like presented in Picture 11.



Picture 11. An AS/RS system. (Handling Technologies Inc. 2021)

An AS/RS system consists of either a single or multiple parallel aisles with racks, stacker cranes also known as storage/retrieval machines, input/output station for the pick-up and delivery as well as accumulating conveyors and a central supervisory computer and a communication system (Vasili et al. 2012, 163). Stacker cranes are fully automated storage and retrieval machines controlled by a central computer. Stacker cranes can move autonomously to pick up and drop off loads based on commands given by a computer. Aisles are formed between the racks in such a distance that cranes can move between the racks. Usually, the width of the aisle and the size of the crane is determined based on the size of stored pallets (Gagliardi, Renaud & Ruiz 2012, 7111). Inbound and outbound stations are stations where outbound materials are dropped off and reserved inbound materials are brought to storage. The AS/RS system can also have a picking location where human workers manually pick items from pallets brought to the picking location by stacker cranes. After materials are picked from the pallet, the stacker crane returns the pallet back to the storage. The AS/RS is connected to WSM (Warehouse Management System), and it automatically updates input and output inventory transactions at both ends so that the WMS is always up to date. (Vasili et al. 2012, 163.)

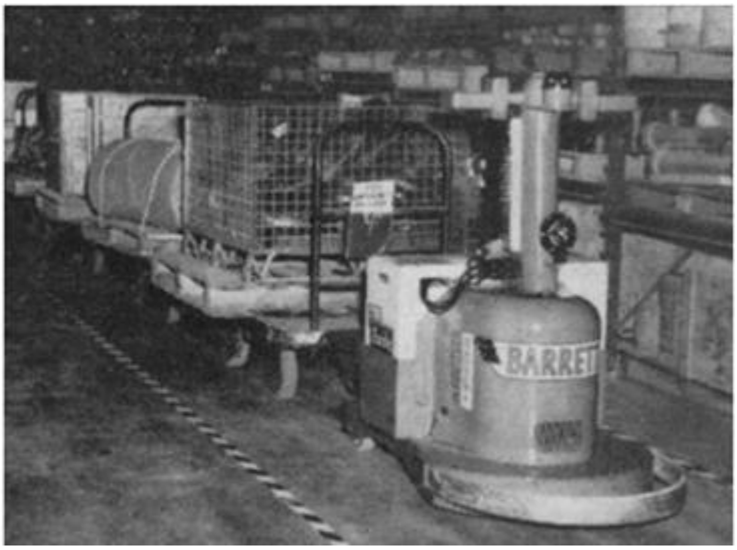
According to Groover (2013, 327) there are at least five benefits that can be achieved when investing in AS/RS technology:

1. Increase in capacity, density and throughput of the storage.
2. Improvements in stock rotation, control over inventories and the level of customer service
3. Improvements in safety and security in storage functions and reduce pilferage.
4. Recovering factory floor space used for storing WIP (work in progress).
5. Reducing labor costs and/or increasing labor productivity in storage operations.

Implementing an AS/RS system to warehouse operations or production is not a small investment, which is why the decision to acquire such a system should be carefully considered and planned. Due to the complexity and high costs associated with the implementation of AS/RS systems, it is of the utmost importance that the project is carried out carefully and with a well thought out plan. After the AS/RS system is built, any modifications can be hard to carry out. Hence, it is crucial to design the AS/RS system to correct volumes and material transactions before building it. The system should be designed so that it can handle all current and known possible future needs regarding, for example, storage capacity, picking efficiency and number of input and output stations. (Vasili et al. 2012, 167.) It is also important to realize that automated storage systems are always just one part of the whole warehouse operations, and the best overall performance can only be achieved when all warehouse processes (automated and manual) work together (Vasili et al.2012, 169).

4.5. Automated guided vehicles

Automated guided vehicles (AGV) can be defined as computer-controlled machines that can perform a set of defined tasks by following specific instructions with minimal or no human intervention (Sabattini et al. 2018). Automation of warehouse logistics with different kinds of automated vehicles or robots is not a new trend. The first applications of automated guided vehicles used to automate material movements in warehouses today originate from the early 1950s when drivers of tractor trailers moving materials from one place to another were replaced with automated solutions (Picture 12). The automotive industry was a pioneer in the introduction of automated vehicle technology for production and warehousing use. Since then, AGVs have become a standard automation tool for all industries with repeated material deliveries. By automating material transportation with automated solutions, companies have better possibilities to optimize productivity and schedule deliveries more effectively to reduce production bottlenecks (Ullrich 2015, 2).



Picture 12. One of the first American AGVs, building started in 1954 as a tractor for five trailers (Ullrich 2015, 2)

Until recently, traditional AGVs were the only mobile solution to automate internal logistics tasks when dealing with continuous material flow between different locations. Today, AGVs are even more flexible, autonomous, and cost-effective, and are now better known as automated mobile robots (AMR). The fundamental difference between AGVs and AMRs can be summed up by the difference noted between a guided vehicle and a robot: A guided vehicle follows fixed routes, while a robot is able to make independent decisions and change the original route by responding in real time to the environment in which it is moving (Mobile Industrial Robots 2021).

Where an AGV uses fixed routes to navigate, an AMR can navigate independently inside a given area using preloaded facility drawings. It can also create maps of the environment in which it is operating using camera vision and laser scanners to scan the facility and navigate based on that information. An AMR uses data from cameras and built-in sensors and laser scanners as well as sophisticated software to detect its surroundings and choose the most efficient route to the defined target. It works completely autonomously and, when faced with obstacles in front of it like other forklifts, pallets or people, the AMR moves safely around them using the best alternative route to ensure that material flows stay on schedule (Mobile Industrial Robots. 2021, Sabattini et al. 2018).

The current trend of the increasing growth in e-commerce shopping has increased the need for AGV and AMR solutions in large logistics centers which handle large numbers of small inbound and outbound orders in a tight time frame. According to Ghelichi (2021, 2), utilizing AMR solutions in fast moving e-commerce businesses has boosted picking performance and improved productivity. Companies like Amazon and UPS, for example, have recently implemented AMR solutions on their facilities to improve picking performance and reduce picking costs.

Typically, AGV and AMR solutions can be classified under three major categories, which are introduced below.

1. Unit load carriers

AGV / AMR unit load carriers are used to move loads from place A to place B. They are usually equipped with a mechanism for automatic loading and unloading of the materials like a roll conveyor, moving belts, lift platforms or other devices build into the vehicle deck like showed on pictures 13 and 14. Unit load AGVs are agile and versatile machines designed to automate any operations that involve a standard movement from one place to another. Unit load AGVs can be used for, for example, working together with AS/RS systems to handle inbound or outbound movements. (AGVnetwork 2021; Groover 2013, 288–289.)

Picture 13. A unit load carrier. (FlexQube 2021)

Picture 14. Types of unit load carriers. (Conveygo 2021)

2. Automatic guided forklift

An Automatic Guided forklift is an automated version of a typical human operated forklift like a reach forklift, counterbalance forklift or very narrow aisle forklift (VNA). In Picture 15, an automated counterbalance reach truck is presented on the left and a VNA forklift on the right. An automated forklift can typically operate both in a vertical and a horizontal way, same as a normal human operated forklift. It can also be used for the same purposes as a human operated forklift (MHI warehouse automation 2019).

Picture 15. AGV forklifts. (Mitsubishi Logisnext Europe Oy 2021)

3. Towing vehicle

A Tugger AGV is a type of automated guided vehicle designed to tow carts, like seen in Picture 16. A tugger AGV is a self-driving tow tractor used at moving trailers inside warehouses or factories like a driverless train that may have several drop-off and pick-up locations along the predefined path. Towing AGV’s capacity to move material can vary from tens of kilograms to several tons, depending on the AGV model (Ullrich 2015, 47).

Picture 16. A towing AGV. (Jiangxi Danbahe Robot Co. Ltd. 2017)

5. Tikkurila Vantaa warehouse today

Tikkurila Vantaa's warehouse has been roughly in the same place from the day it was founded. Over the years the factory and the warehouse area have developed into more modern facilities and the current factory and warehouse buildings have expanded in line with the business. Warehouse facilities have been expanded three times since the day the warehouse was built. All expansions of the warehouse facilities have been built right next to the old one, and facilities have been joined together so that the warehouse can operate smoothly between old and new buildings. Picture 17 shows the Tikkurila factory and the warehouse area in Vantaa, Finland.

Picture 17. Tikkurila factory area in Vantaa, Finland. Google maps.

Tikkurila warehouse in Vantaa is a standard manual warehouse that has manual racks for storage space. Tikkurila Vantaa’s warehouse facilities are seen in Picture 18. Warehouse tasks are operated manually by human operators. Warehouse equipment like forklifts and racks are modern and suitable for the designed tasks but not automated in any way. Some automation solutions are already in use, such as an ERP system, barcode scanners and automated wrapping lines. Main warehouse operations like picking, loading, and receiving production orders are, however, performed manually.

Pallets are stored in 7.5-meter-high shelves. Currently, storage capacity for the whole warehouse is approximately 18 000 euro-pallets of which about 2000 are floor level picking places. Single picking is only done from the floor level. Aisle width varies between the warehouses a little with the narrowest aisles being about 2.7 meters wide. This makes the space challenging to operate with modern reach forklifts or other material handling equipment.

Picture 18. Tikkurila warehouse.

5.1. Warehouse operations

Most of the warehouse related tasks are done with human workforce and manual forklifts. Employees in the warehouse are divided into blue-collar and white-collar employees. Approximately 30 full-time blue-collar workers are needed to run the warehouse operation in low seasons. During high season, the needed number of employees increases close to 50. Two white-collar employees work as warehouse supervisors and four white-collar employees work as delivery coordinators. The total number of employees needed to run the current material flows is between 40 to 60 people depending on the seasonal volumes.

Warehouse's main task can be divided into three distinct categories which are listed below.

1. Receiving inbound material from production and moving it to storage:

Vantaa factory has two different production lines that produce ready products to storage. Full pallets are equipped with barcodes that contain the necessary information related to the pallet, like item name, quantity, and lot number. After receiving the pallets from production, the pallets are scanned by forklift drivers. Then, the ERP system shows to which location in the warehouse the pallet should be delivered. Moving the pallets from production to warehouse is done by manually operated reach trucks.

2. Loading outbound materials to trucks and containers

Tikkurila warehouse is responsible for loading the vehicles and containers on outbound deliveries. This is done using counterbalance forklifts.

3. Full pallet picking and single picking

Picking work is divided into standard full pallet picking and single picking. Standard full pallets are picked directly from the warehouse’s full pallet locations to the loading area by reach trucks. Ready picked full pallets are seen in Picture 19.

Picture 19. Ready picked full pallets.

Single picking is done from floor level using order picker forklifts, as seen in Picture 20. In single picking, an employee drives from one picking location to another and collects the required items on the route to the same pallet. Single pick work lines can contain different amounts of packages from individual pieces all the way to full pallets. Hence, the required workload in single picking can vary greatly, depending on how many pieces the single pick work includes. Single pick pallets that are ready to be delivered to customers are seen in Picture 21.

Picture 20. Order picker forklift Toyota OSE120. Toyota material handling. 2021

Picture 21. Ready single picked pallets.

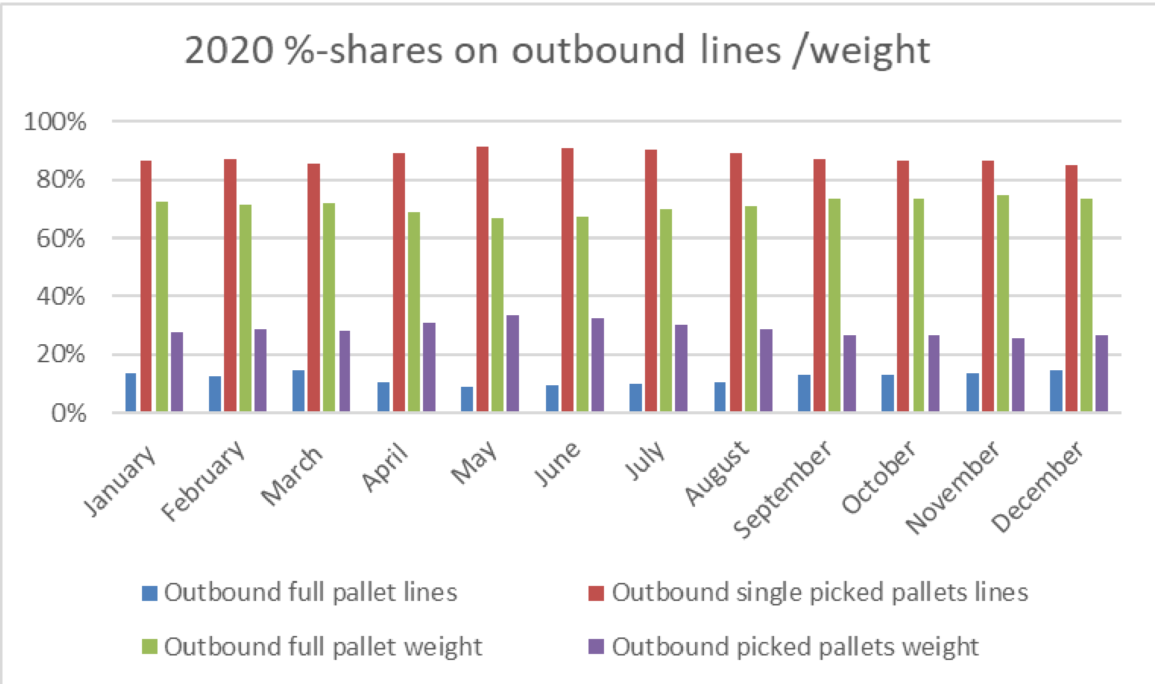
5.2. Tikkurila material transactions during the year 2020

Tikkurila Vantaa warehouse processed nearly 800 000 individual picking lines during the year 2020 and total shipped outbound volume was about 70 million kilograms of paint. Statistics on how the material transactions are divided between different transaction types are presented in Table 6. Percentages of the full pallet and mix pallet deliveries are seen in Table 7.

Table 6. Tikkurila Vantaa outbound picking lines and volumes in percentages.

Statistics 2020												
lines	January	February	March	April	May	June	July	August	September	October	November	December
Outbound full pallet lines	6 608	6 213	10 011	7 955	7 537	9 621	9 318	8 464	8 639	6 691	6 213	5 417
Outbound single picked pallets lines	42 352	42 935	59 264	67 013	77 194	94 463	84 610	70 207	57 423	43 935	39 858	30 818
Inbound lines NT-factory	4 151	4 600	5 420	5 332	4 528	4 927	5 768	4 747	4 582	4 763	4 358	3 703
Inbound lines MC-factory	3 188	4 296	5 962	5 141	5 359	6 878	7 001	5 316	5 144	4 930	4 039	3 776
Sum	56 299	58 044	80 657	85 441	94 618	115 889	106 697	88 734	75 788	60 319	54 468	43 714
Average number of lines 2020	76 722											
Procentages 2020	January	February	March	April	May	June	July	August	September	October	November	December
Outbound full pallet lines	13 %	13 %	14 %	11 %	9 %	9 %	10 %	11 %	13 %	13 %	13 %	15 %
Outbound single picked pallets lines	87 %	87 %	86 %	89 %	91 %	91 %	90 %	89 %	87 %	87 %	87 %	85 %
Outbound full pallet weight	72 %	71 %	72 %	69 %	67 %	67 %	70 %	71 %	74 %	74 %	74 %	73 %
Outbound picked pallets weight	28 %	29 %	28 %	31 %	33 %	33 %	30 %	29 %	26 %	26 %	26 %	27 %

Table 7. 2020 outbound lines and weight in percentages.



As shown in Table 6, most of the picking lines in Tikkurila Vantaa warehouse are single picking tasks. The average percentage of the single picking share from the total line volume is about 90 percent. On the other hand, single picked shipping volumes account for an average of one-third of the total weight of outbound shipments throughout the year.

In conclusion, the Tikkurila Vantaa warehouse handles a large number of material transactions annually. When measured in picked lines, single picking makes up about 90 percent share of all picked lines. When measured in weight, single picked lines account for approximately 30 percent of the total outbound volume in kilograms.

6. A proposal for automation solutions

Based on the statistics shown in Table 6 we can conclude that most of Tikkurila Vantaa's material volumes in kilograms come from full pallet picking. Full pallet picking consists about 70 percent of overall outbound materials but only about 10 percent of picking transactions is required. According to these statistics the Tikkurila Vantaa warehouse would benefit from automation solutions that could speed up the single picking process, which now covers most of the material transactions of the warehouse.

In this chapter I will introduce three different commonly known automation solutions that could be implemented to increase the automation level of the Tikkurila Vantaa warehouse and increase its efficiency. Furthermore, I will assess if these solutions are feasible and reasonable investments to implement into the Tikkurila Vantaa warehouse's operations.

6.1. AS/RS warehouse solution

As already stated, most of Tikkurila Vantaa's outbound volumes in kilograms come from full pallet picking and material transactions. When outbound volumes are combined with Tikkurila's own productions' inbound volume, it becomes clear that one viable and effective solution for this kind of volumes would be an AS/RS warehouse.

With an AS/RS warehouse, Tikkurila Vantaa would be able to automate almost all full pallet material transactions related to retrieving and storing materials from the warehouse shelves. Attempts could also be made to automate the single picking process so that the warehouse would have fixed picking locations and the AS/RS would handle the material movements to this picking location. Material flow could be modified so that the materials are transferred to the picker instead of the picker having to move between different picking locations. I this way, the AS/RS system could also improve the single picking process.

Implementing the AS/RS effectively into the existing warehouse facilities would require major layout changes or even a completely new warehouse building. Both scenarios would require massive investments. Hence, even though the AS/RS solution has immense potential for automating Tikkurila's warehousing operations, it is not an actual option that can be implemented within the existing warehouse and production facilities. Therefore, studying whether the AS/RS solutions could be implemented into the Tikkurila Vantaa warehouse is omitted of this thesis.

6.2. AGV/AMR solutions

AMR and AGV solutions have developed greatly over the last ten years, and they have become a viable option when it comes to warehouse automation. AGV and AMR solutions can operate automatically inside the warehouse and operate the same way as a manual forklift driver. In some cases, AGV and AMR solutions even make independent decisions based on the real-time information received from the onboard sensors and react accordingly. Additionally, the implementation of these solutions has become more flexible compared to previous models in which navigation was done by following magnetic wires that required lots of work when put in place. Nowadays navigation is done with onboard cameras and sensors, which speeds up and simplifies the implementation of these solutions without any changes to the facilities.

The annual inbound material volume from Tikkurila's own production is over 100 000 euro-pallets a year. All pallets arriving from production are full pallets which are packed and wrapped in plastic film and marked with a pallet label. The process of handling this kind of volume is straight forward shelving from production line to the warehouse. AGV and AMR solutions are an attractive option to implement in the Tikkurila Vantaa warehouse. Based on the material transaction data and the current operation of the Tikkurila warehouse, an AGV or AMR solution would be a reasonable choice, for example, for handling inbound material flows from production to the warehouse.

Basic requirement for the AGV to be able to operate in the Tikkurila Vantaa warehouse can be simplified in two basic rules:

Lift capacity must be over 7.5 meters for a 500-kilogram pallet.

Forklift needs to be able to operate in aisle width of 2.7 meters.

These are the two basic requirements that must be fulfilled for the forklift to be able to operate properly in all warehouse areas.

To investigate this option further, I contacted two well-known forklift manufacturers, Toyota and Rocla. Both manufacturers have developed AGV solutions for forklifts, and I made an enquiry whether they had solutions that would fit Tikkurila's requirements.

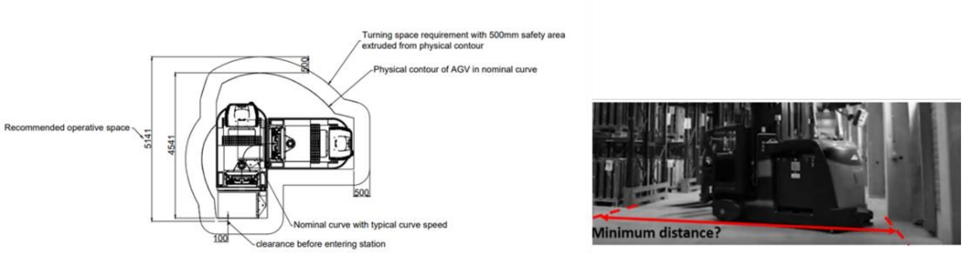
Rocla has implemented AGV technology on two different kinds of forklift types, both of which could be used in the Tikkurila Vantaa warehouse: a reach truck (model ART M16) and a truck for a very narrow aisle (AVT VNA). Toyota, on the other hand, has only one AGV solution for a reach truck model (RAE 160). In Table 8 is a comparison of the main features of these models. What can be seen from it is that all AGV reach truck models require aisle width greater than 2.7 meters. This makes it impossible for the models to operate between the aisles of Tikkurila Vantaa's warehouse.

Table 8. Comparison of different AGV models

Manufacture	Type	Model	Vertical minimum height	Needed operation aisle width	Turning radious	Lifth height
Rocla	Reach truck	ART M16	2,6-4,1 m depending on the selected mast and lift height	3 m or more	3 m or more	up to 10 m
Toyota	Reach truck	RAE 160	3,3 m	2,8m - 3,1 m	2,8m - 3,1 m	up to 10 m
Rocla	Very narow aisle	AWT VNA	4 m	1,7 m	5,09 m	up to 8 m

Based on this comparison, the only suitable AGV solution is a very narrow aisle forklift that can operate in narrow aisles (2.7 meters), such as in Tikkurila's warehouse. Although the

VNA forklifts can operate in narrow aisles, they are quite large machines from other dimensions and require a large turning radius at the end of the aisles, as can be seen from Table 8. The Rocla AWT VNA requires a turning radius of more than five meters, as shown in Picture 22. This makes it clumsy to use in a warehouse that is designed to be operated with reach trucks. As Tikkurila Vantaa’s warehouse is not designed to be operated with VNA forklifts, there is not enough turning space at the end of all aisles.



Picture 22. VNA forklift turning radius. AGV Network 2021

For an automated solution to work effectively, it must be able to move and operate in all aisles of the warehouse. Therefore, the biggest obstacle for implementing an AGV solution to Tikkurila’ warehouse is the current warehouse layout and aisles. Automated vehicles require a greater safety distance to operate between the aisles compared to human operated models. Because of this, AGV /AMR forklifts do not appear to be a suitable alternative to human operated forklifts or to the existing warehouse layout.

6.3. Pick by voice

The third automation solution that was addressed in previous chapters is the pick by voice solution. This technology has potential to increase Tikkurila’s automation level on picking tasks and make the material picking more effective compared to the current situation. As was concluded in chapter five, Tikkurila has annually about 800 000 material transactions of which approximately 90 percent are single pick transactions. According to Honeywell (2017), a pick by voice solution can, in some cases, increase warehouse productivity up to 10-30 percent depending on the previous picking method. Certainly, the benefits of voice picking will be greater if paper list picking is replaced with voice picking compared to Tikkurila’s case, where an ERP system is used, and forklift terminals and barcode scanners support the picking work.

Based on this, the pick by voice solution appears to be a feasible option to improve warehouse efficiency. Compared to the other two solutions, the pick by voice system seems to be the easiest way to increase warehouse productivity with a relatively small investment. Therefore, in this thesis, I examine the pick by voice solution a little further and evaluate how it could be implemented in Tikkurila Vantaa’s warehouse. I will also estimate and calculate the payback time for this investment.

7. Lydia pick by voice solution

Lydia Voice is one of the marked leaders on voice technology. According to Finn-id (2021) Lydia voice solution has already over 200 000 users globally and it is the number one in voice picking technology in Europe. The thing that makes Lydia voice one of the best voice picking technologies on the market, is a deep neural network acoustic learning platform that helps Lydia users to successfully address the age-old problem of difficult worker dialects – a frequent problem in other voice picking technologies. AI based neural network is self-learning, as the data model continues to improve its performance over time and provides extreme accuracy for those with challenging speech patterns and mixed dialects. Lydia voice picking supports nearly all languages, and the voice output can be programmed to be pickers' native language. In new ERP systems the voice picking functions are already integrated. SAP Extended Warehouse Management, for example, already includes seamless interface for voice solutions which makes it easier to implement pick by voice solutions to modern ERP systems. (EPG Lydia Voice Brochure. 2019, Finn-id. 2021, EPG 2021.)

7.1. Lydia pick by voice equipment and their costs

Pick by voice system costs can be divided into two areas: First, the implementation cost that is needed to buy all necessary equipment, like headsets or vests and software to run the system. Second, the yearly operation costs to maintain and run the pick by voice system. These include monthly costs, such as running the license for the pick by voice system and a monthly maintenance fee to fix any occurring problems.

In this section, I will explain the main components that need to be considered for the pick by voice solution to work.

7.1.1. Lydia software

The first part of integrating a voice picking solution into use is the software project. The main goal of this project is to link supplier’s software to the customer’s current ERP system and make sure that the system provided works together with the customer's current processes. Each software project is individual and needs to be tailored based on the customer's needs and current ways of working. Hence, it is not possible to get the exact costs for this part until the whole software integration plan is completed. (Ruhe, Günther & Wohlin 2014, 56.)

Some of the usual activities that are carried out during the pick by voice software project include:

Project definition

Customer specific dialogue design

Pricing includes design of one dialogue (e.g., picking routine) and language

Integration

Installations

On site installation per separate agreement and pricing

Testing

Deployment

Super user training

Project management

Documentation

7.1.2. Lydia voice picking hardware

Voice picking hardware is the actual equipment needed to perform the voice picking in the field. Voice picking hardware usually consists of two different pieces of equipment: A computer, as shown in Picture 23, that processes data between the ERP system and the picker. In addition, a sound system is needed for the operator to hear and respond to voice commands. Usually, voice commands are delivered through a headset, but nowadays new innovations have come to replace this in the form of an audio vest with integrated speakers. Audio vests are ergonomic to wear, and they allow the operator to be not only hands- and eyes-free but also ears-free while working. The headset and vest models from Lydia voice are presented in Picture 24. A more detailed equipment catalog and prices for Tikkurila are presented in Appendix 1.

Picture 23. Voxter elite+ is the equipment that connects worker to Lydia voice picking software. (Lydia voice. 2021)

Picture 24. Headset or voice wear vest are used for listening and executing the commands. (Lydia voice. 2021)

8. Pick by voice payback

For the pick by voice solution to be profitable for any company, the investment needs to improve and speed up existing processes. In the following, I present two case studies of companies that adopted a pick by voice solution and summarize the effects the pick by voice had on warehouse efficiency in the cases.

8.1. CONA SERVICES LLC

Cona (Coke One North America) is an IT platform for the North American Coca-Cola bottling business (Cona services LLC, 2021). Cona offers its participating bottlers common IT solutions and platforms to use, such as common customer solutions, processes for manufacturing and digital business innovations. CONA Services provide its customers with solutions in order for them to optimally run their daily business and refresh the world. (Cona services LLC, 2021)

In 2019 CONA services LLC was facing a dilemma: Their old voice picking system provider informed that manufacturer support for their existing voice solution would be discontinued in 2021 (Lydia voice, 2021). Therefore, CONA needed to find a new supplier for its voice picking technology. After careful research and testing, Lydia voice picking was chosen to replace the former voice picking technology. According to Baron Jordan, CONA's Chief Product Officer, CONA's previous inefficiencies were related to both the voice template training as well as poor voice recognition. Lydia Voice's deep neural network voice recognition eliminated poor voice recognition and the need for voice template training. According to Jordan, productivity has increased an average of 6-7 percent with the Lydia voice solution. (Lydia voice, 2021.)

8.2. Fressnapf Group

Fressnapf Group is a German franchise company for pet food with over 1400 stores and 8000 employees in 12 European countries, which makes it the largest European pet product retailer. Previously picking in Fressnapf's warehouses was done by using electronic picking lists that were provided directly on the monitors in the industrial trucks. The Fressnapf Group is committed to continuously review its processes and improve its efficiency and according to Gerhadr Kunkel, Head of Outbound Logistics, Fressnapf Group had reached the limit on how much picking efficiency can be increased or picking mistakes reduced by existing electronic picking list method, and it was time to look for novel solutions. After thorough testing of different picking methods, like pick by voice, pick by light and pick by visual using smart glasses, Fressnapf ended up choosing pick by voice as the next picking solution for their warehouses. (Lydia voice. 2021)

Since the introduction of the pick by voice solution, Fressnapf Group has recorded a 10 percent increase in picking productivity in both of their warehouse locations. Pick by voice has also had a positive effect on picking accuracy, as picking mistakes have reduced almost 50 percent compared to the previous picking method. One of the reasons for this is the Hands-free/Eyes-free concept, which allows full concentration on the picking process. (Lydia voice. 2021)

8.3. Payback calculation

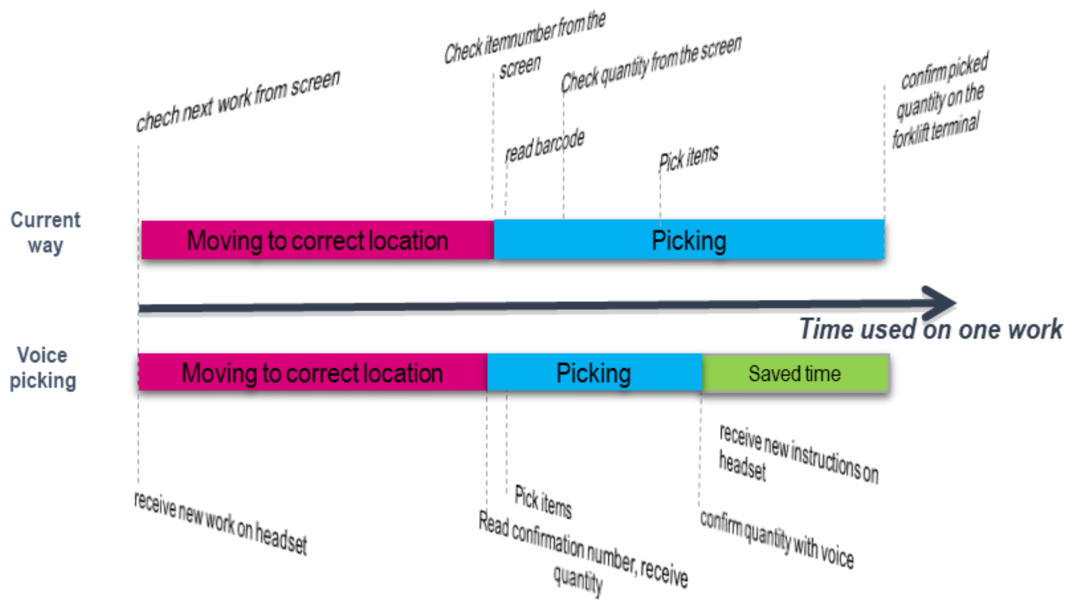
When investing in novel technology in PPG Tikkurila two key elements are investigated before approval. The first is safety, i.e., whether new technology improves the general safety of employees and reduces the risk of work-related accidents. The second is the impact on productivity and the payback time of the investment: How much will the new investment improve productivity and over how long is the investment expected to pay back the amount of money invested in it?

Pick by voice technology does not have a direct impact on work safety, but compared to a regular picking list, an employee's eyes and hands are free with the pick by voice. This has an indirect effect on occupational safety. For example, picking heavy items can be more economical when both hands are available. Driving a forklift can also be safer when the driver does not have to focus on finding the next picking location on the forklift's terminal screen or on a separate picking list. But, of course, the main interest when investing in pick by voice technology comes from how much it can improve picking efficiency and reduce picking errors

8.3.1. Pay back calculation on voice picking in Tikkurila

Voice picking payback calculation is based on the fact that picking can be done more efficiently compared to the current picking method.

In Picture 25, a timeline is shown on how Tikkurila's picking is done currently and how it could be improved with voice picking. The main idea is that with voice picking an employee can process one picking line faster compared to the current picking method. Faster process time with voice picking assumes that the employee does not have to separately confirm or check anything from the forklift terminals, which makes the picking process on the picking location faster. Time spent on the picking location is spent on actual picking work and confirmations are done by voice commands. There is no need to separately confirm or check picking location, quantity, or item from terminal.



Picture 25. Comparison of the current picking method and pick by voice.

As referred to in the earlier chapter, in both case studies the companies reported time savings in the picking process after pick by voice was implemented in their warehouse. CONA estimated that picking efficiency was improved about 6-7 percent and Fressnapfh Group reported even a ten percent increase in picking efficiency. This is in line with information provided by pick by voice manufactures like Lydia pick by voice solution. According to the Finn-id (2021), pick by voice can reduce the time spent in picking by up to 20 percent and reduce the number of picking mistakes even by 55 percent, depending on the earlier picking method.

As mentioned earlier, during this thesis process it was not possible to test the different pick by voice software in real use in Tikkurila warehouse and compare efficiencies between the pick by voice and the current picking method. Therefore, payback calculations presented in this thesis are based on the previously presented case study examples from Cona and the Fressnapf Group.

As was stated on earlier chapter five, the Tikkurila Vantaa warehouse has in average about 75 000 monthly material transactions. Monthly warehouse productivity can be calculated based on monthly material transactions divided with work hours at the warehouse. Calculated this way Tikkurila Vantaa warehouse monthly average productivity is around 12 lines per hour, like presented in Table 9.

As it was not possible to measure by test how much the pick by voice picking could improve Tikkurila Vantaa warehouse's efficiency, payback calculations are presented based on two scenarios:

If efficiency increases 5 percent

If efficiency increases 10 percent

The number of active users for the pick by voice system is defined to be 35 users, which is enough to cover the need of employees in high season.

Voice picking investment and operation costs on the calculations are based on preliminary offer provided to Tikkurila by a selected supplier. A more detailed offer is presented in Appendix 2. As the offer is preliminary, any changes may affect the final calculations. Also, the number of active voice picking users has an impact on the result of the calculations. If the number of pick by voice users can be reduced from the 35 users, which was set as a default value in this case, it would bring down the yearly operation fees, which in turn would have a positive effect on payback times. Since the investment duration and amounts are quite small, the payback time of the investment has been calculated in this thesis without considering the time value of money effect.

Investment payback time = $\frac{Implementation\ costs}{Yearly\ savings - Yearly\ costs}$

Implementation costs: All hardware/software costs to get the pick by voice operational

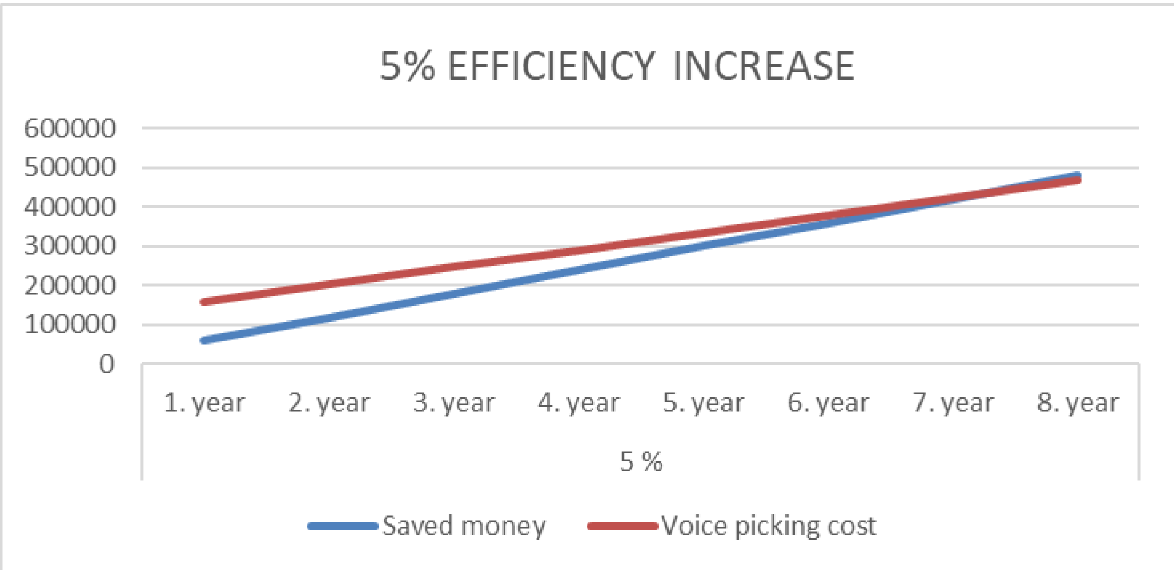
Yearly savings: Saved time in hours multiplied by average employee salary per hour

Yearly costs: Yearly operation fees for the pick by voice system (license and maintenance)

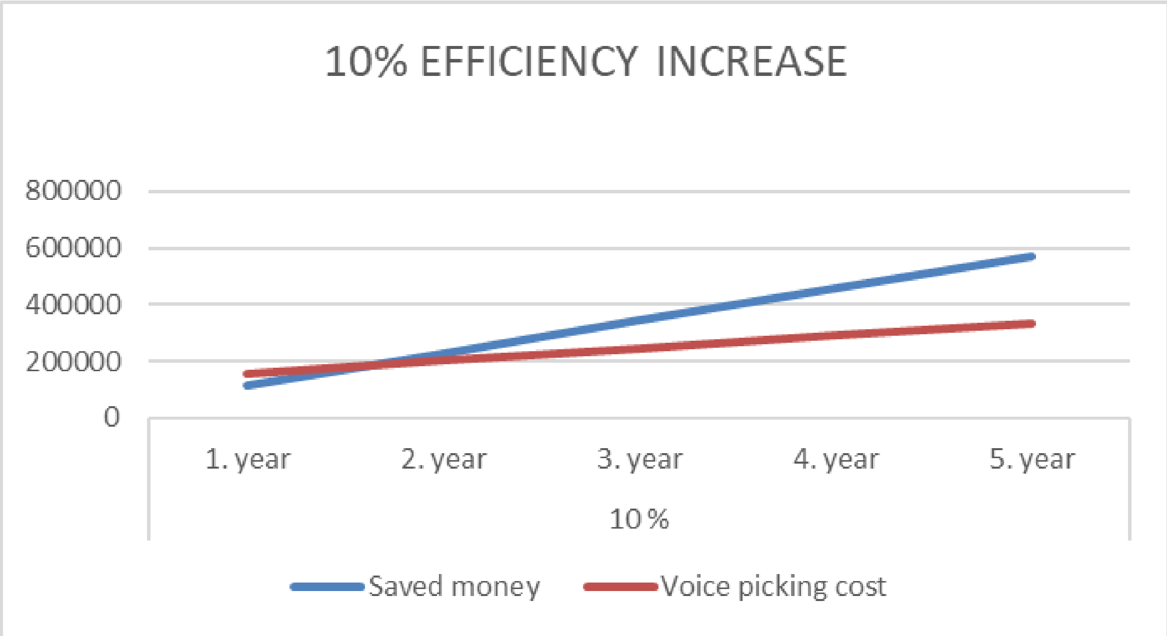
Results of the payback calculation in both before mentioned scenarios are presented in table 9, pictures 26 and 27 and in Appendix 3.

Table 9. Summary of payback calculations.

		5 %	10 %	
	Current way	Pick by voice 5% efficiency increase	Pick by voice 10% efficiency increase	
Average number of lines / month	76700	76700	76700	lines /month
Average number of working hours/month	6300	6000	5727	Hours/month
Warehouse efficiency / hour	12,2	12,8	13,4	Lines/hour
Saved time / month	0	300	573	Hours/month
Saved time / year	0	3600	6873	Hours/year
Payback time		7,2	1,6	year



Picture 26. 5 percent efficiency increase payback time.



Picture 27: 10 percent efficiency increase payback time

As shown in Table 9 and in pictures 26 and 27, based on the preliminary offer from the voice picking supplier, a 5 percent increase in picking efficiency yields a payback period of 7.2 years. A 10 percent efficiency increase, on the other hand, results in a much faster payback time, only 1.6 years.

9. Discussion and conclusions

As was stated in the previous chapter, payback times for voice picking technology varies quite a lot depending on the efficiency increase it can accomplish. With a 5 percent efficiency increase the payback time is over 7 years and with a 10 percent increase the payback time is slightly over 1.5 years. When these two scenarios are compared, it is quite clear that the required increase in warehouse efficiency with pick by voice technology in PPG Tikkurila's case should be close to 10 percent for it to be a reasonable investment. An increase of 5 percent will result in a payback period of more than seven years, and such a long payback time for voice picking technology is not a reasonable investment.

In the following chapter, I answer research questions set at the beginning of this thesis. In the second chapter I will introduce possibilities for future studies and in the concluding chapter I will summarize the entire process.

9.1. Answering the research questions

This thesis had two research questions that I was trying to find answer to. The first research question was:

What are the main technologies used in warehouses to automate processes?

Automatization on warehouses can be divided into two separate areas: Automatization of material flows and automatization of current warehouse processes. On the material flow area, the main automatization solutions in current markets are AS/RS solutions, automated guided vehicles, or autonomous mobile robots. AS/RS solutions are fixed installations that have reasonably high implementation costs. These solutions work best in industries with lots of full pallet transactions.

AGV and AMR solutions, on the other hand, are more agile solutions to automate material movements. These solutions can be used almost in any kind of material transaction work. They can be used to retrieve pallets from storage to picking location or to handle material movements from production line to shelf. AGV and AMR solutions are designed to operate and work in standard facilities like any other normal forklift. They are relatively easy to take into use because they use machine vision and laser triangulation for navigation. Therefore, big modifications for the existing facilities are not needed, although the AGV and AMR solutions require a slightly larger operating space compared to manually operated forklifts. If no big modifications are needed to be made to the facilities and the AGVs are fit to operate in the existing warehouse layout, the implementation costs of these solutions are quite reasonable, at least when compared to an AS/RS solution.

As stated earlier in this thesis, not all warehousing processes can be automated so that machines handle material movements on behalf of employees. In some cases, it is simply not possible or financially beneficial to invest in such material moving technology. Yet even in these cases, there are ways to take advantage of automation. For instance, automatization can be used as a solution to automatize some of the existing processes or process steps. Examples of such solutions are voice picking and RFID solutions. These technologies can be used to automate some of the existing work processes so that warehouse work can be done faster. The basic idea is the same as in all automatizations, i.e., replace an unproductive task with automatization. In voice picking, for example, unnecessary tasks, like filing in the picked quantities or checking a new picking location from the terminal or paper, are replaced by voice commands to speed up the picking work.

The second research question was:

Which of these technologies could be applied in use at the Tikkurila Vantaa warehouse?

Tikkurila Vantaa has a large number of full pallet movements and picking activities, which makes it a suitable environment for the above-mentioned automation technologies to be applied to. However, even if volumes and products can be handled with robots or cranes, Tikkurila's existing warehouse facilities and their layout pose a problem: Tikkurila Vantaa's current warehouse racks are built with quite narrow aisle width (2.7-3 meters). Thus, automated vehicles would not fit to operate in the existing warehouse layout, and automated storage and retrieval systems would require a new layout or even new buildings to be implemented effectively. The most preferable automation solution, therefore, would be to automate the current warehouse processes as they are. Improving picking efficiency, in particular, could improve the overall productivity of the warehouse, as almost 90 percent of PPG Tikkurila Vantaa's warehouse material transactions are related to picking. Improving the time spent in picking activities improves the productivity of the entire warehouse.

Based on the literature reviews, supplier information and other case studies like CONA and Fressnapf Group, pick by voice can improve picking efficiency up to 20 percent depending on the company's starting point. Pick by voice is a relatively easy and low-cost technology to invest in, as it mainly requires the implementation of software and does not require modifications to facilities.

If pick by voice can live up to the supplier's promises and improve picking efficiency in Tikkurila by 10 percent or more, I would recommend investigating this solution as a first option of automatization.

9.2. Future studies

In the future, it would be advisable to test the pick by voice technology in action in the Tikkurila Vantaa warehouse and clock the difference between pick by voice and Tikkurila's current way of picking. Based on this information, it would be possible to see how big of a difference there is in efficiency between the current picking method and voice picking technology. It would then be possible to deduce what the real efficiency gains are and to calculate the actual payback time for the investment.

In this thesis I have focused mainly on the potential increase in efficiency and the potential benefits of the pick by voice technology for warehouse operations. It would also be interesting to measure the effects on picking accuracy and see if the pick by voice technology could be beneficial in this area as well. Any improvements that have a positive effect on picking mistakes also have a positive impact on overall costs.

9.3. Conclusions

Over the years we have seen a massive development in technology, and it has become business as usual for several industries. The same development has happened to warehousing activities as well, and nowadays modern warehouses are full of technology designed to help and improve warehouse efficiency. One of the biggest changes in this area is the fundamental difference in how material flows are organized in warehouses. Previously warehouses were designed with the person-to-goods way of thinking with the basic idea that warehouse employees are the ones that move around the warehouse and collect materials from storage locations. The problem with this way of thinking is that the employees spend quite a lot of time moving between separate locations and not on the actual effective work which is collecting the goods from storage.

Nowadays, thanks to automatization, it is possible to turn the material flow from person-to-goods thinking to another direction. In the automated method employees are the ones that stay put and materials will be delivered to them by automated solutions, like automated mobile robots or automated storage and retrieval systems. Because of these inventions the efficiency of the warehouse work has risen to a new level and employees can focus on actual work instead of spending time travelling between separate warehouse locations. Even though the current automation technology in material movement has multiple advantages, modern material movement technology can be an expensive investment and, in some cases, the benefits from automatization are not worth the money that the investment requires. Even if many automation solutions are related to the physical movement of materials, it does not have to be like that in all cases. Automatization can be a highly effective tool in other areas as well, like improving current processes by removing unnecessary or time-consuming activities, such as scanning the pallets manually or reading picking locations from a paper picking list.

In conclusion, countless different automatization technologies exist that could be used to automate different warehouse tasks and operations. The most important task, therefore, is to find the technology that is suitable for a specific purpose, fits in with the existing facilities, and is in a reasonable price range so that investment in the technology as a whole is profitable.

References

AGV network. (2021). AGV types. [Online document]. [Accessed 20th of January 2021]. Available at https://www.agvnetwork.com/unit-load-agv-automated-vehicle

AGV Network. (2021). VNA AGV - List of Manufacturers and Characteristics of Very Narrow Aisle Robots. [Online document]. [Accessed December 2021]. available at https://www.agvnetwork.com/very-narrow-aisle-vna-agv

Azanha, A., Vivaldini, M., Pires, S. R. I. & Batista de Camargo Junior, J. (2016) Voice Picking: Analysis of Critical Factors through a Case Study in Brazil and the United States. International journal of productivity and performance management 65, 5, 723–739.

Banner engineering corp. (2021). Pick-to-Light for Manufacturing and Assembly. [online document]. [accessed 4 of January 2021]. available at https://www.bannerengineering.com/sg/en/solutions/pick-to-light/assembly.html#

Battini, D. Calzavara, M. Persona, A. & Sgarbossa, F. (2015). A Comparative Analysis of Different Paperless Picking Systems. Industrial management + data systems 115, 3 . 483–503.

Brilliant WMS. (2021) What Is Voice Picking? How Warehouse Voice Picking Works. [online document]. [accessed Decemper 2021]. available at https://brilliantwms.com/what-is-voice-picking-how-warehouse-voice-picking-works/

Business wire. (2021). PPG to Acquire Tikkurila, a Leading Nordic Paint and Coatings Company. [Online document]. [Accessed November 2020]. Available at https://www.businesswire.com/news/home/20201217006244/en/PPG-to-Acquire-Tikkurila-a-Leading-Nordic-Paint-and-Coatings-Company)

Christopher, Martin. (2011). Logistics & Supply Chain Management. 4th ed. Harlow: Financial Times Prentice Hall.

Cona services LLC. (2021). Company. [Online document]. [accessed Decemper 2021]. available at https://www.conaservices.com/about/company/

Conveygo. (2021). Types and Applications of Autonomous Mobile Robots (AMRs). [online document]. [accessed 20 of January 2021]. available at https://www.conveyco.com/types-and-applications-of-amrs/

EPG Lydia Voice Brochure. (2021). Smarter Connected Logistics with Lydia Voice. [Online document]. [accessed Decemper 2021]. available at https://us.epg.com/fileadmin/user_upload/EUP/PDF/Brochures/ENU/EPG_Lydia_Voice-Brochure__US__2019-V1.pdf

EPG. (2021). Integrating Lydia voice with SAP eWM and WM. [Online document]. [Accessed November 2021]. Available at https://www.epg.com/gb/voice-solutions/voice-picking-integration/voice-integration-with-sap/

Finn-id. (2021). Älykäs puheohjausratkaisu logistiikkaan. [Online document]. [accessed Decemper 2021]. available at ww.finn-id.fi/lydiavoice

FlexQube. (2021). Automated Guided Vehicle Systems: 5 Things to Know Before Introducing AGVs to Your Shop Floor. [online document]. [accessed 4 of January 2021]. available at https://www.flexqube.com/news/automated-guided-vehicle-systems-5-things-to-know-before-introducing-agvs-to-your-shop-floor/

Gagliardi, J.-P., Jacques Renaud, and Angel Ruiz. (2012). Models for Automated Storage and Retrieval Systems: a Literature Review. International journal of production research 50.24, 7110–7125.

Ganesh, Mohapatra. (2014). Enterprise Resource Planning: Fundamentals of Design and Implementation. Cham: Springer International Publishing AG.

Ghelichi, Z. & Kilaru, S. (2021). Analytical Models for Collaborative Autonomous Mobile Robot Solutions in Fulfillment Centers. Applied mathematical modelling 91, 438–457.

Gligorije, M., Bakić, Z. & Djapic, M. (2019). RFID Technology in the Function of Generating Flexible Robotic Sequences of the FMC. Journal of the Brazilian Society of Mechanical Sciences and Engineering 41, 12, 1–12.

Groover, M. P. (2013) Automation, Production Systems, and Computer-Integrated Manufacturing. UK, Pearson Education UK.

Handling Technologies Inc. (2021). Automated Rack System (AS/RS). [online document]. [accessed 20 of January 2021]. available at https://handlingtechnologies.com/automated-rack-system-asrs/

Hebergemetnwebs. (2021). SCM. [online document]. [accessed 23 of May 2021]. available at https://www.hebergementwebs.com/supply-chain-management-tutorial/supply-chain-management-introduction

HI warehouse automation. (2019). Picking The Right AGV For Your Operation Depends On Your Handling Needs. [Online document]. [Accessed 10th of January 2021]. Available at http://www.warehouseautomation.org/2019/07/09/picking-the-right-agv-for-your-operation-depends-on-your-handling-needs/

Hokkanen, S. Karhunen, J. & Luukkainen M. (2010) Johdatus logistiseen ajatteluun. 5. p. Kangasniemi, Sho Business Development.

Hompel, M. & Schmidt, T. (2006) Warehouse management: Automation and Organization of Warehouse and Order Picking Systems. Berlin, Heidelberg: Springer Berlin.

Honeywell International Inc. (2017). the ROI of voice picking. [online document]. [accessed 23 of May 2021]. Available at https://sps.honeywell.com/us/en/support/automation/resources/whitepapers/calculating-roi-voice-picking

Jiangxi Danbahe Robot Co. (2021). The significance of AGV car for the auto parts industry. [online document]. [accessed 4 of January 2021]. available at http://www.danbach.net/news/technical/agv-car.html

Kato, H., Tan, K. T., & Chai, D. (2010) Barcodes for Mobile Devices. Cambridge, Cambridge University Press.

Lucasware. (2021). voice picking indroduction. [online document]. [accessed 10 of Januarry 2021]. available at https://www.lucasware.com/voice-picking-introduction/

Lydia voice. (2021). Cona selects Lydia voice. [Online document]. [accessed Decemper 2021]. available at https://www.lydia-voice.com/gb/voice-know-how/case-studies/cona-services-success-story

Lydia voice. (2021). Lydia wins performance comparison. [Online document]. [accessed Decemper 2021]. available at https://www.lydia-voice.com/gb/voice-know-how/case-studies/lydiar-wins-performance-comparison

Mobile Industrial Robots. (2021). AGV vs. AMR - What's the Difference? [online document]. [accessed Decemper 2021]. available at https://www.mobile-industrial-robots.com/insights/get-started-with-amrs/agv-vs-amr-whats-the-difference/

Mitsubishi logisnext Europe Oy. (2021). Case Valio Haapavesi. [online document]. [accessed 4 of January 2021]. available at https://www.rocla-agv.com/en/customer-cases/case-valio-haapavesi

Optiscangroup. (2021). viivakoodiopas. [online document]. [accessed 10 of January 2021]. available at https://www.optiscangroup.com/fi/en.php?k=219742

QRcode. (2021). Information capacity and versions of the QR code. [online document]. [accessed 10 of January 2021]. available at https://www.qrcode.com/en/about/version.html

Park, B. C. (2012) Order Picking: Issues, Systems and Models. In: Manzini, R. (eds) Warehousing in the Global Supply Chain: Advanced Models, Tools and Applications for Storage Systems. London, Springer-Verlag. 1-30.

PPG. (2021). Company history. [Online document]. [Accessed November 2020]. Available at http://corporate.ppg.com/our-company/company-history.aspx

Rouwenhorst, B et al. (2000). Warehouse Design and Control: Framework and Literature Review. European Journal of Operational Research. 122, 3, 515–533.

Ruhe, Günther, and Claes Wohlin. (2014). Software Project Management in a Changing World. Berlin, Heidelberg: Springer Berlin Heidelberg.

Sabattini, Lorenzo et al. (2018). The PAN-Robots Project: Advanced Automated Guided Vehicle Systems for Industrial Logistics. IEEE robotics & automation magazine, 55–64.

Shehab, E.M. Sharp, M.W. Supramaniam, L. & Spedding, T.A. (2004). Enterprise resource planning, An integrative review. Business Process Management Journal. 10, 4, 559-386.

Stellar group. (2021). Manual warehouse. [online document]. [accessed 5 of March 2021]. available at https://stellarfoodforthought.net/why-an-integrated-approach-is-crucial-in-designing-and-building-distribution-facilities/

Stephens, M. P. & Meyers, F. E. (2019) Manufacturing Facilities Design and Material Handling. Sixth edition. West Lafayette, Indiana: Purdue University Press.

Shutterstock. (2021). Full automated warehouse. [online document]. [accessed Decemper 2021]. available at https://www.shutterstock.com/fi/image-illustration/modern-automated-logistics-centers-interior-agv-1086485342

Su, X. Chu, C. C. Prabhu, B. S. & Gadh, R. (2007). On The Creation of Automatic Identification and Data Capture Infrastructure via RFID. Auerbach Publications, Taylor & Francis Group.

Tikkurila Oyj. (2018) About us. [Online document]. [Accessed November 2020]. Available at https://www.tikkurilagroup.com/about-us

Tikkurila Oyj. (2018) History. Tikkurila – nearly 160 years of decoration and protection. [Online document]. [Accessed November 2020]. Available at https://www.tikkurilagroup.com/about-us/history

Tikkurilagroup. (2018). Konserni/liiketoimintamme. [online document]. [accessed November 2020]. available at https://www.tikkurilagroup.com/fi/konserni/liiketoimintamme

Tikkurilagroup. (2018.) Konserni/strategia. [online document]. [accessed November 2020]. available at https://www.tikkurilagroup.com/fi/konserni/strategia

Want, R. (2006) An Introduction to RFID Technology. IEEE pervasive computing 5, 1, 25–33.

Toyota material handling. (2021). Semi-automation. [online document]. [accessed Decemper 2021]. available at https://toyotamaterialhandling-international.com/logistic-solutions/smart-logistics/semi-automation/

Turck GmbH. (2020). Pick-to-light advantages. [online document]. [accessed 20 of January 2021]. available at https://www.turck.de/en/advantages-38518.php

Ullrich, G. (2015). Automated Guided Vehicle Systems A Primer with Practical Applications. Berlin, Heidelberg: Springer Berlin Heidelberg.

Vasili, M. R., Tang, S. H. & Vasili, M. (2012) Automated Storage and Retrieval Systems: A Review on Travel Time Models and Control Policies. In: Manzini, R. (eds) Warehousing in the Global Supply Chain: Advanced Models, Tools and Applications for Storage Systems. London, Springer-Verlag. 159-209.

Z. Zainal Abidin, N.A. Zakaria,Z. Abal Abas, A.A. Anuar, N. Harum, M.R. Baharon, Z. Ayop. (2019). International Journal of Advanced Computer Science and Applications. 10, 3.

Vasili, M. R., Tang, S. H. & Vasili, M. (2012) Automated Storage and Retrieval Systems: A Review on Travel Time Models and Control Policies. In: Manzini, R. (eds) Warehousing in the Global Supply Chain: Advanced Models, Tools and Applications for Storage Systems. London, Springer-Verlag. 159-209.

Z. Zainal Abidin, N.A. Zakaria,Z. Abal Abas, A.A. Anuar, N. Harum, M.R. Baharon, Z. Ayop. (2019). International Journal of Advanced Computer Science and Applications. 10, 3.