Whether the AGV/AMR can be used in e-commerce

Keyi Zhou

Bachelor's thesis
June 2022
Technology, transport, and automation
Degree Programme in International Logistics Engineering

Jyväskylän ammattikorkeakoulu
University of Applied Sciences

jamk

Description

Zhou Keyi

How picking robots can be used in e-commerce

Jyväskylä: JAMK University of Applied Sciences, June 2022, 61 pages

School of Technology. Degree Programme in International Logistics. Bachelor’s thesis.

Permission for web publication: Yes

Language of publication: English

At a time when labor is becoming more and more expensive in Europe, replacing workers with robots will reduce amount of money that is spend by companies on employees. Meanwhile, the number of people of working age is declining in some Asian countries. Automated warehouses can ease the burden of finding staff. To do so, choosing the proper AGV/ AMR in warehouse is not only optimizes the use of warehouse land space, but also increase efficiency and decreases the rate of damaged cargo.

The purposes of research was to analysis, highlight and illustrate how picking robots were changing the status quo in e-commerce warehouses. It was also examining what were benefits and risks of using robots for warehousing. Equipment and technology for automated warehouses required high investment upfront. Consequently, uncertainty of recouping capital was deterred many small and medium-sized e-commerce companies from taking the risk. My goal was to help more hesitant online sellers by analyzing the performance, pros and cons of the picking robot's equipment available on the market.

Qualitative and desk research methods were gathered in this paper for accomplishing the goals, because it is less common today for articles on AGV to be analyzed as a whole, usually experimented with a particular technology or algorithm. Massive data were used in article which involved scholarly journals, peer-reviewed papers, white paper, and expert statements. As a result, the data within the automated warehouse was traceable. Data could be used to optimize the path of picking robots or to adjust the layout of the shelves in the warehouse. The increased speed of dispatch made it possible to improve the competitiveness of e-commerce platforms. Furthermore, the data collected can also contributed to other areas such as goods sorting and customer management.

Keywords/tags (subjects)

Automated guided vehicle, automated mobile robot, E-commerce warehousing, automation, picking robot, warehousing, artificial intelligence, vehicle navigation.

Miscellaneous (Confidential information)

Figures

Tables

List of abbreviations

AGV - Automated Guided Vehicle

AI- Artificial intelligence

AMR - Automated Mobile Robot

B2C - Business to consumer

E-commerce - Electronic commerce

FARAI - Fear of autonomous robots and artificial intelligence

CQNs - Closed queuing networks system

GPS - Global positioning system

GTP - Goods- to- person

LiDAR - Light detection and ranging

LP - Linear programming

ML - Machine learning

MLP - Mixed-integer programming

OP - Order picking

OQNs - Open queuing networks system

PLC - Programmable Logic Controller

PTG - Person- to goods

PTL- Pick to Light

RMFS - Robotic mobile fulfilment systems

RPA - Robotic Process Automation

REID - Radio Frequency Identification

SAC - Standards approval committee

SKU - Stock Keeping Unit

SLAM - Simultaneous Localization and Mapping

SME - Small and medium enterprise

SOQN - Semi-open queuing networks

WMS - Warehouse management system

1 Introduction

The implementation and application of automated warehouse system construction using AGV/AMR picking robots were introduced in this study. The rapid development of AGVs technology and its widespread adoption by large companies has made it more necessary for some business executives to study and discuss the subject. For this reason, this paper was followed by a review of the literature and the analysis of case studies to find gradual answers to research questions. What is more, the progressive process of analysis has resulted in a clear understanding of the concepts and potential impacts (benefits and challenges) of the AGVs technology on the E-commercial industry, as well as a decision on whether to widely adopt new technologies at last.

1.1 Research framework

The research was based on desk research and qualitative research approach as this work was performed in case studies and documentation review that was helping to collect, summarize, and analyze all information related to it through the last decade, until the present time. By collecting data from two robots' companies, Kiva and Geek+, the aim was to provide insights on AGV technology in the e-commerce warehouse picking field.

Literature of other authors was discussed in section 2, which was shown the brief history, basic definitions, advanced technologies, equipped systems, and the standards of Automated guided vehicles. Detailed explanations of electronic trade and their special requirements were illustrated in section 3 for drawing out areas of research limitation. In addition, types of suitable picking robots also had been referred to in this chapter. To analyze the operating possibility in real life, two successfully adopted cases that are Amazon robotics with kiva system and Geek plus robot fleets were presented in section 4. And then, results and insights were provided in later section 5. Moreover, summarizing the answers to the research questions, and making detailed recommendations for future research based on gaps in the literature was done by the author. The last, reached conclusion was in section 6.

It was notable that some highly relevant articles, which are English language sources, were cited to answer research questions about AGVs. In addition, paper sources from Google Scholar, ScienceDirect, International Journal of Production Research, White book, Web of Statista were included for higher trustworthiness and scholarly nature of the article. Furthermore, some keywords and terms would be used to narrow the scope of the research such as automated guided vehicles, autonomous mobile robots, automated E-commerce warehouses, picking robots, order picking and so on. (Oyekanlu et al., 2020)

1.2 The objective and problem definition

The main objective of the study was to analyze cases based AGV technology and determine how it could be useful in an e-commerce warehouse. This type of technology aims at increasing the overall service quality, productivity, and efficiency while minimizing costs and failures (Geest et al., 2020).

By using new picking robot systems to replace manual picking in the distribution centers, the thesis aimed to explain how picking robots are changing the status quo in e-commerce warehouses. The main research regions were the EU, Asia, and other countries where warehouse technology has already been advanced. To achieve those purposes, the orientation was provided in the following three research questions. The thesis goals will be divided into three sub-goals:

- What are the benefits and risks of using robots for warehouses?

- Whether picking robots can be widely used in e-commerce warehousing.

- What is the future trend of AGV?

To better understand this technology and the functional basis for its application in distribution and storage place, the automated guided vehicle should be defined, and the questions "What is an automated guided vehicle and equipped systems?" and "How do automated guided vehicles work?" should be answered in the literature review section before describing in detail above three research questions later.

One of the main problems that has still existed in the warehousing field was funding. Theoretically, high investment upfront was required in equipment and technology for automated warehouses. With no certainty of recovering the capital, it deters many small and medium sized e-commerce companies from taking the risk. Another was safety, as people's wavering attitudes towards robot safety and anxiety of job replacement make a state of working with robots unstable.

But, in the long run, the cost advantages of automated warehouses over normal warehouses were becoming more and more obvious. In the background of rising costs of both land and labour, infrastructure investment and manpower operation & maintenance costs would be saved significantly from automated warehouses after completion. (Fragapan, 2021) The fundamental purpose of the thesis has written to help more hesitant online sellers by analyzing the performance and pros and cons of the picking robot's equipment available on the market.

While answering the questions step by step, the article gradually has been gone into the specific area of AGVs by utilizing key advances in AGV/AMR research. The remaining shortcomings, the possibilities of future trends and developments have been concluded by presenting and summarizing.

1.3 Constraints and research method

The topic of picking robots has been covered widely in this study. The results could be too broad for the scope of the study, which might lead to inaccurate results. For the sake of making the results sharp and concentrated, the scope of this research was limited to e-commerce sector warehousing. Sophisticated and digital industrial warehouses were booting up fast across the world. Many serve giant companies like Amazon and Walmart (WMT) that ship to consumers and several smaller merchants did as well. They were building or overhauling warehouses to use software and robotics (Martínez-Barberá, 2010), rather than just sweat and muscle from workers. Especially during this year, worker safety issues were highlighted in the situation of Covid-19 pandemic. At the same time, demands for one-day shipping were speeding it up. The consumer was uncomfortable suddenly with exposing themselves to strangers in shopping centers, car parks and so forth. Some sectors of business have even been entirely shut down by the governor. Moreover, many workers were nervous about being on the front line (Bhatti et al., 2020). For this reason, this would be a fitting time to explore smart warehousing for e-commerce.

The main research methods for the study were to combine qualitative and desk methods. Desk research involved using already existing data that was summarized and gathered for increasing the overall effectiveness of the research. Current inventory requirements of E-commerce warehousing and characteristics of picking robots were analyzed by desk research method. Qualitative research is mainly exploratory (Steckler et al. 1992). It was used to obtain an indication of underlying causes, perspectives, and motivations. Due to examining the place, function, and importance of documents analysis in qualitative research, Bowen (2009) carried out research at a very early stage. It provides insights into problems and helps to formulate potential quantitative research after collecting and analyzing robotic data. Given two case studies have shown at last how the current situation of small and medium enterprises and large-scale e-commerce companies using different picking robots, as well as what were their benefits and deficiencies (Brown, 2009). As this was a research-based thesis, the theoretical part must be very rich and comprehensive.

2 Automated Guided Vehicle Theory

Beginning from 1955, when the first AGV was introduced (Muller 1983, 28), the importance of AGV has been stressed in a considerable amount of academic research and specific literature. (Mattaboni, 1987; Iris, 2006; Le-Anh et al., 2006; Huang, G. Q et al., 2015) Nowadays, automated guided vehicles have long been increasingly attracted people's attention (Muller, 1983). The concept and movement definition of AGV were revealed and discussed in depth in this chapter for obtaining a better knowledge of its technology as well as implementations. Meanwhile, the answer to three questions “what the AGV is”, “how AGV works” and “how to use it” would be shown as follow. This chapter might also be utilized as one of the key resources for analyzing AGV's strengths and weaknesses in later parts.

2.1 Definition of AGV

Günter Ullrich (2015) presented an article in the book 'Automated Guided Vehicle Systems' about a historical review of AGV. The history of AGVs began around sixty years ago. The first known Automated Guided Vehicle (AGV) was introduced by Barret Electronics in 1953. It was notable that the article emphasizes AGVS has become a critical part of today's intralogistics. A theory had been proposed by Oyekanlu et al. (2020) that both AMRs and AGVs are often used interchangeably. They can accomplish industrial tasks together which include material handling, collaborative work with humans, cooperative activities with another AGV or AMR and so on (Fragapane et al., 2021).

2.1.1 Comparison

For the sake of paper clarity, it is necessary to give a clear definition of the robot difference at the beginning. The intention of next subsection is to promote a deeper definition and differentiation of AGV types.

A literature overview was provided by Fragapane et al. (2021) on automated guided vehicles (AGV) and autonomous mobile robots (AMR). Research outcomes have been observed that the automatic guided vehicle, also known as an autonomous mobile robot, was a high-performance, intelligent logistics handling device that could be divided into railed and trackless guided vehicles (p. 1-2). As the same implies, for rail-guided vehicles, the track is required to be laid and only moved along marked lines or wires on the floor (Long & Zhang, 2012, p. 1626).

Trackless vehicles, on the other hand, do not require tracks and can turn at will. This kind of vehicle is making them more flexible and intelligent by using radio waves, vision cameras, magnets, or lasers for navigation. (ibid)

Typically, ARM has certain advantages over AGVs because of an advanced form of AGV, mainly in terms of three aspects, like (i) more intelligent navigation, being able to use a camera, intrinsic sensors, and detecting scanners to explore the surroundings and designing the path of the best choice; (ii) higher flexibility in the process of automating operations, being able to freely adjust the transport route through simple software adjustments; and (iii) affordability, being able to be deployed quickly and with low initial costs. Many AMRs also do not require installation or prerequisites. At the same time, a potential challenge that needs to be addressed is the lack of a human supervisor who understands the limitations of the system. An AMR must, therefore, monitor its state autonomously, spot potential system faults and react appropriately (Fragapane et al. 2021, p. 1-4).

Nowadays, the growth of AMR and AGV technology has become more interlinked. More and more AMR technologies are becoming available in AGVs, so a comprehensive discussion of two supporting technologies and equipment required for them have been put together. Therefore, using AGV instead of AMR and any other acronyms used would be followed in this report. (ibid)

2.2 Navigation system

The elaboration of this section is essential to successfully understand the operating principles and to determine the safety of AGVs. Besides that, it is also preparing the ground for the research question “Application and future trend in the field of e-commerce”.

“AGV navigation can be an extremely critical part of AGV technology, which involves AGV’s position, attitude estimation and correction, trajectory tracking, obstacle detection and obstacle avoidance, and control of drive devices. The attitude estimation is divided into relative way and absolute ways. The relative estimation relies on the internal sensors of AGV, and the absolute estimation requires external sensors to obtain the external environmental variables of AGV” (Wang et al., 2018, p. 4).

The growing body of literature has been shown that navigation methods were driven by constant change and evolution, even though the application of AGVs in warehousing has become relatively mature. Different types of navigation technology, such as lasers, magnetic, natural navigation and so on, have their advantages in different warehouse picking scenarios. (Fragapane et al. 2021)

Therefore, combined navigation could be the trend of the future. (Wang et al., 2018) Examples include the integration of QR codes with SLAM navigation, the use of SLAM navigation in mixed human scenarios, and the use of QR codes when driving in areas where high accuracy is required. In detail, combined navigation refers to the application of two or more guidance or navigation methods to realize automatic guided vehicle operations. The combination of QR codes and inertial navigation uses the characteristics of inertial navigation with high positioning accuracy over short distances to connect the blind spots between two QR codes. The combination of laser and magnetic spots navigation is used to increase the stability of the AGV positioning. Therefore, combined navigation is a common navigation method to adapt AGVs to various usage scenarios and will be increasingly used on a wide range of AGVs. (Jazzyear, 2020)

2.3 Technical principle

The equipment and technology used in AGVs are focused on in this chapter. The literature sources were researched from the studies presented thus far. But, to simplify the description of the paper, only the main technical concepts needed for the research will be presented and described in this section.

At the level of individual AGV robots, the core of the technologies is used to achieve positioning, navigation, and obstacle avoidance operations. (Ti-Chun et al. 2018) In the actual operation of e-commerce warehouses, there are dozens or even hundreds of AGV robots, which require co-ordination and mutual deployment between AGV fleets, making the technical requirements higher. (Huang, G. Q et al., 2015) The following diagram shows the components and operational requirements of a single AGV (see Figure 1).

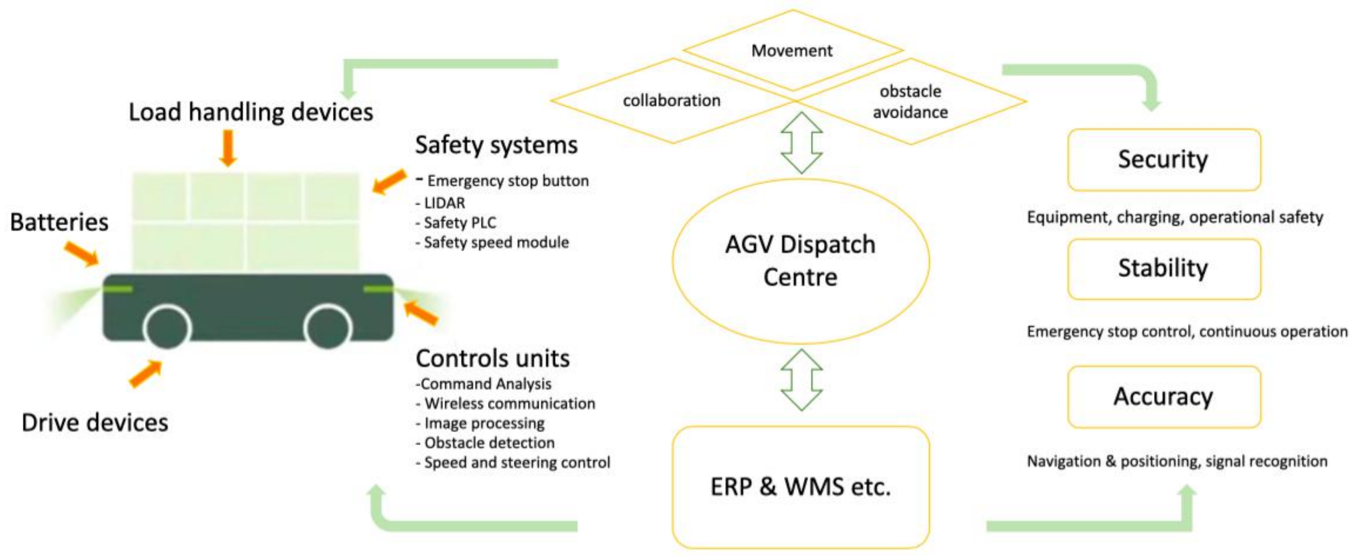

Figure 1. AGV components and operational requirements

An AGV body usually is consisted of modules such as batteries, drives devices, sensors, and load handling devices, and is equipped with some functions such as command resolution, navigation data processing, wireless communication, image processing, obstacle detection, and speed control and power management. (Fragapane et al., 2021) Next, I will go through everything in greater depth.

2.3.1 Sensor devices

A diverse set of compact, low-cost, and energy-efficient sensor devices are commonly integrated into the body of AGV that provides input data for autonomous navigation. (Fragapane et al., 2021, p,4)

The sensor has described by a group of researchers (De Silva et al., 2018) that is integrated laser scanners such as Light Detection and Ranging (LiDAR), 3D cameras, accelerometers, gyroscopes, and wheel encoders. The data providing the wheel position information will be captured by sensors, which is counting the distance the AGV will be driven to turn. While an exact distance point relative to the AGV in its environment was offered from LiDAR laser scanners, broad-angle assistance for visual obstacle identification was presented by 3D cameras (Fragapane et al., 2021).

These technologies have grown in popularity for their easy of use and quick presentation of results. Judgments will be influenced by the ability to fully recognize the environment concerning to guide path selection, potential collision, vehicle deadlock, and breakdown management. Sensing its surroundings enables AGVs to help, cooperate, and interact with humans and machines, resulting in more decisions. (Jazzyear, 2020)

2.3.2 Drive device

Robot's locomotion mechanism has a significant influence on its stability, maneuverability, and kinematics. Generally, AGVs are equipped with a steerable traction wheel located at the front and two independent driving wheels in the rear for pushing the robot to travel. But there is an omni-directional support wheel that can be used along with low cost and simplicity of use. (Fragapane et al., 2021)

The wheels of the OP robots can be combined in a variety of ways and different configurations. A case about spherical wheels was shown by Fragapane (2021), who mentioned the advantage of achieving a high degree of operability by powering spherical wheels or increasing the number of wheels, causing the robot to be able to travel in any direction along the surface of the ground at any moment, independent of the robot's orientation. Since many intralogistics activities demand a high level of stability, wheeled AGV are typically the preferred choice. (ibid., 4)

2.3.3 Batteries

Higher energy capacity and advancements in charging techniques, from traditional plug-in connection power sources to wireless power transmission, have a considerable influence on AGV battery management. (AGV network, n.d.)

According to research, wireless power transfer may be used in many situations, removing the requirement for connected connections (Huang et al., 2018). The limited battery capacity and the long charging times have been identified by users as two weaknesses of AGVs, resulting in much worse performance and usability. However, new high-capacity batteries allow for longer operational times and greater power for the calculations required for autonomous navigation and operations. The size of AGV is also enabled to be smaller, allowing them to be placed in narrow-aisle regions or immediately below several goods packed closely in deep lanes (Lamballais et al., 2017). Additionally, more intense scheduling decisions be encouraged as increasing battery power. With more and more technological improvements, battery life could also increase in the future. (AGV network, n.d.)

2.4 Equipped technology

2.4.1 SLAM technology

SLAM, simultaneous positioning and map construction, is a technology that helps the machine to quickly understand the surrounding environment and map out the environment by moving and observing when entering a strange warehouse environment. (Bloss, 2008)

Two core tasks are contained in Slam system that involves simultaneous localization and mapping. (Bloss, 2008) The machine will be required to have a three-dimensional perception of the environment due to those two tasks, so depth information becomes a crucial part. Combining sensor data to properly estimate the location of the AMR at any moment has proven to be a significant challenge. LiDAR, monocular/binocular cameras, or RGB-D depth cameras are typically used as eyes for AGV robots. Distance and speed are calculated with LiDAR by transmitting and receiving reflected laser beams. Analyzing the image changes while moving can provide a distance measurement. RGB-D is equipped with an infrared transmitter and receiver by using the structural light method. It can directly obtain the depth information about the outside environment. (Fragapane et al., 2021) Furthermore, information can be used to create an environment map, which can allow robots to move more smoothly or complete more complex tasks by stitching together images from their surrounding environment. At the same time, tracking errors also may be reduced. (Oyekanlu, 2020)

Recent advances in Kalman filter technology have led to a breakthrough achievement. Estimations from different sensor sources must be combined to generate a probability distribution over all possible robot locations and to predict a robot's position and orientation (Bloss, 2008). To correct a prediction over time, the Kalman filter makes use of a recursive algorithm. Using several measurement sources, measurement noise and sensor inaccuracy issues can be overcome (Pratama et al., 2016). Two different technologies can support the use of SLAM in different situations, such as in outdoor environments with GPS systems, while ultra-wideband technology can be used indoors. As a result, accuracy and reliability have been improved. At the same time, the safety of the working environment will be improved, when multiple AGVs are deployed to work with staff in an industrial environment or another. (Oyekanlu, 2020)

2.4.2 Motion planning

Motion planning is an essential part of the vision-based guidance systems and manipulation of equipment. By combining the two perspectives of Fragapane et al. (2021) and Karaman & Frazzoli (2011), this idea will be better understood. The motion planning algorithms provide speed and turning commands to the vehicle actuators such as wheels or manipulators to reach the set of guidance points along the path. (Karaman & Frazzoli, 2011)

AGVs are equipped with sensors and SLAM technology to track their path and provide feedback to correct their position. During the moving and travelling of the robot, AGV are allowed by the motion planner to reduce speed, or even stop, based on traffic or congestion. All aspects will be controlled by the robot itself including avoiding obstacles while finding directions. Codes are available of payable or charge on several open-source platforms for controlling AGVs and other robots. (Fragapane et al., 2021)

2.4.3 Artificial intelligence

As the result of the advent of hardware development trends, artificial intelligence (AI) techniques can be applied in support of AGV navigation as well as service provision. (Almasri et al., 2016)

The variety of well-known fusion techniques that help robots move from the start of their journey to their targets without colliding with any obstacles along the way, including a combination of AI and ML (machine learning), fuzzy logic, neural networks, and neuro-fuzzy and genetic algorithms. (Dias et al., 2018). These techniques have been attributed to researchers who have explored the responses of the brain based on environmental changes. Without these techniques, obstacles will be reacted to by the AGV in the same way. New approaches to making decisions have been created by the introduction of AI in all decision fields. The AI branches of vision, ML, and planning have been proven to be very promising. (Phil, 2021).

The ability of AI to collaborate with AGVs will be improved as AI develops and advance constantly. Human-machine collaboration can be achieved through oral commands and gestures made by staff, whether searching for goods in the warehouse or confirming the fulfilment of a which has successfully replaced the tactile method of operation. In addition, fault management is an area that needs to be attended to intensely. By utilizing artificial intelligence, AMRs can be recovered after failures and strategies can be found to rectify faults and build them quite durable. (ibid)

The AI algorithm is also described in detail on Geek plus's official website specifically, which contain different types of algorithm applications, such as task matching, path planning, order grouping, shelf adjustment, 3D bin-packing and smart replenishment. (Geekplus, n.d.)

2.4.4 RMF systems

Robotic Mobile Fulfillment Systems (RMFS) which is a new category of automated storage and part-to-picker order picking systems are developed specifically to fulfill e-commerce orders (see Figure 2). The demand for daily orders has been detected to fluctuate widely. Focusing on this issue, the core innovation of an RMFS is the robots that transport the pods, shelves containing SKUs, to workstations (Merschformann et al., 2019). At a workstation, the pods is waiting in line or queues until SKUs on the pod will be picked or replenished. Until now, these have been brought to the market by many companies such as Amazon Robotics, Swisslog, Interlink, GreyOrange, Scallog, Mobile Industrial Robots Quicktron and so forth (Lamballais et al., 2019). Picker walking time be eliminated because of RMFS. Hence, high pick rates can be expected. Jünemann was the first to conceptualize RMFS. (Enright & Wurman, 2011)

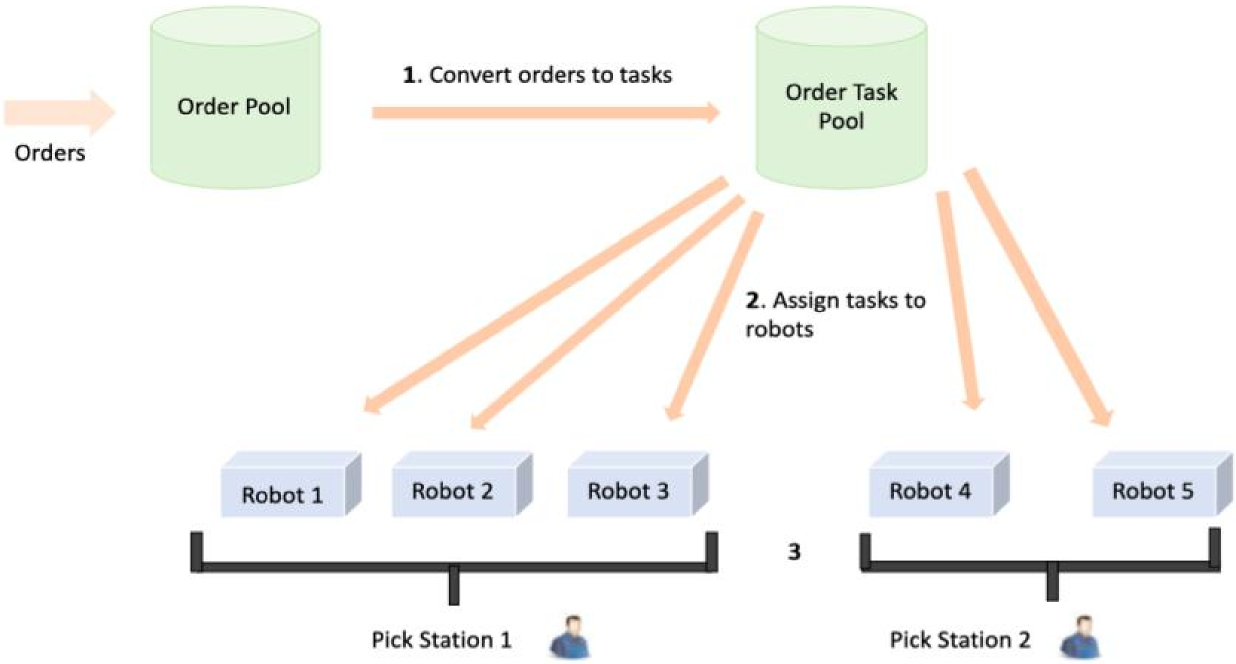

Figure 2. Robotic Mobile Fulfillment System

The most common analytical models for storage and retrieval were summarized by Kaveh Azadeh (2019) analytical model section, which is classified into several categories.

Several categories were divided into linear programming (LP), mixed-integer programming (MIP) models, travel time models and queuing network (QN) models. (Kaveh Azadeh 2019)

Three kinds of queueing networks and their algorithms have been studied for fifty years (Baskett et al. 1975; Roy 2016), that involves open queuing networks (OQNs), closed queuing networks (CQNs), and semi-open queuing networks (SOQNs). For the aim of accuracy, SOQN is the most suitable model compared with another. Kaveh Azadeh (2019) article quoted the paper of Bolch et al. (2006) refer an approximate algorithm to evaluate the performance of queueing networks. Approximation and performance metrics of the system, at the same time, can be used by this algorithm to match clients in waiting inbound with resources available in the internal resource queue. (Roy 2016; Kaveh Azadeh 2019)

2.5 Safety standards for mobile robot systems

The use of mobile robots has increased quickly in the past decade, and as a result, manufacturers and integrators found themselves uncertain about the right standards to apply. According to this situation, in this section, safety standards for current AGVs will be presented. Mobile robots in industrial environments have much more interaction with people than stationary robots. Franklin realized, what is vastly different about mobile robots is that they don’t stay in their cage and travel around the factory floor. And the hazard presented by the robot moves with it, even if humans are not thinking about interacting with a robot, for example, if they are walking down an aisle, a mobile robot can approach. (Robotic Industries Association, 2021)

ISO 3691-4 is currently regarded as the " most valuable" unmanned industrial vehicle standard in the EU, which is applicable for the mobile platform including AGV, tunnel tugger, under cart and so on. The white paper from the international organization for standardization and SICK company (2021) was described that the aim of this standard not only provide further improvement of the safety framework in a comprehensive perspective, but also expand the safety function requirements, as well as clarify the more practical verification methods. From risk assessment and analysis of front-end application scenarios, hardware architecture of safety systems, software safety design, safety function testing and field implementation, the new standard provides authoritative design guidelines for a new generation of unmanned industrial vehicles. Although that, risk evaluation must be carried out for the individual parts in AGVs. Furthermore, safety standards in detail are found in EN ISO 3691-4:2020 "industrial trucks -safety requirements and verification- part 4: driverless industrial trucks and their systems". (AGV network, n.d.)

The aim of R15.08-1-2020 standard is to ensure the safety of human workers near industrial mobile robots. (Robotic Industries Association, 2021) The R15.08 drafting subcommittee, which included a cross-section of the robotics industry, has developed R15.08-1. And this standard was approved by the R15 Standards Approval Committee (SAC), a Standards Developing Organization sponsored and administered by RIA and accredited by ANSI to develop standards in the field of robotics. (Alexandra et al., n.d.)

3 E-commerce warehousing

For indicating whether AGV can be widely used in the e-commerce warehousing industry, the definition, characteristics, and special terms of e-commerce logistics need to be mentioned as a priority. Chapter 3.1 describes the transformation of the e-commerce industry during the viral pandemic which encompasses the purpose of choosing the e-commerce sector for studying AGV. Chapter 3.2 describes the demands of e-retail warehousing and difficulties in picking orders.

3.1 E-commerce

E-commerce has seen a steep rise in recent years which is a phenomenal growing segment in the retail trade (Diniela, 2021).

In 2012, e-commerce sales be the high as US$1 trillion for the first time. In 2013, it was still accounted for under 10% of total retail sales but has been growing steadily at a rate of around 15% per year and was expected to continue at this rate for the rest of the decade (Bogue R, 2016, p. 2). Meanwhile, the major influence of e-commerce and online consumer behavior was owing to the worldwide coronavirus (COVID-19) pandemic. With more than millions of people staying at home in the whole 2020s to control the spread of the virus, digital channels such as shopping websites have become the most popular alternative instead to crowded shopping malls (Bhatti et al., 2020). Global retail e-commerce flows reached a record 22 billion monthly visits in the summer of 2020, with normally high demand for routine products and clothing, but also electronic products. Given a set of data was published from Raynor de Best (2021) clearly showing the total payment volume of PayPal between 2014 to 2021 by quarter. PayPal's payment volume was revealed below (see Figure 3) worldwide up to 285 billion USD. (Bhatti et al., 2020)

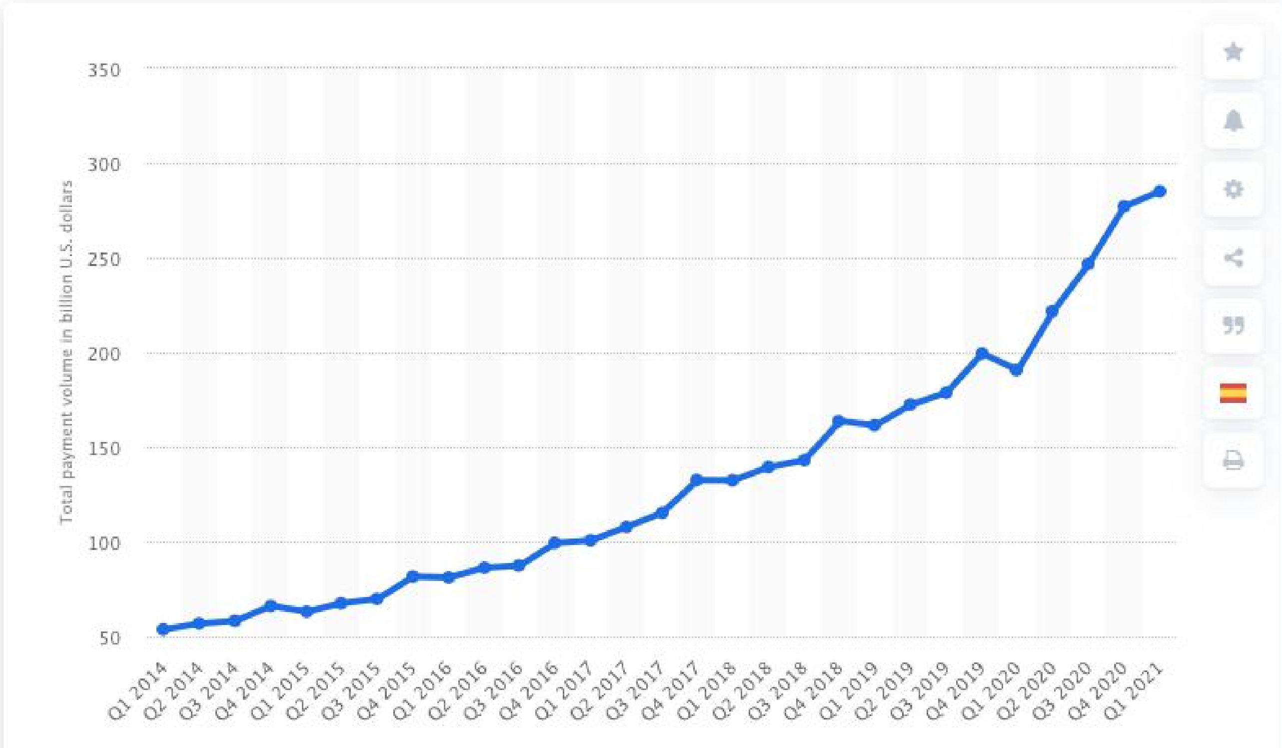

Figure 3. PayPal's total payment volume from 1st quarter 2014 to 1st quarter 2021 (Raynor, 2021)

Furthermore, retail e-commerce sales around amounted to 4.28 trillion USD in 2021 and e-retail revenues are projected to grow to 5.4 trillion USD in 2022. Daniela Coppola also predicted that e-commerce share will account for 21.8% of total global retailer sales in 2024. (Tugba Sabanoglu, 2021)

Along with the rise of digital trade and expend on the logistics supply chain, e-retailer and network businesses have changed the way they shop. Millions of online orders are received day by day. The orders may be comprised of multiple items of different sizes and the customers expect to receive their orders within 24 hours (Liang et al., 2016) resulting in an annual delivery of 4.2 billion parcels (Ecommerce Europe 2016). Previously, the customer placed an order online, waited several days, and received it at their delivery location. What they don't know is that the back end is nowhere near as slick relaxed and optimized as the front-end system they get to use. The goods sold on e-commerce platforms were varied and complex, but workers must be rummaging through storage to find the required items and get them into the shipping phase of the order. (Liang et al., 2016)

This is the reason why warehouses need to be equipped with technologies that allow them to keep up with manufacturing, production, and consumer demand. Nowadays, manual labor is replaced by robots with the result that efficiency and accuracy are improved, as well as reducing costs. And the solutions that are implemented give flexibility and capability to the employees and their processes. AGV logistics picking systems use many mobile robots to load and carry express parcels. Some kinds of AGVs can be implemented in the warehouse without a complete revisiting of the layout and systems, with the ability to add and expand vehicles complement as required, in line with the growth of the business. The automation of logistics sorting is now a popular area of research and application. With the development of "Industry 4.0", the future of logistics picking will also develop in the direction of intelligence, and the prospects for automated sorting are enormous. (MD Ryck et al., 2020).

3.1.1 Industry 4.0

Cross-industry and cross-sector collaboration is focused on this subsection that will result in the introduction of intelligent warehousing and picking robot fleets concepts into e-business platforms for the consequences of providing a highly flexible sales model.

Industry 4.0 is denoted as the Fourth Industrial Revolution. This term was introduced in 2011 at the Hannover Messe, one of the world’s largest trade shows, and since then widely used by the German industry and government (GTAI, 2016). Industry 4.0 is the era of industrial transformation using information technology, which can also be called I4. This concept first emerged in Germany. Nowadays, the discussion of how the shift to Industry 4.0, especially digitization, will affect the labor market (Springer, 2020).

Industry 4.0 involves many different companies and sectors. It is consequently leading to cross-industry, cross-sector, and even cross-national collaboration inevitable. If all the processes of logistics, procurement and sales were digitalized, e-commerce will predominate more than 90% of global business transactions. Also, business processes and e-commerce will not be managed in isolation. Underlying every service will be digital processes that are integrated with the entire network of business players. (R Geissbauer et al., 2016) Furthermore, Industry 4.0 is therefore all about data analysis. And e-commerce is based on data analysis to manage and improve current business processes. (Geest et al., 2021)

3.2 Requirements

Receiving, storage, order selection, and transportation are the core activities of e-commerce warehousing, which is the interim storage and processing of items between two consecutive stages of the supply chain (Gu et al., 2007). As a result, it is seen as a crucial aspect of any supply chain. Their primary responsibilities are included buffering material flow through the supply chain to account for changes caused by factors such as product seasonality or batching in production. (Bartholdi & Hackman, 2011)

As e-commerce has grown in popularity over the last decade, the new types of warehouses have been devised for final customer demands in the B2C market. They, typically, face the following requirements: small order size, a wide range of products, unstable demand, and tight delivery schedule. (Yaman et al., 2012)

Tight delivery time: Many online sellers, particularly in the B2C market, are found increasingly under pressure in their warehouse operations to essentially struggle to guarantee next-day or even same-day delivery (Yaman et al., 2012) and the order fulfilment process is becoming increasingly time sensitive. After all, late shipment dates have a negative impact on various areas of client buying behavior, including decreased order frequency, order quantity and size, as well as customer anxiety levels increasing (Rao et al., 2011).

Tiny orders: The majority of private clients prefer to place a few orders, each requiring only limited quantities of goods, for example, at the Amazon facility in Germany, a quantity of average order demanded was merely 1.6 items (Boysen et al., 2018b).

The range of products, such as assortment or brand, is constantly changing in line with customer demand due to local policies and seasonality. At the same time, it can also lead to a varying workload. This is because the stock levels and projected sales are constantly changing from month to month. (ibid., 2)

In addition, a notable advantage is that limited and expensive shop storage space such as stacking shelves will not be consumed because all the goods be offered online. It is why online retailers can offer a greater variety of goods (Brynjolfsson, E et al., 2003). This also results in very limited space for storage and order processing in e-commerce warehouses, particularly during peak seasons and holiday eve. Order picking has always been labor-intensive and involved long movements of human operators and/or goods. human operators and/or goods (Boysen et al., 2018b).

According to recent market research, the global warehouse robotics market has valued at USD 3.19 billion in 2018 and growing at a CAGR of 11% during the period 2019 to 2025. (see Figure 4) The warehousing industry is forecasted to witness significant demand in the deployment of robotic systems to reduce the operational time and labor cost and to enhance the throughput of whole warehouse operations. The warehouse robotic market is expected by researchers to grow substantially driven by the rising demand for automation and increased understanding of the potential value of safety and high-quality manufacturing. (Grand View Research, 2019).

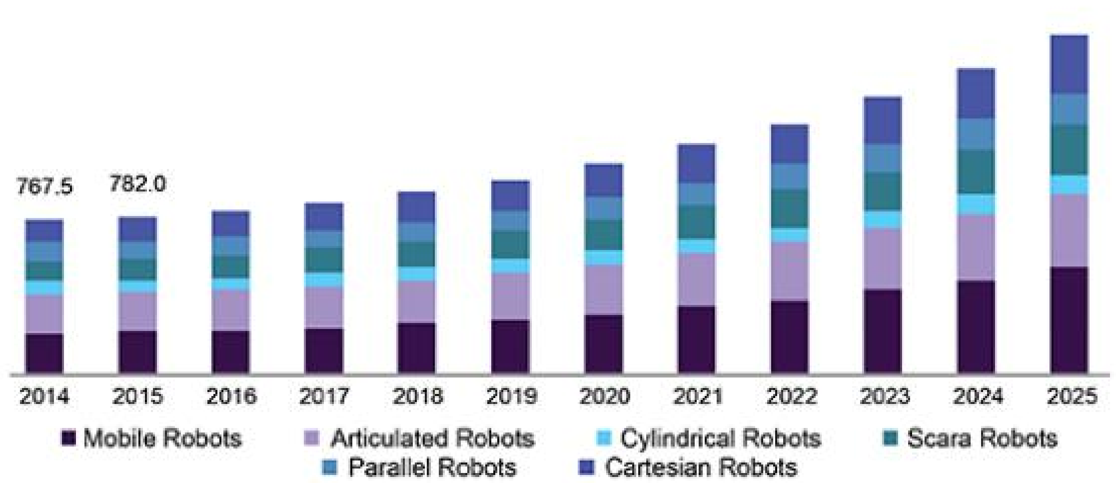

Figure 4. The U.S. warehouse robotic market size, by product, 2014–2025

3.3 Order-picking method

The process of obtaining items from buffer or storage regions for client requests is known as order picking (OP). In warehouses with manual systems, OP is known as the most labor-intensive job, while in warehouses with automated systems, it is the most capital-intensive operation. (Goetschalckx & Ashayeri, 1989)

Order picking systems are typically known as person-to-goods (PTG) or goods-to-person (GTP) picking systems. (Ashgzari & Gue, 2020). PTG is pickers travel to the goods platform that is seem as a low-end system. The other one, on the contrary, is GTP OP systems, where a material handling system brings the containers or pods to the pickers. Less labor will be required by GTP OP system since reducing the travelling time at the higher cost of an initial investment in automation warehouse. (Geest et al.,2021; Bozer & Aldarondo, 2018)

OP has long been identified as the most labor-intensive and costly activity for almost every warehouse. Any underperformance in order picking can result in unsatisfactory service and excessive operational cost for the warehouse, and consequently for the entire supply chain. The order-picking process must be well-designed and well-controlled to function efficiently. (Ho et al., 2008)

Order picking includes clustering and scheduling client orders, assigning stock to order lines, releasing orders to the floor, choosing goods from storage locations, and discarding the chosen products. Customer orders are divided into order lines, each of which represents a single product or SKU in a certain amount. Figure 5 distinguishes order-picking systems according to whether humans or automated machines are used. (Ashgzari & Gue, 2020)

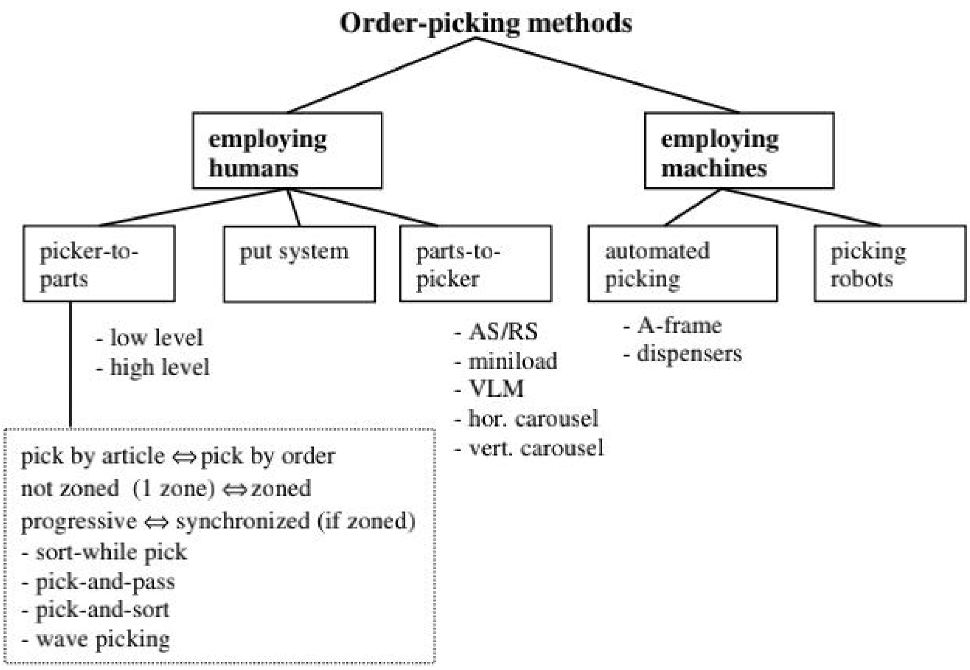

Figure 5. Classification of order-picking systems (based on De Koster, 2004)

Previously picking that is automated or robotized is only employed in exceptional circumstances that involves valuable, small, and delicate items. Over the last decade, the consumer market has been driven by the combined effects of the growing retail and e-commerce sectors and energy efficiency-driven technological shifts in automation.

Robotics and automation technologies have been used in many firms to grow their businesses wildly. (Grand View Research, 2019)

3.3.1 Restriction

The vertical axis in the table below is arranged according to the automation level. Online retailing has faced the challenge of assembling large numbers of time-critical picking orders, each consisting of just a few order lines with low order quantities. Traditional picker-to-parts warehouses are often unsuitable for these prerequisites. (Boysen et al., 2018b).

In most cases, huge amounts of small-size orders must be constructed from a broad selection under tight deadlines, and online retailers must be able to adapt order fulfillment operations to changing workloads per month. In internet selling, these demands are extremely essential. Suitability of each warehousing system will be discussed in the below survey through these requirements introduced before. Thereby finding which one or more specific warehousing systems have fitted these requirements. Thus, all the above-mentioned conditions should be considered in this survey. (Boysen et al., 2018b) According to the specific requirements of e-retail warehousing, Mr. Nils Boysen's research tables are referred to (see Table 1).

Table 2. Overview of warehousing systems suited for e-commerce (based on Boysen et al., 2018b)

	Tight delivery time	Small order	Varying workload	Large assortment	
Traditional warehouse		☑		☑	
Scattered Storage	☑	☑	☑	☑	Scope of survey
Batching and zoning picking	☑	☑	☑		
Dynamic order picking	☑		☑	☑	
AGV assisted picking	☑	☑	☑	☑	
Shelf-moving robots	☑	☑	☑	☑	
Advanced picking workstation	☑	☑	☑	☑	
Compact storage system		☑			
A-Fram system	☑		☑		

In the scope of the survey, it is obvious from the picture that the picking methods of mixed-shelf storage, shelf-moving robot, and AGV-assisted OP are fully satisfied with all the above requirements.

The main point behind scattered storage is that by dispersing items around the warehouse, the average distance between an arbitrary location in the warehouse and the nearest unit for each SKU will be significantly reduced. The likelihood of finding needed SKU nearby will be enhanced. (Weidinger et al., 2018)

Shelf-moving robots using RMFs are a kind of goods-to-person solution, where AGV can lift movable pods or inventory pallets to the picking station, and then return to the replenishment station for restocking (Boysen et al., 2018b, p. 18-21). An about equipped system, RMFS, has been mentioned and defined in detail in the previous 2.4.4 section. In addition, the application of shelf-moving robots in the e-commerce industry is also referred to in the case study of Chapter 4.

AGV-assisted order picking also is called follow-pick in many papers. Two different assignment strategies in AGV- assisted OP system was referred by both Boysen et al., (2018b) and Azadeh et al., (2018), which are fixed-assignment policy and free-floating policy. For the first one, the simple process is the picker puts units onto the AGV that is around them. At the same time, AGV accompanies autonomously pickers on their way through the warehouse. The AGV backs to the warehouse depot autonomously, while the employee stays in the storage area when the current order has been done. The other situation is the free-floating strategy, where the AGV randomly travels toward a picking spot as well as waiting there until the required units have been loaded by the picker. And immediately following that, they drive to the next position to wait for another picker to execute their work. (Azadeh, K et al., 2018)

4 Case study

Two cases have been shown about how AGVs companies have applied technology to their business and explained how the automated guided vehicle success in e-commerce business.

4.1 Amazon case kiva

In terms of new-age warehouse management solutions, Amazon probably was called the most prominent example. The giant online retailer has long incorporated warehouse robots into the supply chain, making manual labor obsolete. (Adrian et al, 2020)

The company, Kiva Systems, has its headquarters in Woburn, Massachusetts, and aims to reinvent the century-old warehouse business. What was the most worth mentioning is, the Amazon bought Kiva System for USD 775 million in 2012 (Nussbaum, 2015; Adrian et al, 2020).

The first orange box-shaped robots appeared in Amazon's facilities in 2014 and started implementing the System in August 2015. The idea behind Kiva was simple: by making inventory items available to warehouse workers instead of vice versa, orders could be fulfilled by employees faster (MWPVL, 2021). All robots and racks were tracked by a cluster of computers, with resource-allocation algorithms facilitating their efficient movement. Kiva systems wanted to revolutionize distribution centers by setting robots loose on the inventory. (Guizzo, 2008)

Broadly, this project was initially developed by Kiva Systems and Amazon Robotics acquired it. Since then, Amazon warehouse robots were evolved into reliable automatic assistants that function alongside humans. This project has several main goals, including faster warehouse management, enhanced workplace safety, and reduced walking distances and working hours. The news from Brown in Dailymail website was reported that this company has over 500,000 employees worldwide on top of contractors and part-time workers, as well as 100,000 robots that assist humans with labour-intensive tasks. (Brown, 2018) The robots, powered by computer vision and machine learning, picked up some heavy loads, moved them to the picking station, and performed loading. While troubleshooting and maintaining would be completed by Amazon workers, who analyzed the data they receive, ensured the robots have bins to load, and removed hindrances for smooth delivery later, such as stuck items in a packaging machine or dropped items. Consequently, the company's clear technological and automation preponderance was over its rivals at that time. (Peng et al., 2021)

Kiva System was preferred by E-commerce retailers because its solutions were both flexible and scalable. This is no doubt one of the most powerful selling points. Previously almost all merchants faced challenges when it came to growth rates, which was seen as a big unknown. Facing the situation of growth sales rates of online products tended to surpass expectations, as early as 2006 to 2011, Kiva cut a striking figure in the E-commerce industry where rapid scalability and flexibility were key strengths. Some collaborating companies were included, such as Staples, Gap Inc Direct, Von Maur, Gilt Group, Drugstore.com and so on. Up to now, it had already enjoyed success in the world. Since the acquisition, Amazon Robotics has been working on new robots for similar and completely different tasks. Two new AGV of Amazon’s designed were introduced for logistics center operations at the re:MARS 2019 conference. With the support of artificial intelligence technology, the aim of these robots was expected to further improve their cooperation with human employees. The two new AGV announced by Amazon were known as Xanthus and Pegasus. Xanthus just required one-third of the parts and costs half as much as the old robot. Pegasus was smaller than Xanthus and characterised by its ability to sort packages quickly and accurately. Amazon has already deployed more than 800 Pegasus to a sorting station in the US. (MWPVL, 2021)

At present, safety was regarded as the first challenge that needed to be overcome. Amazon has revealed that it went to enable human employees to move alongside mobile robots in logistics centres. Therefore, a reliable safety system was needed to develop that would allow the AGV to cope with human employees moving around and changes in the environment. At re:MARS, Amazon announced that with the acquisition of Canvas, an automated warehouse robotics start-up, they would be able to use its artificial intelligence technology to improve the coordination of mobile robots. And it was allowing AGV to move outside of their original robot-specific sites and interact more with the employees in the future. (Amazon Staff, 2022)

While the majority of Kiva's success was driven by rapid growth within the e-commerce retail sector, Kiva Systems was seeking new ways to expand into other distribution sectors that could benefit from its unique approach. (Adrian et al, 2020)

4.2 Geek plus case

Geek+ was a global technology company specialized in smart and intelligent logistics. Flexible, available, reliable, and highly efficient products and services were created by applying advanced robotics and artificial intelligence (AI) technologies for warehouse and the management of the whole supply chain. Founded in 2015, Geek+ successfully completed over 200 projects across continents, deploying more than 20,000 robots nowadays. (Lu, 2020)

Reliable and efficient solutions were provided by Geek plus with unmatchable performances proven and tested during several mega e-commerce sales promotions, providing clients with the agility to respond to fluctuation and market demands. (Li, 2017) For instance, smart logistics solutions of Geek+ were provided to Winit, one of the world's most trusted providers of cross-border after-sales logistics services. In 2019, hundreds of Geek+ P800R picking robots were installed in Winit Cincinnati Fulfillment Center for solving the current challenges of large SKU volumes and shallow inventory in US warehouse. With an inventory subject to a wide variety of products, massive SKUs, and a rapid increase in online sales, a solution was found by Winit that would streamline their warehouse operations, mitigate against management issues due to high turnover of warehouse workers, and enable flexible yet affordable scaling of operations. (International online, 2022)

Cost-effectiveness was the second reason why Geek plus was chosen by Winit. An affordable option of Geek plus was offered that are Robot-as-a-Service (RaaS) Model. RaaS was a flexible and innovative business cooperation model which proposed firstly in the industry in 2018, allowing enterprises to not only purchase, but also choose robot leasing, operate for the owner and so on. Two obvious benefits could be realized that are lowering the capital and capacity barriers for enterprises to deploy robot systems and helping them to achieve supply chain upgrades more quickly. Therefore, this kind of affordable solution met start-up in demand. And it was also a tailored solutions that would be offered to a big band. In addition, the Geekplus' robot fleets with its equipped system were rented flexibly or charged on a per-unit basis, fully meeting the diverse needs of cross-border e-commerce. (Geekplus, n.d.)

Xiaoliang Luo, vice president of operations at Winit indicated that for quickly coping with the impact of the epidemic and the problems such as bursting warehouses, Winit was chosen once again to cooperate with Geek plus for the third phase of the project, which has been implemented in June 2021. (Cision, 2020)

One of the other beneficiary companies was Athinaiki S.A., a B2C distribution centre in Greece specialised in "last-mile delivery" for online business companies. At the same year, along with an implementation of Geek plus AGV solution, Athinaiki S.A. was seen increased in productivity and a 99.99% picking accuracy rate. Vassilis Karakoulakis, chairman of FDL GROUP claimed that Geek plus flexible picking robots provide an efficient tool that widens their reach, allowing them to help SMEs and big firms meet customer expectations for accurate and efficient services to compete and grow. (Cision. 2021)

More than that, in addition to a detailed introduction before to the Winit and Athinaiki S.A warehouse, Geek plus was demonstrated a robot combination solution for the increasingly complex picking scenario in overseas eCommerce warehouses - the optimal combination of C200M (goods-to-person) and P800 (bin-to-person) which allowed for complex picking challenges such as mixed storage of large and small items, massive SKUs, and shallow inventory to be solved. (ibid)

Other industries such as pharmaceutical, third-party logistics, automobile manufacturing, and apparel have also been found to be suitable for Geek+ Goods-to-Person Picking System. At present, automation solutions of Geek+ was won trust of over 500 global industry leaders. (Sun, n.d.)

5 Result and Discussing findings

Two main pieces of company cases were reviewed in this chapter and provided a statement and summary of the literature referenced for questions. However, the two automated robot companies, Kiva robotics and Geek+ mentioned in the cases did not respond to my request for an interview. Therefore, some vital academic sources, whitepaper and another related thesis from the official website would be used to support my research.

5.1 Literature supplement for cases studies

These two case studies were chosen for one reason, that they were founded in different regions as well as more than a decade apart from each other. As a result, a broader and more comprehensive analysis of the research topic can be conducted.

In an article conducted by Bozer & Aldarondo (2018), The Kiva system was pointed out as having poor cube utilization but higher flexibility and scalability over mini-load system. To increase the cube utilization, The feasibility of installing mezzanines and lifts in warehouses with the Kiva system could be further researched.

A study was carried out by a group of researchers Peng Hui et al., (2021), they designed a virtual QR code section to examine the causes of the deadlock phenomenon. And the result was concluded that it would cause a chain of waiting for all deadlocked AGV once a deadlock occurs. And at the same time, the chain conflict and waiting of multiple AGV would also harm the efficiency of the RMFS system.

According to the Geek+ website, white paper and magazine published, multi-sensor integrated navigation-based Slam algorithm and QR codes are already installed and used in Geek+ robots. The most appropriate mode can be switched arbitrarily by the operator depending on the complex work situation. SLAM navigation could be used for real-time positioning and 3D mapping of terrain by using a combination of laser and camera sensors fusion to maintain accurate positioning and motion control in complex environments. In simple terms, the robot equipped with a pair of eyes is capable to obtain immediately its current location information and planning its path to reach a dispatched location on the map. Thus, it not only contributes to compensating for the defect of objectivity caused by a single sensor, but also reduces the occurrence of deadlocks or congestion in the warehouse. (Jazzyear, 2020)

5.2 Advantages and challenges

This subsection illustrated the review of the strengths and weaknesses that appeared in the table below. For answering next two research questions, it was essential that characteristics of OP robots were needed to separate audits and clearly understand. Noteworthy, all the strengths and limitations emerging were derived from the different types of academic sources that have been collected. To ensure the availability and reliability of the article, the year of publication of all the literature used was sourced after 2017. In summary, 18 articles were used for this paragraph and most of them have analyzed both sides of the situations mentioned. The author's observations and comments would be concluded in chapter 6.

Advantages

More and more prior studies that were noted the importance of automated guided vehicles and seen great opportunities for equipped systems such as OP systems, RMFS, SOQN and so forth. But only several reports were shown because of suitable for answering the first question.

The impact of throughput on picking efficiency was examined by M. Merschformann et. al (2019). Implementation of decision logic should be strongly focused on when designing an RMFS for achieving high output with a minimum number of inputs, such as staff, pods, pickers, and robots. The aim of the observation was to illustrate how reduced capital costs and increased efficiency and the same time. In their experiments, a conclusion was drawn about the importance of decision-making. The matter of decision rules tailored specifically for RMFS was deserved to be taken into account by other researchers in the future. Therefore, investment costs will be reduced, as the number of necessary equipment is decreased with the upgrade of the outdated logic control system. (p. 12)

Zou Bipan et al. (2017) preferred to find an assignment rule for minimizing the retrieval throughput time. For that, a new SOQN was established to assess the performance of the RMFS, and through a two-phase approximation method, simulation validation and numerical experiments to validate the availability of analytical models.

While the throughput capacity of the system, capital cost and even return-on-investment were considered the key factors in selecting an AGVs, other factors such as in particularly flexibility, scalability and timesaving at the pick stations should also be considered. (Bozer & Aldarondo, 2018)

The excellent robot features of flexibility and scalability were summarized in a paper composed by Bozer & Aldarondo (2018), that systems offered flexibility in the number of pick stations and AGV fleets that could be activated and staffed. This attracted many small and medium-sized companies in the growth phase. Briefly, the amount of AGV and pods can be added or decreased to meet the needs of the user, resulting in shorter downtimes, or waiting times. Besides, if warehouse in rapid growth was forced to relocate, the AGVs was portable while the robotic arms and another hardware were costly to relocate. However, even if the development of routes for AGV operations can be analyzed for traffic control, too many robots could still lead to congestion as they are constrained by the limitations of the handling system. But it was discussed later. (p. 17)

Timesaving was noticed as a very noteworthy strength. New robotics technologies were attempted to discuss the potential time-savings in order-picking operations. They provided lots of limitation hypotheses that would affect robots' travel times. There are includes constrained payload capacity, different warehouse design, impacts on the number of crosses, and picking-aisles, as well as the location of packing stations within the warehouse. (Hung-Yu Lee and Chase C. Murray, 2018)

For reducing unproductive working time during order picking, a better way was aimed to find all the time in academic literature. Scattered storage using AGV was especially ideally suited, if only a few items are required per order line, that is why they are mainly used by B2C e-retailers. The biggest advantage of scattered storage strategy claimed by Weidinger and Boysen was that warehouse was filled with items from each SKU instead of being crammed into one corner. Some items were always closed by, so that unproductive walking time was reduced. (Weidinger & Boysen, 2018)

However, a limitation was revealed to exist in scattered storage, if this method was applied to large size orders, multiple storage places would have to be accessed for collecting sufficient items in demand by the picker, which would also take longer picking times. At the same time, a hypothesis issue being pointed out was increasing additional workload about newly delivered loads, because goods must be taken to more than one spot. (ibid)

The robustness and reliability of the system was found another important aspect of AGVs. The mobile car can be recovered automatically from unexpected breakdowns and can therefore be operated without surveillance or interference from workers. Thus, in the European Journal of Operational Research, some factors affecting system dependability were required to investigate and study. And decision-making methods which supported AMR planning and control abilities would be introduced. (Fragapane et al., 2021)

Disadvantages

When it came to the challenges associated with OP robots, four points were thought firstly in the most online big brand and small and medium enterprises (SME) including safety hazards in the workplace, the huge upfront investment in the warehouse, the risk of worker unemployment, and resistance to robots in cooperation of staff and AGV fleets.

A specific form of sociological fear was examined by Liang & Lee (2017), which name as fear of autonomous robots and artificial intelligence (FARAI) examined the extent and frequency of FARAI, demographic and media exposure predictors, and correlates with other types of fear, for example, loneliness, drones, and unemployment and something like that. On a scale of 1489 participants, only 28.4% reported no fear.

Similarly, the employee not only in eCommerce warehouses, also in production environments was afraid of getting replaced by mobile robots. (Alexandra et al., n.d.) But a survey offered by Liang and Lee (2017) and resulted that the probabilistic navigation and autonomous obstacle avoidance with dynamic plan reconfiguration at high-speed leads to a skeptical attitude of the workers. However, moving with a precise purpose was rendered to feel rare intimidating, as the places where the mobile cars moved would be known exactly by the staff. while positive effects were produced due to the ease and slower movement. But the challenge behind time-consuming was increased according to the slower driving mobile robots. For online retailers, the time pressures were increasing particularly during the holiday period, especially on Black Friday. Therefore, a compromise including the production time and the employees’ opinion must be made. (Liang and Lee, 2017)

Interestingly, a contrary view was held by Lee and Murray (2018) about the risk of unemployment. The task of searching and retrieving items would be assigned to humans, on the same time, the mobile robots following them would take the goods into the wrapping place and then return to repeat the above process. In their points of view, items were presently more adept identified and grasped by human being from a storage shelf. Accordingly, staff working with machines would be regarded as a pandemic in the future. Logistics order pickers could also not be widespread faced on loss job. (p. 2)

In addition to the safety of workers needed to be focused on, Alexandra has raised the point that the hazards of robots in industrial surroundings needed to be at the forefront of buyers' minds as well. To detect walkers and barriers around paths, most AGVs were implemented and fitted with safety-certified laser scanners by manufacturers to prevent negative situations such as the robot getting stuck or even self-destructing. This perspective was also highlighted again at LogiMAT Exhibition in 2019. But older versions of AGV were used by few merchants remained without this function, which might be some threats such as queues in the middle of the road caused by parts jammed, financial losses due to dropped objects, and safety issues due to collapse. (Alexandra et al., n.d.)

Order delay because of road blocking was a potential challenge. The reason for jamming might come from scattered storage that caused the SKU on the AGV to be consumed so fast. Thus, replenishing new loads with frequent trips to the replenishment station would have a worse consequence. In scenarios with many SKUs and small orders, especially e-commerce, this saturation point would be reached earlier. (Merschformann et al., 2019)

Phase 2 simulation runs were devised by Merschformann et al. (2019) in Operations Research Perspectives, because lots of online retailers struggled with high return rate. An experimental result for effecting return orders was proposed. Honestly returning items in small quantities caused relatively less impact on cargo throughput than other changes. But the volume of returned orders that need to be processed raised as customer purchases increased during peak times, which result in adverse effects. Not only was the normal workflow of warehouse management disrupted, but around 20 percent of the time was spent by robots on replenishment operations. Additionally, returned products generally have a high probability of being reordered soon, imposing additional constraints on OP. (Boysen et al., 2018b)

5.3 Possibility of implementation

According to the literature review, this part was conceived with the aim of reviewing the literature to summarize and answer the second question, which was the question of whether PO robots could be widely used by online businesses. The characteristics and requirements of electronic commerce were mentioned in the 3.2 chapter, as well as the advantages and disadvantages were summarized above. In connection with the prior, it would be giving the perspective of different researchers on the applicability and suitability of both.

For adapting to the e-commercial demand, the article was noted by Merschformann et. al (2019) that successfully dealing with the peak time and meeting the requirement for e-retailer is essential. In different scenarios, the type and quantity of robots required might be changed, whether in terms of the scale and geographical location of the warehouse, or the volume of customer orders and the number of SKUs. AGVs with flexible characteristics were therefore fitted perfectly with the online retail model. Additionally, high throughput performance can be easily achieved by adding more AGVs with less handling time per pod. (p. 12)

According to a study conducted by Weidinger Felix et al. (2018), mixed-shelves storage of implementing AGVs was especially suited for small-sized orders demanding just a few items per order line. (p. 21)

The article of Weidinger (2018), in the same year, showed another situation was omni-channel sales. The aim of the study was designed to determine the most appropriate storage allocation strategy to achieve the aim of omnichannel sales for a business. Ultimately split storage was considered by researchers to be the appropriate strategy, which divides bulk handling areas and mixed shelf storage areas to distribute and store goods. It divided the goods being sold online and offline into two areas. The side with some mixed-shelve was therefore set up to meet the demand for online orders. By stacking items of the same SKU in the same area, the dedicated storage space catered for the supply of bulk shipments to the physical shop. Thus, goods sold online and offline can be handled at the same time. This strategy was successful for small and medium-sized businesses as there was no need to build two separate stockrooms and hence the operating and maintenance capital of the warehouse did not ramp up. (p. 21)

In the opinion displayed by Lamballais et al. (2017), RMFS was particularly suited for e-commerce distribution centers that faced strong demand fluctuations and large assortments of small size products. During the PO process, the flexibility of the RMFS was unanimously praised, and the fleet of the AGV was allowed to be added or removed at will to mitigate tight delivery time. (p. 3-5)

AGV system costs depended on the number of variables that greatly affected the overall cost. The whitepaper, AGV Cost Estimation, from Kollmorgen automation ab (n.d.) was shown a platform AGV cost near 15000 dollars if it was performed magnetic navigation, while the cost of natural feature navigation was around 25000 dollars. That paper listed all investments needed the AGV software management system cost, installation and commissioning cost, peripherals of system cost, maintenance cost, transportation, training and even factory acceptance test fees were involved. AGV network website also offered critical data for AGV payback. (p. 26-32)

A project on the Geek+ website was illustrated for mitigating fund-pressure in AGV and equipped system. The Robot-as-a-Service project was developed from the Geek+ robot, which was conceived with the aim of decreasing the challenges of cash investment in an intelligent warehouse. The standout advantages of RaaS in four aspects included simple deployment, less prior investment, update technology and long-term cooperation. (Kollmorgen automation ab, n.d.)

The choice of a correct warehousing system was seen as an indispensable point for warehouse managers. Thus, the suitability of different systems was discussed and deduced as well as a conclusion was confirmed by researchers. Most of the online retailers interviewed did not just apply a single system for all products, but rather applied multiple systems in parallel and connected them via conveyors. (Marchet et al., 2015; Davarzani &Norrman, 2015) However, potential issues were not addressed such as decision support, regarding when and how multiple parallel warehousing systems should be applied in combination. (Boysen, 2018b)

The advantages of omnichannel sales were mentioned in the previous paragraphs. However, this type of business trend was found to make warehouse operations rather complex. Even with the implementation of zoning and batching strategy, it still places a burden on the warehousing process in physical shops, as the urgency is identical as in online retail. Boysen raises the question, which type of WMS was appropriate for simultaneously servicing the size of small and large orders? Or is the hybrid system more suited? The implications of different scales of orders on storage process were not yet properly tackled in the literature. The reliability of the implementation would be influenced by these factors. (ibid)

5.4 Further development and trend

The final subchapter presented a review and focused on the third research question, which was the future trend of AGV.

Future studies may consider slotting based on AGV velocities. The systems will benefit from storing high-velocity AGV closer to the pick stations, even though congestion has occurred when putting AGV fleets with fast-moving at identical locations in the Kiva system. Once the SKU loaded into multiple AGV was consumed rapidly, a large number of robots at the same time would cause the negative situation of queues outside the picking and replenishment stations. At the same time, the impact and timing of replenishment in AGV systems were demonstrated which is another direction to explore. (Bozer & Aldarondo, 2018)

The accentuated obstacle was proposed in the European Journal of Operational Research, which described how balancing between AGVs and the number of receiving

/replenishment stations in a warehouse. Theoretically, the time spent by AGV travelling between service points (Receiving and Replenishment stations, staff) is highly variable, some unexpected situations are difficult for employees to detect and prevent, for instance dropping goods from a height or short-circuiting vehicles. Because of its flexibility and the uncertainty associated with the environment, it is difficult for the inspector to predict the road conditions in the depot an hour later, and then identify the number of vehicles to be assigned. For this reason, new algorithms need to be developed and emphasized to calculate the right number of matched mobile vehicles using new methods in the future. Hence, the number of vehicles and the type of equipment must be determined at the tactical level. (Fragapane et al., 2021, p.7)

About research direction on controllers, controllers could be equipped with different robot bodies to form a variety of AGV fleets which have different velocities, and load capacities. Customization and modular services for AGV manufacturing were asked to provide by AGV controller manufacturers. Thereby, the controller will implement that not only can single robots be controlled, but also clusters of robots can be dispatched. It is a fast and effective solution. A technical development trend of AGV navigation supported with multi-sensor also be outlined by this magazine. (Jazzyear magazine, 2020, p. 22)

To improve the accuracy and stability of navigation, the methods of integrated navigation and barrier prevention have been calculated and applied. Through collecting different operation information and data of AGV by different sensors, the dependability, stability, and survivability of mobile robot was enhanced using fusion navigation devices compared with the single sensor. What’s more, further benefits included increasing real-time and information utilization, improving accuracy, and extending the space coverage of mobile vehicles. (Wang et al., 2018)

A problem with holistic research was revealed in the paper of Boysen et al. (2018a). Most existing papers concentrated on analyzing rigorously the individual problems. But unifying observation for the whole model that involved AGV robots, software, and AI algorithm was the needed for the warehouse manager. For example, from the AGV's parking location in the storage area, order allocation, path selection and movements speed, to the

QN and replenishment frequency should be considered comprehensively. Therefore, a holistic model is needed to provide a unified view of the complete OP processes. (p. 24-25)

5.5 Research overview

For e-commerce businesses that sell a variety of items online, the use of AGVs in the picking process created more value for the enterprise and was a core objective of the merchants. The theory presented in the literature in Chapter 2 and Chapter 3 provided a foundation and framework for the study. The results are based on the theories being successfully presented that AGVs can not only adapt to circumstances with variable order volumes but also save time as well as reduce the rate of goods damage. Ideally, warehouse security would also be greatly improved, which is crucial in any business. The safety and health of the staff would also present a favorable appearance to the public. Wealth could be generated for the e-commerce firm while simultaneously beating competing companies.

AGV, on top of being used in industrial manufacturing and warehousing, would also be suitable for other industries. In post offices, libraries, docks and airports, the handling of goods was characterized by large changes in quantity, frequent route adjustments and repetitive single processes. These problems were solved by AGV which achieved automated, intelligent, and flexible day-to-day handling, greatly facilitating and helping to improve the living standards of people. In the tobacco, pharmaceutical, food and chemical industries, the requirements for moving work must be higher, and clean, safe, and pollution-free therefore is the necessities. Consequently, manual handling was prone to product contamination, except for mobile trucks. Hazardous sites and special industries would be adapted to the AGVs. Military detective vehicles, steel mill trucks, and so on were difficult to operate manually due to the high-risk factor and the influence of radiation, whereas such challenges were solved by AGVs.

Intellectualization serves as an essential step toward cost optimization. From the creation of a task to the end of its life cycle, the status of the task could be monitored by the employee constantly. Not only does this ensure that the AGV system works properly, but the data generated by the mobile car and warehouse management system (the number of each type of goods leaving the warehouse per day) could help companies to optimize the warehouse layout, the classification of goods and even customer management, for example by recommending similar products to customers based on the goods they have purchased online. Nowadays it is the era of big data, the data being kept is priceless because of its traceability.

The approach of desk research was used for the article, so the number of journal articles being investigated was an important source of reference. Regarding the reliability of the research findings, 85 articles were used as references, published over a period of 47 years, from 1975 to 2022, including 42 documents from the last five years. Nevertheless, all the conclusions drawn were based on theoretical knowledge and expert opinions because of the lack of actual interviews with specialists and company seminars, which could restrict the usefulness of the articles.

6 Conclusion

The final chapter discussed the objectives and summarized answers to the three research questions that were initially mentioned in the article. Immediately afterwards, the feasibility and recommendations within the research for the future were shown.

What're the benefits and risks of using robots for warehouses?

In the beginning, E-commerce companies needed to ask themselves some questions and define their actual needs before working with AGVs. Based on this, this technology was understood detailed both large companies and SMEs. They were required to figure out if they are the beneficiaries of the technology and find out what the risks involved are. Because of this, a comprehensive review of advances in AGVs was presented over the past few years. If technology was used properly, the benefits demonstrated could be enormous. Based on the technical characteristics, the significant advantages included five points: high precision, flexibility, timesaving, efficiency and safety.

At first, the combined navigation not only increased the accuracy and correctness of the mobile vehicle system, but also enhanced safety in scenarios where people and machines work together. Then, the high flexibility of AGVs was reflected in their scalability and mobility. Robot fleets can easily be installed or replaced either at peak times or afterwards. In addition, the manager could decide to remove robots and their tracks for transport to a new destination when a warehouse was recommended to be replaced. Another feature of the technology was the high picking accuracy and low time consumption of the robots. The long-term benefits will also lead to an increase in brand competitiveness. Based on the equipped system, the contributions of SOQN to this point were significant. Scattered storage concepts and warehouse design also have an impact on it, like picking speed were boosted by automatic ABC zoning of shelves. Regarding technology safety, the probability of collision is reduced by combined navigation, whether human or robotic. And artificial intelligence can support the recovery of AMR after a failure. Furthermore, more scheduling decisions for the system were supported by a new battery, thus mitigating the risk of unexpected surprises.

Four potential challenges behind those strengths were identified again. Safety hazards were again raised, as balancing AGV speed with picking efficiency during OP peak times was still a major challenge. Secondly, adding too many robots in pursuit of the ability to process orders faster could lead to congestion on the road, when taking advantage of the scalability of the technology. Ultimately, this could get a bad result in the OP efficiency. The third is the uncertainty of upfront cost recovery. Geek+'s RaaS can be a good solution to this concern, while meeting the start-up needs of businesses. However, according to the author findings, there were still a few cases where robots could be rented and installed with assistance. A final challenge related to the risk of employee unemployment. Although employees needed to work with robots to complete the picking process of large shipments. Most e-commerce warehouses are now moving towards full automation, so this will still be an issue.

Whether picking robots can be widely used in e-commerce warehousing

According to the survey carried out, the OP situation of e-commerce companies is often faced with the following requirements: small order sizes, a wide range of products, unstable demand, and tight delivery times. Dividing the online shop, physical shops, and the returns service into three areas, using either ABC storage or scattered storage, eased tight delivery times. Depending on the zone, the number of AGVs can be increased or decreased, therefore reducing capital while increasing efficiency. The authors believed that a deep understanding of the topic could lead many companies to adopt this technology in their operations. From the first question, it was obvious that the number of benefits outweighed the other one. But from the perspective of the author, it does not guarantee that this technology will be useful for every company, as such technology requires in-depth understanding and executives must know the usage cases and how they intend to achieve their goals with the help of AGVs.

What is the future trend of AGV?

A further study will assess the long-term effects of two aspects. The first future work needs to be done to establish how to balance the number of platforms and robots in the warehouse. Platforms refer to working stations and replenishment stations. For the scattered storage, SKU which is spread across multiple pods can be consumed extremely fast, especially in handling large numbers of small-sized orders. With this comes an increase in the frequency of replenishment, mobile vehicles would be fully replenished. With a constant replenishment velocity, the only things that can be changed are an increase in the number of replenishment stations or faster AGV travel speeds. But, in this instance, two situations will be thinking. The increase in the number of replenishment windows caused an increase in costs. The risk to employee safety increases due to the increase in AGV fleet speed. Therefore, in addition to future in-depth research and optimization of robot' travel speed and the ratio of replenishment platforms, path planning also might be considered. Consequently, the quantity of AGVs per SKU is also a research direction as it slows down the consumption of SKUs. The second is combined navigations. As the field of robot navigation continues to develop, this multiple navigation may become a future trend. Especially in mixed human-machine environments, the strength of this technology will be amplified.

Research limitation and suggestion

The main weakness of this study was the paucity of quantitative research. And The scope of this study was limited in terms of AGVs application in only electronic commerce.

Nowadays, e-commerce businesses must face the crisis of brick-and-mortar shops caused by the epidemic situation, in addition to various cost increases including but not limited to staff and land costs. Multiple factors have created a bad situation, so it is necessary to have a better understanding of AGV systems in advance. The future is the age of digitalization and globalization, while the impact of this technology goes much further than this. As what has been talking above, there is no doubt that AGVs will be a major factor in the future.

Most of the current literature is focused on the rigorous analysis of isolated problems in individual subsystems, so this topic is still a good subject for research.

References

Almasri, M., Elleithy, K., & Alajlan, A. (2016). Sensor fusion based model for collision free mobile robot navigation. Sensors, 16(1), 24.

Alexandra, M., Maximilian, P., David, K., Michael, R., Vinzenz, S., & Mathias, B. (n.d.). Safety of Mobile Robot Systems in Industrial Applications.

Adrian, Y., Dwi, A. S., Yulianti, K., & Veronica. (2020). Can the mobile robot be a future order-picking solution? A case study at Amazon fulfillment center. Global Research on Sustainble Transport & Logistics 2020. http://proceedings.itltrisakti.ac.id/index.php/altr

Amazon staff. (2022, February 23). Amazon re:MARS returns to explore ML, automation robotics, and space. https://www.aboutamazon.com/news/aws/amazon-re-mars-returns-to-explore-ml-automation-robotics-and-space

Ashgzari, M. S., & Gue, K. R. (2020). A puzzle-based material handling system for order picking. International Transactions in Operational Research. https://doi.org/10.1111/itor.12886

Azadeh, K., de Koster, M.B.M., & Roy, D. (2017). Robotized warehouse systems: Developments and research opportunities. Social Science Electronic Publishing. https://doi.org/10.2139/ssrn.2977779

Azadeh, K., De Koster, R., & Roy, D. (2019). Robotized and Automated Warehouse Systems: Review and recent developments. Transportation Science, 53(4), 917-945. https://doi.org/10.1287/trsc.2018.0873

AGV network. (n.d.). How does wireless charging for mobile robots (AGV & AMR) work? [white paper]. Geek plus. https://blog.geekplus.com/company/download

Bartholdi III, J. J., & Hackman, S.T. (2011). Warehouse & distribution science: Release 0.94. Supply Chain and Logistics Institute.

Baskett, F., Chandy, K. M., Muntz, R. R., & Palacios, F. G. (1975). Open, closed, and mixed networks of queues with different classes of customers. Journal of the Acm, 22(2), 248–260. https://doi.org/10.1145/321879.321887

Bhatti, A., Akram, H., Basit, H.M., Khan, A.U., & Bilal, M. (2020). E-commerce trends during COVID-19 Pandemic. International Journal of Future Generation Communication and Networking, 13(2), 1449-1452. https://lovacky.eu/ws/media-library/8291b8bb61d0458d9bec753432dc4842/qualitativepaper.pdf

Bloss, R. (2008). Simultaneous sensing of location and mapping for autonomous robots. Sensor Review, 28(2), 102–107. https://doi.org/10.1108/02602280810856651

Bogue, R. (2016). Growth in e-commerce boosts innovation in the warehouse robot market. Industrial robot, 43(6), 583-587. https://doi.org/10.1108/IR-07-2016-0194

Bolch, G., Greiner, S., Meer, H. D., & Trivedi, K. S. (2006). Queueing Networks and Markov Chains: Modeling and Performance Evaluation with Computer Science Applications. Wiley-Interscience. 10.1002/0471791571, 703-806. https://doi.org/10.1002/0471791571.ch13

Bozer, Y. A., & Aldarondo, F. J. (2018). A simulation-based comparison of two goods-to-person order picking systems in an online retail setting. International Journal of Production Research. https://doi.org/10.1080/00207543.2018.1424364

Bowen, G. A. (2009). Document analysis as a qualitative research method. Qualitative Research Journal, 9(2), 27-40. https://doi.org/10.3316/QRJ0902027

Boysen, N., Stephan, K., & Weidinger, F. (2018a). Manual order consolidation with put walls: The batched order bin sequencing problem. EURO Journal on Transportation and Logistics. https://doi.org/10.1007/s13676-018-0116-0

Boysen, N., DK René, & Felix, W. (2018b). Warehousing in the e-commerce era: A survey. European Journal of Operational Research, 277(2), 396-411. https://doi.org/10.1016/j.ejor.2018.08.023

Brynjolfsson, E., Hu, Y. J., & Smith, M. D. (2003). Consumer Surplus in the Digital Economy: Estimating the value of increased product variety at online booksellers. Management Science, 49(11), 1580–1596. https://doi.org/10.1287/mnsc.49.11.1580.20580.

Brown, A. (2018). Rise of the machines? Amazon's army of more than 100,000 warehouse robots still can't replace humans because they lack 'common sense'. Dailymail. https://www.google.com/amp/s/www.dailymail.co.uk/sciencetech/article-5808319/amp/Amazon-100-000-warehouse-robots-company-insists-replace-humans.html

Cision. (2020, July 1). Geek+ Helps Streamline Winit's Warehouse Operations. PR Newswire. https://www.prnewswire.com/news-releases/geek-helps-streamline-winits-warehouse-operations-301087070.html

Cision. (2021, Sep 9). Geek+ and FDL Group accelerate e-commerce in Greece and Cyprus with smart sorting robots. PR Newswire. https://www.prnewswire.com/news-releases/geek-and-fdl-group-accelerate-e-commerce-in-greece-and-cyprus-with-smart-sorting-robots-301372108.html

Da Costa Barros, Í. R., & Nascimento, T. P. (2021). Robotic Mobile Fulfilment Systems: A survey on recent developments and research opportunities. Robotics and Autonomous Systems, 137(7). https://doi.org/10.1016/j.robot.2021.103729

Davarzani, H., & Norrman, A. (2015). Toward a relevant agenda for warehousing research: Literature review and practitioners' input. Logistics Research, 8, 1-18. https://doi.org/10.1007/s12159-014-0120-1

De Koster, R. (2004). How to assess a warehouse operation in a single tour. RSM Erasmus University, the Netherlands.

Dias, L. A., de Oliveira Silva, R. W., da Silva Emanuel, P. C., Ferrus Filho, A., & Bento, R. T. (2018). Application of the fuzzy logic for the development of autonomous robot with obstacles deviation. International Journal of Control, Automation and Systems, 16(2), 823–833.

Diniela, C. (2021). E-commerce worldwide Statistics & Facts. Statista. https://www.statista.com/topics/871/online-shopping/#topicHeader__wrapper

De Silva, V., Roche, J., & Kondoz, A. (2018). Robust fusion of LiDAR and wide-angle camera data for autonomous mobile robots. Sensors, 18(8), 2730.

Enright, J., & Wurman, P. R. (2011). Optimization and coordinated autonomy in mobile fulfillment systems. Automated action planning for autonomous mobile robots: Papers from the 2011 AAAI Workshop, San Francisco, California, USA, August 7, 2011. AAAI Press.

Ecommerce Europe. (2016). European B2C E-commerce Report 2016. Technical Report. Brussels: Ecommerce Europe.

Fragapane, G., de Koster, R., Sgarbossa, F., & Strandhagen, J. O. (2021). Planning and control of autonomous mobile robots for intralogistics: Literature review and research agenda. European Journal of Operational Research, 294(2), 405-426. https://doi.org/10.1016/j.ejor.2021.01.019

Germany Trade and Invest. (2016). Promoted by federal ministry for economic affairs and energy in accordance with a German parlament resolution. https://scholar.google.com/scholar?cluster=7397817708312154039&hl=zh-CN&as_sdt=2005&sciodt=0,5

Geest, M. Y., Tekinerdogan, B., & Catal, C. (2021). Design of a reference architecture for developing smart warehouses in industry 4.0. Computers in Industry. 124, Article 103343. https://doi.org/10.1016/j.compind.2020.103343

Geekplus. (n.d.). Robot-as-a-service [website]. https://www.geekplus.com/raas

Geekplus. (n.d.). AI algorithm [website]. https://www.geekplus.com/cn/technology/ai

Goetschalckx, M., & Ashayeri, J. (1989). Classification and design of order picking systems. Logistics World, 2(2), 99–106. https://doi.org/10.1108/eb007469

Grand View Research. (2019). Warehouse robotics market size report, 2019 - 2025. Report ID: GVR-3-68038-923-4. https://www.grandviewresearch.com/industry-analysis/warehouse-robotics-market

Gu, J., Goetschalckx, M., & McGinnis, L. F. (2007). Research on warehouse operation: A comprehensive review. European Journal of Operational Research, 177(1), 1–21. https://doi.org/10.1016/j.ejor.2006.02.025

Günter Ullrich. (2015). The History of Automated Guided Vehicle Systems. Springer Berlin Heidelberg.

Guizzo, E. (2008). Three engineers, hundreds of robots, one warehouse. IEEE Spectrum, 45(7), 26-34. https://doi.org/10.1109/MSPEC.2008.4547508.

Huang, G. Q., Chen, M. Z. Q., & Pan, J. (2015). Robotics in ecommerce logistics. HKIE Transactions, 22(2), 68–77. https://doi.org/10.1080/1023697X.2015.1043960

Huang, S.J., Lee, T.S., Li, W.H., & Chen, R. Y. (2018). Modular on-road agv wireless charging systems via interoperable power adjustment. IEEE Transactions on Industrial Electronics, 66(8), Article 5918–5928.

Ho, Y. C., T, S. Su., & Z, B. Shi. (2008). Order-batching methods for an order-picking warehouse with two cross aisles. Computers & Industrial Engineering, 55(2), 321–347.

International Labour Organization. (2020). World employment and social outlook: Trends 2020 (1st ed). ILO Flagship Report. 56-58. https://www.ilo.org/global/research/global-reports/weso/2020/lang--en/index.htm

International organization for standardization. (2020). ISO 3691-4:2020 Industrial trucks - Safety requirements and verification — Part 4: Driverless industrial trucks and their systems. International organization for standardization. https://www.iso.org/standard/70660.html

International Online. (2022, Jan 8). Geekplus's 2021: order volume exceeds $2 billion, leading edge is emerging. https://baijiahao.baidu.com/s?id=1722277981909130446&wfr=spider&for=pc

JAZZYEAR. (2020). 2020 China Warehouse Automation Research Report [White paper]. From https://www.sohu.com/a/437855623_407401

Karaman, S., & Frazzoli, E. (2011). Sampling-based algorithms for optimal motion planning. The International Journal of Robotics Research, 30(7), 846–894.

Kollmorgen automation ab. (n.d.). Agv cost estimation how much does an automated guided vehicle system cost [white paper]? AGV network. https://blog.geekplus.com/company/download

Lamballais, T., Roy, D., & De Koster, M. B. M. (2019). Inventory allocation in robotic mobile fulfillment systems. IISE Transactions. https://doi.org/10.1080/24725854.2018.1560517

Lamballais, T., Roy, D., & De Koster, M. (2017). Estimating performance in a robotic mobile fulfillment system. European Journal of Operational Research, 256(3), 976–990.

Lee, H. Y., & Murray, C. C. (2018). Robotics in order picking: evaluating warehouse layouts for pick, place, and transport vehicle routing systems. International Journal of Production Research. https://doi.org/10.1080/00207543.2018.1552031

Liang, C., Chee, K. J., Zou, Y., Zhu, H., Causo, A., Vidas, S., Teng, T., Chen, I. M., Low, K. H., & Cheah, C. C. (2016). Automated robot picking system for e-commerce fulfillment warehouse application. The 14th IFToMM World Congress. Nephron Clinical Practice, 398-403. https://doi.org/10.6567/IFToMM.14TH.WC.OS13.077

Liang, Y., & Lee, S. A. (2017). Fear of autonomous robots and artificial intelligence: Evidence from national representative data with probability sampling. International Journal of Social Robotics, 9(3), 1-6.

Li, S. S. (2017). Geek+: the robotic intelligent logistics specialist. China Business. https://wenku.baidu.com/view/f2c4d86ed8ef5ef7ba0d4a7302768e9950e76e65.html?fr=income1-wk_app_search_ctr-search

Le-Anh, T., & De Koster, M. (2006). A review of design and control of automated guided vehicle systems. European Journal of Operational Research,171(1), 1–23.

Long, J., & Zhang, C. L. (2012). The summary of AGC Guidance Vehicle Technology. Advanced Materials Research, 591-593 (2012), 1625-1628. https://doi.org/10.4028/www.scientific.net/AMR.591-593.1625

Lu, P. S. (2020). China Smart Storage Industry Overview. LeadLeo. https://download.csdn.net/download/qq_38412739/16554747

Martínez-Barberá, H., & Herrero-Pérez, D. (2010). Autonomous navigation of an automated guided vehicle in industrial environments. Robotics and Computer-Integrated Manufacturing, 26(4), 296–311. https://doi.org/10.1016/j.rcim.2009.10.003

Marchet, G., Melacini, M., & Perotti, S. (2015). Investigating order picking system adoption: A case-study-based approach. International Journal of Logistics Research and Applications, 18, 82-98. https://doi.org/10.1080/13675567.2014.945400

Mattaboni, P. J. (1987). Autonomous mobile robot. Google Patents.

MD Ryck., Versteyhe, M., & Debrouwere, F. (2020). Automated guided vehicle systems, state-of-the-art control algorithms and techniques. Journal of Manufacturing Systems, 54(1), 152–173. https://doi.org/10.1016/j.jmsy.2019.12.002

Merschformann, M., Lamballais, T., de Koster, M.B.M., & Suhl, L. (2019). Decision rules for robotic mobile fulfilment systems. Operations Research Perspectives. https://doi.org/10.1016/j.orp.2019.100128

Muller, T. (1983). Automated guided vehicles. Kempston England: IFS Ltd.

MWPVL International Inc. (2012). A Supply chain consultant evaluation of Kiva Systems (Amazon robotics) [white paper]. Leadership in Global Supply Chain and Logistics Consulting. http://www.mwpvl.com/html/kiva_systems.html

Nussbaum, R. (2015). Changing the tooth-to-tail ratio using robotics and automation to beat sequestration. Technical report, DTIC Document.

Oyekanlu, E. A., Smith, A. C., & Thomas, W. P., Mulroy, G., & Sun, D. (2020). A review of recent advances in automated guided vehicle technologies: Integration challenges and research areas for 5g-based smart manufacturing applications. IEEE Access. https://doi.org/10.1109/ACCESS.2020.3035729

Peng, H., Zhao, N., & Sun, Y. J. (2021). A digital twin system orienting robotic mobile fulfillment system. Industrial Engineering Journal, 24(3), 121-129.

Phil, B. (2021). How growing E-commerce demand is driving growth in mobile robotics [white paper]. Robotics business review.

Pratama, P. S., Gulakari, A. V., Setiawan, Y. D., Kim, D. H., Kim, H. K., & Kim, S. B. (2016). Trajectory tracking and fault detection algorithm for automatic guided vehicle based on multiple positioning modules. International Journal of Control, Automation and Systems, 14(2), 400–410. https://doi.org/10.1016/j.ejor.2021.01.019

Robotic Industries Association. (2021). ANSI/RIA R15.08-1:2020 American national standard for industrial mobile robots safety requirements - Part 1: Requirements for the industrial mobile robot. Ann Arbor, Michigan USA. Association for Advancing Automation.

Roy, D. (2016). Semi-open queuing networks: A review of stochastic models, solution methods and new research areas. International Journal of Production Research, 54(6), 1735–1752.

R, Geissbauer., J, Veds., & S, Schrauf. (2016). A strategist's guide to industry 4.0. Strategy and Business. https://www.strategy-business.com/media/file/sb83_16213-A_Strategists_Guide_to_Industry_4.0.pdf

Raynor de Best. (2021, May 17). PayPal's total payment volume from 1st quarter 2014 to 1st quarter 2021. Statista. https://www.statista.com/statistics/277841/paypals-total-payment-volume/

Rao, S., Griffis, S. E., & Goldsby, T. J. (2011). Failure to deliver? Linking online order fulfilment glitches with future purchase behaviour. Journal of Operations Management, 29(7-8), 692–703. https://doi.org/10.1016/j.jom.2011.04.001

Springer, Cham. (2020). Industry 4.0. 309-333. https://doi.org/10.1007/978-3-030-35032-1_18

Steckler, A., McLeroy, K. R., Goodman, R. M., Bird, S. T., & McCormick, L. (1992). Toward Integrating qualitative and quantitative methods: An introduction. Health Education & Behavior, 19(1), 1–8. https://doi.org/10.1177/109019819201900101

Sun, H. (n.d.). Geekplus: The new age robot logistics expert - Interview with Zheng yong, founder and CEO of Beijing geekplus technology Co. China storage & transportation. https://wk.baidu.com/view/f73c623bccc789eb172ded630b1c59eef8c79a1f?pcf=2&bfetype=new

Ti-Chun, W., Chang-Sheng, T., & Ben-Ling, X. (2018). Agv navigation analysis based on multi-sensor data fusion. Multimedia Tools & Applications, 1-16. https://doi.org/10.1007/s11042-018-6336-3

Tugba Sabanoglu. (2021, May 26). Global retail e-commerce sales 2014-2024. Statista. https://www.statista.com/statistics/379046/worldwide-retail-e-commerce-sales/#statisticContainer

Vis, I. F. A. (2006). Survey of research in the design and control of automated guided vehicle systems. European Journal of Operational Research, 170(3), 677–709. https://doi.org/10.1016/j.ejor.2004.09.020

Weidinger, F., Boysen, N., & Schneider, M. (2018). Picker routing in the mixed- shelves warehouses of e-commerce retailers. European Journal of Operational Research, 274. https://doi.org/10.1016/j.ejor.2018.10.021

Weidinger, F., & Boysen, N. (2018). Scattered storage: How to distribute stock keeping units all around a mixed-shelves warehouse. Transportation Science, 52(6), 1297-1588. https://doi.org/10.1287/trsc.2017.0779

Yaman, H., Karasan, O. E., & Kara, B.Y. (2012). Release time scheduling and hub location for next-day delivery. Operations Research, 60, 906-917.

Zou, B. P., Gong, Y. M., Xu, X. H., & Yuan, Z. (2017). Assignment rules in robotic mobile fulfilment systems for online retailers, International Journal of Production Research. http://dx.doi.org/10.1080/00