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Challenges and opportunities with manual order picking

An investigation into the essential factors associated with order picking and the resulting concept designs

Master's thesis in Computer science and engineering

JONATHAN HEININ
ROBIN SOHLBERG

Department of Computer Science and Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
UNIVERSITY OF GOTHENBURG
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Supervisor: Beata Stahre Wästberg, Department of Computer Science and Engineering
Advisor: Mattias Allring, Toyota Material Handling Logistics Solutions AB
Examiner: Mikael Wiberg, Department of Computer Science and Engineering

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Department of Computer Science and Engineering
Chalmers University of Technology and University of Gothenburg
SE-412 96 Gothenburg
Telephone +46 31 772 1000

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Abstract

Order picking is a process of selecting and collecting items from a warehouse inventory to fulfill customer orders, and is one of the most expensive and labor intensive parts of warehouse operations. This thesis, conducted in collaboration with Toyota Material Handling, aimed to investigate the challenges and opportunities associated with manual order picking operations and propose innovative solutions.

The research commenced with an extensive background research, which delved into different order picking technologies and strategies, in order to gain a comprehensive understanding of the existing landscape and identify areas in need of improvement.

Following this, multiple visits to warehouses and interviews with order pickers were conducted to gain insights into current order picking practices. The visits fostered a deeper understanding of the practical challenges faced by order pickers, as well as what factors affect their efficiency and well-being. Utilizing the insights gathered from the visits and interviews, an analysis was conducted to establish requirements needed for successful, efficient and pleasant order picking.

Based on these requirements, two design concepts were developed aimed at enhancing existing order picking strategies. The proposed design concepts strive to address the identified challenges in novel ways, and aim to improve the activity of manual order picking both from the perspective of the order picker and the company. The novel features proposed may provide a solid basis for future research and has the potential to provide a better work flow for manual order pickers.

Keywords: Order Picking, Automation, AGV, Augmented Reality, Zone Picking, Vision Picking.

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Jonathan Heinin & Robin Sohlberg, Gothenburg, May 2023

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List of Abbreviations

AGV	Automated Guided Vehicle.
AS/RS	Automated Storage and Retrieval System.
CMD	Cart-Mounted Display.
OMS	Order Management System.
OPS	Order Picking System.
WMS	Warehouse Management System.

1
Introduction

Manufacturing automation is becoming more prevalent and within a decade manufacturing is expected to be automated by at least 80 percent (Ericsson, 2021). The Covid-19 pandemic might even have hurried this development up as restrictions introduced novel challenges to the human work force (Foster, 2022). As a leader in forklift manufacturing and development, Toyota Material Handling has taken to focus on how material handling can be made more efficient through automated processes. With several Automated Guided Vehicle (AGV) design concepts for forklifts (Toyota Material Handling, n.d.) put forth, they are now interested in leaning into how manual order picking can be effectivized in collaboration with their future additions to their AGV line-up.

Order picking is a process of customizing orders in accordance with the specific needs of the customer, and it is the single most expensive and labor intensive part of the warehouse operations, accounting for more than half of all warehouse operations (Hopstack Inc., n.d.). This activity is notoriously difficult to fully automate because of the diverse range of manual actions associated with customized picking orders. However, if parts of the picking process could be automated to such a degree that the manual tasks were to be made significantly more efficient, the entire process would benefit (Vijayakumar & Sgarbossa, 2021).

This thesis will examine the potential need that order pickers might have for a system that would be utilized in collaboration with Toyota's AGV's. An interface for such interaction is to be produced as a result of the process throughout this thesis. The resulting artifact is expected to rely on three of the nine pillars associated with the fourth industrial revolution, namely: the Industrial Internet of Things, Cyber Physical Systems and Autonomous Robots (SAP, n.d.). These technologies are fundamentally important in the expansion and utilization of smart manufacturing objects to allow for the effectivization and revolutionizing of order picking on a realistic timescale through novel ways of interacting with AGV's.

1.1 Aim

The aim with this thesis is to map out the problem space associated with the role of manual order picking and their needs in order to perform their jobs successfully. The insights gathered by the first phase will then be utilized to put forth design concepts aimed at improving the efficiency with which order pickers can perform their jobs.

1.2 Objectives

In order to map out the problem space associated with manual order picking, warehouses will need to be visited in order to observe the order picking activity hands on. Furthermore, interviews will be held with key stakeholders and order pickers in order to understand the environment in which they work, as well as to learn the essential details of successful order picking. The data gathered will be analyzed in order to provide an insightful foundation on which to base the concepts to be produced for improving the order picking.

1.3 Expected Results

The objectives outlined above are expected to result in a list of key principles for successful order picking. This list is expected to prove valuable when designing the concepts, as well as to be a solid base for further inquiry into the activity of order picking. The two deliverables from this thesis work, to our employer Toyota Material Handling, are (1) the list of key requirements for successful order picking from the perspective of the order picker, and (2) several concept designs detailing possible improvements to current systems intended to make order picking more efficient. Included in the deliverables are sketches and scenarios detailing their usage.

1.4 Research Questions

The following research questions have been devised as a result of the above:

1. What are the essential factors for successfully performing the activity of manual order picking?
2. How might the resulting insights be conceptually implemented in order to innovate on manual order picking?

1.5 Scope Delimitation

Due to certain insights gained during this thesis, the scope and focus changed from the development of key design principles for an AGV mounted display meant to be used for order picking, to the more general approach of what is essential for order pickers in order to successfully perform the activity. This led to a greater focus, and more time spent, on data gathering than initially anticipated, which consequentially forced the subsequent design activity to be less elaborate and unfortunately untested. See 6.1 for additional details and the reasoning behind them.

1.6 Challenges

This thesis presents several challenges. Firstly, it is paramount to understand who the target users might be. As part of this initial exploration, a market analysis will have to be performed in collaboration with Toyota regarding which customers to focus on and what their needs are. The reason for this is that picking can be done in a multitude of ways, not all of which will be relevant for the results of this thesis.

Secondly, as we get to know the pain points and manage to identify the problem areas for the intended target audience, the challenge will be to reach relevant solutions to a seemingly diverse problem space. For instance, it may be relevant to find out how the AGVs will be able to communicate with pickers, what technology should be utilized as well and how it will be implemented.

It should also be mentioned that how such a system works may impact the safety of the warehouse. It is important that the resulting artifact does not distract pickers unnecessarily, while allowing all the relevant information to reach them when they need it.

And finally, as this thesis is part of an R&D (Research and Development) project, large parts of this might have to be handled with utmost discretion, which might present challenges during testing/evaluation phases, both during formative and, likely primarily, summative evaluations.

1.7 Ethics

During the thesis, several warehouses will be visited and some material might be recorded during the visits. It is of high importance to the authors of this report that all participants stay anonymous. Furthermore, to protect all parties and the company for whom they work, every warehouse visited will be coded and mentioned as Company A, B, C, etc.

Since we will be utilizing a user-centered design (Interaction Design Foundation, n.d.-d) process with a high degree of user testing and stakeholder engagement, it is important to adhere to the basic ethical principles in research involving people. It is important that all participants are anonymous to the degree that it is relevant, that their participation is voluntary and may be terminated at any point according to their choosing, and that they have all agreed to participation through informed consent (Bhandari, 2022b). All data gathered should adhere to GDPR (Wolford, 2023) in terms of data storage where any participant has the option to have their data deleted at any point after collection. This refers, mainly, to video or audio recordings of interviews and data that is not entirely anonymized.

Furthermore, it is crucial for us to ensure that any research conducted has a positive risk/benefit ratio such that no risk should be greater than the potential benefits (Shaughnessy et al., 2014). For instance, as part of this research might include forklifts and/or warehouses, it is imperative that proper precautions are taken for each of these contexts.

In terms of accessibility, it is important to make sure that certain principles are considered to ensure that the results are ethically defensible. For instance, the use of color should be to highlight information, rather than delimit it, as color vision deficiency or visual impairments are common (Hausler, 2015). It is important that contrast is sufficiently high in order to allow for high visibility (W3C, n.d.) of user interface elements, and that any text is large enough to be easily legible. These accessibility considerations, along with the usability principles, should all work to ensure that the interface is usable and navigable in the intended context of use as these environments may present several health and safety hazards (SETON, 2020).

2
Background

Order picking is the part of the customer order fulfilment process where the items to be shipped are retrieved. This can, in it's simplest form, be performed by a person, equipped with a paper detailing which items to retrieve, walking throughout the warehouse. Through automation, however, market interests lie in trying to optimize the efficiency with which this can be performed where the most sophisticated solutions require no person at all (see Jaghbeer et al. (2020) for a review of automated picking systems).

This section will focus on the different methods, systems and technologies associated with order picking.

2.1 Order Picking Systems OPS

As alluded to above, order picking can be performed in a range of different ways. The two most common *order picking systems* are based on whether the order picker travels to, and collects, each item or if the item is automatically transported to the order pickers.

Goods-to-Person is a technology heavy system with a greater focus on warehouse automation with the intent of reducing the amount of walking as the goods are brought to stationary workers automatically. These *automated storage and retrieval systems* (AS/RS) are usually seen as a means to increase efficiency and reduce errors in the process of picking (enVista Thought Leadership, 2017).

One such example of an AS/RS with increasing prevalence is called Autostore [1], where items are fed into an automated system of boxes which are relocated using robots. When an order is registered, robots are sent to retrieve each relevant item to fulfill the order and delivers them to the stationary human worker who packages the items and labels the package. It is thereafter placed on a conveyor belt to again automatically be transported to outgoing.

Person-to-Goods, on the other hand, is the more traditional system for order fulfilment, where the order picker is responsible for traveling to each item in order to retrieve them. This is done primarily through walking or driving forklifts. While Person-to-Goods may suffer in efficiency due to the greater distances traveled by the

[1] https://www.autostoresystem.com/

order pickers, it is usually the cheaper system to set up (enVista Thought Leadership, 2017). Additionally, there are certain strategies often in effect to reduce effective travel time, such as arranging the layout of the items in the warehouse with the use of a Warehouse Management System (WMS) optimization algorithms, as well as providing opportunities for order pickers to engage in batch picking, effectively fulfilling several different orders throughout the same route (Jenkins, 2021c).

Goods-to-Person may be unrivaled in efficiency, but the fact remains that these systems are vulnerable to failures. Should the system stop working, the entire chain of distribution may come to a halt, as well as hinder any and all access to the inventory prohibiting the operations to continue until the failure has been fixed (enVista Thought Leadership, 2017). In this regard, it is clear that Person-to-Goods is more robust.

Additionally, Person-to-Goods continues to provide the opportunity to handle any and all items regardless of size and weight, whereas AS/RSs are usually limited in their spatial capabilities.

2.1.1 Pick-by-Systems

Systems that alleviate information provision in Person-to-Goods systems are plenty and of differing technological sophistication. They are usually made to provide support for order pickers to more efficiently be guided throughout the picking route and to reduce the otherwise error prone manual work (Team Warehouse Logistics, 2023). The following section provides an overview of the most common systems in use today.

2.1.1.1 Pick-by-Paper

This system is the most fundamental way for information provision, and as of 2019 still used by more than 50 % of manual order picking systems (Winkelhaus et al., 2021). Order pickers receive a paper list of items to be picked. The list is usually optimized sequentially in terms of which item to pick in which order, and where to start. This list contains all the relevant information about every item to pick, such as location of the items, the article number, amount of items to pick and where to place it. The pickers have to manually carry this paper on their person, or place it on their forklift (Picavi, 2023).

This system is cheap to implement and easily understood by pickers, but with the downside of providing plenty of opportunities for picking errors and the fact that the picker may need to hold onto a list, prohibiting efficient picking (Picavi, 2023).

2.1.1.2 Digital picking list

With close resemblance to paper lists albeit presented through the use of a tablet, mobile phone or *cart-mounted screen*, this system provides more opportunities to implement systems for error prevention through pick verification, such as through the use of scanning, and it offers seamless integration with WMSs which may help with optimal picking routes. It could also provide pick information such as images of what to pick, as well as dynamically changing stock statu (Logiwa Marketing, 2023).

While a mobile phone or tablet may need to be carried by hand, this system does provide the opportunity for wearing the screen on the arm, providing a hands-free picking experience.

2.1.1.3 Pick-by-Scan

Scanning is an addition to picking, usually combined with the previously mentioned digital picking list, utilizing a barcode scanner (Lydia Voice, 2023). The picker receives information about which item to pick, which they then need to scan in order to verify that pick. Each item needs to be scanned, and quantity confirmed, in order to successfully fulfill each order. This leads to fewer picking errors and a more efficient workflow (Finale Inventory, 2023), as confirmation no longer needs to be performed by the picker, relieving them of a potential mental burden. In certain instances, even the placement of the picked item may need to be confirmed by scanning the bin in which the item is to be placed.

2.1.1.4 Pick-by-Voice

Pick-by-Voice is an information provision system where the picker wears a headset through which they receive all the information they need to fulfill the order, such as items, their locations and quantity to pick, etc. They can communicate with the system by voice in order to verify what they picked, where they placed it, among other commands (such as ask it to repeat itself or tell the time) (Jenkins, 2021a). As such, it is easy for order pickers to receive the relevant information at all times. Since this system utilizes audio as the means to communicate, the information flow is sequential, which prohibits how much information can be provisioned at any point in time. However, utilizing this system has proven to have several benefits when compared to other technologies, such as higher pick accuracy, better productivity due to the hands-free nature of the product, and its intuitive interface which provides fast introduction and learning of the system (Miller, 2004).

2.1.1.5 Pick-to-Light

Pick-to-Light is a technology that bases its information transmission through lights. Most commonly, it is used in a Goods-to-Person system where containers are automatically transported to order pickers who proceed to scan the container. This prompts which lights on the shelves to light up, corresponding to which items to be picked. After picking the item, the order picker confirms the pick by pressing a button next to the light which turns it off. An alphanumerical display provides information on quantity of each pick. Like Pick-by-Voice, Pick-to-Light provides benefits such as pick accuracy, efficiency and ease of use (Glynn, 2023a).

2.1.1.6 Pick-by-Vision

Pick-by-Vision is an emerging system where the order picker wears smart glasses equipped with augmented reality (AR) technology. Any relevant information regarding the orders to be fulfilled will be displayed somewhere in the field of view for the order picker. Like with Pick-by-Voice, information availability is high, but the potential for displaying richer information is evident since different information can be shown simultaneously compared to only sequentially, as with Pick-by-Voice. This system can be extended with the use of voice recognition technology for communicating actions, or a wearable scanner, for example. Pick-by-Vision provides hands-free movement for the order pickers. This system may even provide the potential for displaying visual cues and guiding throughout the warehouse, given the adequate technological environment (Interlake Mecalux, 2021).

2.1.2 Picking methods

Picking methods refer to the different approaches that can be taken towards effective order picking. This is heavily dependent on the warehouse layout and size, the tools and the technology available, to name a few important factors with high variability between different warehouses (Glynn, 2023d). This section aims to explore the most common methods with relevance to this thesis.

2.1.2.1 Single Order Picking

In *Single order picking*, each picker receives one order to be fulfilled, either by walking or driving a forklift throughout the warehouse, by manually picking items one at a time. This method is the most common, and while viable it may be least effective if not correctly optimized. The method is best suited for smaller warehouses, where walking is not compounded by more orders, or in warehouses where the orders are few but the items on each are many. However, this method has some clear benefits in regards to initial setup and ease of use, as well as high pick accuracy (Glynn, 2023b).

2.1.2.2 Batch Picking

Batch picking is the next step up from single order picking. Here, instead of a single order, the order picker receives several different orders to be fulfilled during the same picking route. This can be managed through order grouping and route optimization by the *order management system* (OMS). This method has the clear benefit of allowing the order picker to pick the same item, or items from the same zone, during a single route, which greatly reduces time spent traveling. Due to the nature of this method being more complicated than single order picking, it is also more prone to errors (Jenkins, 2021c).

2.1.2.3 Wave Picking

Wave picking (also known as cluster picking) is a method where the fulfillment orders are picked in waves, or within shorter intervals that allow for certain orders to correspond with logistical schedules. This means that order picking can be planned in advance, which results in higher efficiency by reducing idle time for order pickers. Like batch picking, the orders to be fulfilled are based on like products, which means that several orders can be fulfilled during the same route (Jenkins, 2021b).

2.1.2.4 Walk the dog

Walk the dog is a way to perform single order picking and batch picking, but with the assistance of an *Automated Guided Vehicle* (AGV). The concept revolves around an AGV receiving instructions on where the next pick will be, automatically drives there and waits for the picker to place the item on the pallet. Thereafter, the picker confirms the pick and the AGV drives to the next location, during which the picker walks beside the AGV. This method is often combined with Pick-by-Voice to allow the picker to receive information regardless of their position, and to allow the pickers to be hands-free. This combination has shown to be quite effective, even though the effectiveness seems to be heavily dependent on travel distance between each pick. (Toyota, personal communication, 2023)

2.1.2.5 Zone Picking

Zone picking is a method where the layout of the warehouse is divided into different zones. One or more order pickers are located in these zones tasked with picking to AGVs that pass through their zone into another, requesting each item to be picked. This method is particularly useful to reduce the distance that the order picker has to travel, letting them focus almost entirely on picking. Another benefit is that each zone can be customized and modified individually where needed (Glynn, 2023c). One example could be to allow bulky items to be located in one zone, and let another zone handle smaller items through an AS/AR system, both of which could still pick to the same AGV from different storage systems.

2.2 Related work

Friebel (2022) conducted a qualitative study of perceived usability of interfaces for AGVs and investigated how usability affects *human-machine interaction* (HMI). Six exploratory user interviews were carried out with both customers and internal employees to identify overlaps between existing user experience formalities and prepositions for HMI. The study proposes four main aspects to be considered when designing AGV user interfaces. Although no interface was designed in this thesis, it could prove useful for our thesis to serve as a foundation for the development.

Dauti (2022) investigated how the need for external communication for autonomous trucks to pedestrians could be solved. Dauti found that arbitrary signaling, such as lights, colors and symbols were difficult to interpret for pedestrians in comparison to using plain text. However, as trucks need to provide more universally clear communication, since there is no idiomatic standard for autonomous signaling between pedestrians and vehicles “in the wild”, this thesis has a chance to introduce idiomatic standards when it comes to communication between automated forklifts and warehouse personnel.

Vijayakumar and Sgarbossa (2021) present an overview of the level of automation in picker-to-parts order picking systems. They highlight the significance of order picking systems in various industries, emphasizing the need for efficient and automated solutions. The authors discuss key technologies, methodologies associated and delve into topics such as human factors, warehouse layout designs, routing algorithms and real time decision-making processes. They conclude the paper by highlighting the need for continued research and innovation in picker-to-parts order picking systems to enhance efficiency, productivity and adaptability in various industries. This paper provides useful information regarding topics surrounding order picking and can come to prove useful in our research and final product.

Egger and Masood (2020) explored the application of AR technology in the context of intelligent manufacturing. They conducted a systematic literature review to analyze existing research to find benefits, challenges and trends associated with AR in manufacturing processes. Through this systematic review, they analyzed a range of studies and identified several key findings. They discussed the benefits of AR in manufacturing such as enhanced visualization, reduced errors, improved productivity and increased safety. They also highlight various challenges and limitations of implementing AR in such a setting, including technological limits and cost considerations. Furthermore, the authors address the importance of user-centered design and the need for human factor considerations when integrating AR into manufacturing processes which is relevant to the final product of this thesis.

2.3 Current solutions

Locus Robotics[2] is a company that specializes in the development of autonomous robots for use in warehouses and distribution centers. Locus Robotics has developed multiple robots and solutions that provide fulfillment in different areas. Most similar to the autonomous machine in context for this thesis, is their robot Locus Origin, which, equipped with sensors and algorithms, can navigate through complex warehouse environments and efficiently retrieve items. It can be integrated in existing warehouse systems and communicates with workers through a tablet interface. What differs this robot from the machine in question for this thesis is its size and application. Locus Origin has a smaller build, and is meant for order picking of smaller orders. However, this solution can provide useful ideas to the human-robot interaction that will be required.

Gideon Brothers Inc.[3] is a robotics and AI company that specializes in developing autonomous mobile robots for various industries such as logistics, manufactur-

[2]https://locusrobotics.com/
[3]https://www.gideon.ai/

ing and retail. Similarly to Locus Robotics, their robots are designed to navigate through complex environments and perform various tasks, for instance pallet and box moving, transportation of goods and inventory management. Gideon provides two robotic solutions, one which applies exclusively to order picking and one that is an autonomous forklift. This solution can prove to be useful to give an insight to how similar systems manage their workflow.

Picavi[4] is a leading Pick-by-Vision provider that offers a complete intralogistic solution using smart glasses. Together with the glasses, they offer tailored accessories as well as a software solution to manage their products. Picavi's website highlights their expertise in enabling hands-free, paperless, and error-free order picking, leading to improved efficiency and productivity. Picavi's Pick-by-Vision solution utilizes lightweight smart glasses equipped with a heads-up display that provides real-time visual guidance to warehouse workers. This allows them to perform tasks such as order picking, inventory management, and replenishment with increased speed and accuracy. This solution can be used as inspiration for our future solutions regarding AR.

[4]https://picavi.com/en/

3
Theory

This chapter provides an overview of key concepts in user experience, user interface design and human-computer interaction. It explores the multifaceted nature of user experience, important usability attributes and fundamental design principles for interface design. Furthermore, it introduces the topic of human-machine interaction and automation, wicked problems and its effect on this project as well as Fitt's law.

3.1 User Experience

User Experience (UX) is a widely used term within the field of interaction design and its definition is multifaceted (Hassan & Hassan Galal-Edeen, 2017). According to ISO 9241-11:2018, UX is defined as "user's perceptions and responses that result from the use and/or anticipated use of a system, product or service" (ISO, 2019). Norman and Nielsen suggest that UX "encompasses all aspects of the end-user's interaction with the company, its services, and its products" (Norman, 2022). Consequently due to the lack of a formal definition, it might be easier to break it down to its components from which it is built, by looking at Hassenzahl's model (Hassenzahl, 2003). Hassenzahl divides UX into two different perspectives: the designer's and the user's. Furthermore, he suggests two different characters the product can take, derived from the perspectives; the intended product character and the apparent product character respectively.

From a designer's perspective, the intended product character is the form the product takes from combining features such as content, presentation, functionality and interaction. However, this created character or user experience is only subjective and intended by the designer. The intention of the designer might not always convey what is perceived by the user. This is the apparent product character, which represents the user's actual perception of the product's character. This model emphasizes the importance of considering the subjective and holistic nature of UX, and to balance design considerations from different user perspectives.

3.1.1 Usability

Another important aspect of UX is *usability*. Usability has different definitions by many authors. One definition by ISO 9241-11:2018 describes usability as "the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO, 2019). Nielsen (2022b) defines usability according to five different attributes:

- **Learnability** - the user's ability to accomplish tasks the first time they encounter the system.
- **Efficiency** - the rate of speed with which the users can achieve their goals.
- **Memorability** - the ability of infrequent users to relearn the system after returning from a period of inactivity.
- **Errors** - refers to how many errors the user makes, the significance of them and their ability to recover from them.
- **Satisfaction** - the user's contentment of using the system in regards to aesthetics, expected behavior and valuable functionality. (Nielsen, 2022b)

3.2 User Interface Design & Human-Computer Interaction

A *user interface* (UI) can be thought of as the physical or logical intermediary for allowing humans to issue commands to, or interact with, external systems (PCMag, n.d.), such as computers, cars and phones (Martinez, 2011), or in simpler terms how users may interact with computers. It is comprised of all the parts of a system that the user can see, hear and issue commands to, not entirely unlike the aspects that provide the basis for the user experience as denoted above. As such it is arguably one of the most important things to get right in order to provide the user with a positive experience (Galitz, 2007).

In order to ensure that a user interface provides the best user experience possible, it is crucial to consider some fundamental design principles. According to Norman (2013), the seven design principles to consider are:

- **Affordances** – The characteristics of the object in accordance with those of the user, which together allow for interactions. All of the possible things that a certain person can do with a certain object are the affordances of that object.
- **Signifiers** – Signifiers are the indicators (visual, auditory, etc.) of what affordances there are and where the affordances take place.
- **Feedback** – The self-explanatory indications of the results of certain actions.
- **Mappings** – Mapping concerns the relationship between controllers and what is being controlled. Good mappings often utilize natural mapping, which is to say that the controls resemble what is to be controlled (i.e. the square configuration of knobs on the stovetop would resemble the square configuration of hotplates through natural mapping).
- **Constraints** – Norman mentions constraints in physical, logical, semantic and cultural forms. These constraints could be thought of as selective friction to guide the user's attention and actions through restrictions.
- **Discoverability** – The degree to which the workings of an object can easily be discovered. Good discoverability results from appropriate usage of affordances, signifiers, feedback, mappings and constraints.

- **Conceptual Model** – The user's mental models and entire understanding of an object. These result from all of the design principles above. (Norman, 2013)

User interface design may fall under the broader concept of *Human-Computer Interaction* (HCI), the multidisciplinary field of study where computer science, human factors engineering and cognitive science have been synthesized to cover all types of interactions and designs surrounding information technology at large (Norman, 2013).

3.3 Human-Machine Interaction & Automation

More relevant to this thesis, based on the fundamentals of HCI is the concept of *Human-Machine Interaction* (HMI). HMI refers to the communication and interaction between humans and machines through the use of an interface (Ke et al., 2018). What differentiates HMI from HCI is the focus on machines rather than computers in general. Both control interfaces, but the former controls and interacts with machines and the latter a computer (Nelson Miller Team, 2020). Additionally, with HMI's, a human has to adapt to the interaction with the machines, often due to the complex environments they occur in (Coetzer et al., 2020). In this case, automation plays a role in how the interface is inaugurated. Due to this, tasks are becoming more advanced and less structured, thus changing the dynamics in how people interact and behave with this technology (Feil-Seifer & Matarić, 2009).

According to Degani and Heymann (2002) there are four elements regarding interaction between users and machines, in the context of automation, stated as: (1) the machine's behavior, (2) the operational goals or task specification, (3) the mental model about the machine's behavior by the user and (4) the user interface through which information is communicated. These elements have to synergize, to create a system where the mental model and interface is corresponding with the task specification, thus creating the correct interaction when using it. When the automated system works smoothly, the tasks required by human workers are limited to only monitoring and executing simple manual tasks that are not yet automated. (Degani & Heymann, 2002)

However, when issues arise, the workers switch from monotonous responsibility to high cognitive demand when troubleshooting, creating a rapid change of context (Pohl & Oehm, 2022). This possible scenario introduces new aspects to consider when designing for solutions within this context, such as increasing the situational awareness by providing the ability to perceive all relevant process changes to ease the adaptation of the situation (Endsley & Kiris, 1995; Pohl & Oehm, 2022). In other words, the HMI should provide enough information for many, if not all possible states of the machine, to enable operators to make sensible decisions if the automation fails to function properly. Therefore, it is important to design with the awareness that human intervention will be necessary (Pohl & Oehm, 2022).

3.4 Wicked Problems

Wicked problems were formulated by Rittel and Webber in 1973 in contrast to what they termed "tame" problems. According to them, a "tame" problem is one related to the sciences and engineering where the mission and goal is clearly defined. Rittel and Webber describe chess, math and chemistry as examples of where you can know whether or not the problem has been solved. These problems present exhaustible numbers of solutions which can be known before initiating any problem solving activity.

A wicked problem, then, lacks this type of clarity. These problems present challenges and complexities in simply trying to understand the problem and all underlying facts required to attempt solving it, which ultimately makes it impossible to clearly formulate a problem definition. Consequently, there is no way of knowing whether or not the problem has been solved. Rittel and Webber argue therefore that solutions to wicked problems cannot be true or false, but rather good or bad.

Rittel and Webber provide an example of a wicked problem of how to solve “crime in the streets”, which could just as well be the symptom of a higher level problem, such as moral decay or poverty, or any other reasonable problem, each of which could themselves be wicked.

Throughout this thesis, it will become evident that our initial scope were difficult to grasp in its entirety, which forced us to consider alternative delimitations to a problem that presented itself as wicked. (Rittel & Webber, 1973)

3.5 Fitt’s Law

Fitts’s law is a design principle initially proposed by Paul Morris Fitts in 1954 (Fitts, 1954). The law states that the distance to, and size of, a target determines the speed of target acquisition (Interaction Design Foundation, n.d.-b). In other words, the longer the distance to the target, and the smaller the target is, the more errors will be performed in trying to interact with it.

Two important concepts related to Fitts’s law are the prime pixel and magic pixels. The prime pixel refers to, in the example of a cursor on a computer screen, the location of the cursor at any time. This changes constantly as the cursor moves, of course, and is unreasonable to try predicting. It is, however, useful in terms of sequences of actions. Expected subsequent actions should therefore be placed closer together.

Magic pixels refer to the boundaries of the interactive area, or more specifically the corners of the screen. These are the four pixels that are always the furthest away from the prime pixel regardless of its position. It is therefore regarded unwise to place any important pieces of interactables or information close to the magic pixels (Interaction Design Foundation, n.d.-b) even though the magic pixels, by the very nature of the constraints proposed by the boundaries of the screen, are the quickest and easiest place to move a cursor (Sharp et al., 2019b).

Fitts's law may become relevant for this thesis almost regardless of the resulting solutions. It is reasonable to assume that any resulting design will benefit from taking matters such as size, placement and speed of target acquisition as a result of travel time into account. Therefore, this law of design will be considered when relevant, while not necessarily at an algorithmic level, at least on a framework and design principle level.

4
Methodology

This chapter provides an overview of the methods planned for this project. It covers design thinking and double diamond as user-centered approaches. The methods described are organized by the stage of which they are used according to the design process frameworks. Due to the changes made to the initial scope, the methods described in the section 4.6 Evaluation were never utilized.

4.1 Design process

Design Thinking is a method for approaching problems through an iterative process (Interaction Design Foundation, n.d.-a). This non-linear problem solving approach has the benefit of being able to tackle wicked problems – those with an unknown problem definition or which otherwise lack a clear stopping rule for when ultimately solved (Rittel & Webber, 1973) – by focusing on the most important needs of the intended users (Stevens, 2021).

One such process, as defined by the Hasso-Plattner Institute of Design at Stanford, has five phases (Institute of Design at Stanford, n.d.). The first step is to (1) Empathize with your users. This is done through qualitative user research, or by putting oneself into the shoes of the users. The data gathered is then unpacked and analyzed in order to (2) Define the correct problem to solve. This is followed by (3) Ideating a multitude of potential solutions with focus on quantity over quality. Some of the resulting ideas might then be brought into the fourth phase (4) Prototyping, where these are actualized and subsequently (5) Tested. The last phase generates feedback which might be used to refine the prototypes thus creating the iterative process. This process may seem sequential, but may be modified or iterated as needed depending on the project, as exemplified by Figure 4.1. (Institute of Design at Stanford, n.d.)
A similar method proposed by Banathy (2014) and popularized by The Design Council has been coined the Double Diamond (Design Council, 2023). This innovation framework represents the design process by the likes of two diamonds, each of which has a divergence and convergence phase. In likeness with the design thinking process described above, this model puts initial focus on the users in gathering understanding regarding the users needs and issues through a divergent Discovery phase. Subsequently, the insights gathered can then converge into a refined problem definition in the Define phase. The second diamond launches off from the revised problem statement into a new divergent phase called Develop where potential solutions are put forth and again converging into the solution through the fourth and

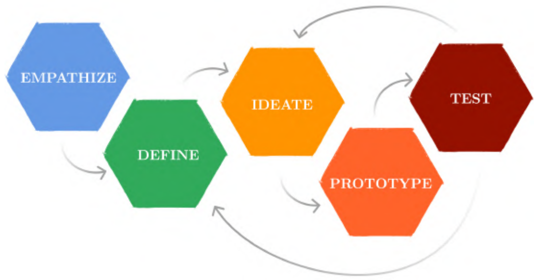


Figure 4.1: Depiction of the Design Thinking Process.

final phase called Deliver. A visual representation of this can be seen in Figure 4.2. (Design Council, 2023)

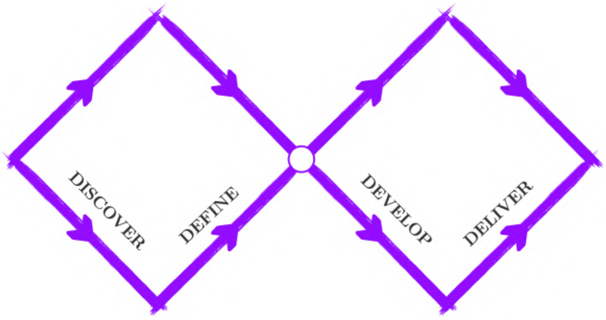


Figure 4.2: Depiction of the Double Diamond design process.

The two proposed models for the design process share more similarities than they differ from each other and arguably the most important one being the user-centric research process (Costa, 2018). Throughout this project, the methods to be used will be chosen in high accordance with the above design processes and will be heavily grounded in accordance with user centered design (Interaction Design Foundation, n.d.-a).

4.2 Data Gathering

A central part of any interaction design, or user experience, process is the activity of gathering data (Sharp et al., 2019a). Particularly during the formative (evaluation to determine what works and what does not) and summative (evaluation of performance) stages of the process (Joyce, 2019). Good data gathering is determined solely on what is relevant to collect at a given time in order to yield the relevant insights. It is therefore important to make sure that the correct method is chosen at each stage in the process.

There is, for instance, a clear separation of qualitative methods and quantitative methods, where quantitative methods aim to provide a large number of measurements and data points (through methods such as surveys and experimental research (Bhandari, 2022a)) while qualitative methods are more focused on diving deeper into the why of the numbers (Fullstory Education Team, 2021) (such as through observations and interviews (Bhandari, 2023)).

In this section we will introduce several methods for gathering data to be used throughout the process.

4.2.1 Interviews

Interviews are often likened to conversations and depending on the type of interview performed the conversation can be more or less like a regular conversation. There are three different types of interviews ranging from open-ended questions in the unstructured interview to the opposite in the structured interview, with semi-structured questions in between.

Unstructured interviews do not necessarily have a predefined set of questions, but rather aims at covering a certain topic. The questions are open-ended, meaning that there is no expected answer to be gleaned from the question. These interviews are often quite unlike each other and do provide a lot of unique data which makes the data heftier to analyze compared to the other interview techniques.

Structured interviews, on the other end of the spectrum, are closed-ended, which means that questions are often seeking a specific answer, such as multiple choice questions. These interviews are to be performed identically for each participant.

Semi-structured take inspiration from both techniques. These interviews often follow a script, but allow for follow-up questions to be asked in order to probe for further, deeper information. (Sharp et al., 2019a)

As unstructured interviews are well suited for exploratory purposes, they are likely to be used early on in the process, while the comparability of the results from structured or semi-structured interviews will provide good data in later evaluations.

4.3 Data analysis

Analyzing data can be done in a multitude of ways and differ substantially depending on whether the data is qualitative (unstructured, rich data, such as when gathered from interviews, recordings, etc. (Dye, n.d.)) or quantitative (structured data, often in the form of numerical values (Stevens, 2022)). The nature of this thesis lends itself to garner primarily qualitative data which is the most difficult and time consuming type of analysis of the two (Dye, n.d.). There are generally five steps to be taken when analyzing qualitative data, as follows: (1) *gathering*, (2) *organizing* and (3) *coding the data* allows it to be (4) *analyzed* and (5) finally *reporting* the insights

(Dye, n.d.). To manage this, we will primarily be using the following two methods for qualitative data analysis.

4.3.1 Thematic Analysis

Thematic analysis is a method for boiling down large amounts of text into meaningful patterns. These patterns represent different themes. There are several approaches to consider when performing thematic analysis, two of which are inductive and deductive. With the inductive approach the data dictates the themes. Contrastingly, with the deductive method, the data is approached with predetermined themes through which the data is viewed (Caulfield, 2022).

4.3.2 User Journey Maps

User Journey Maps is a method used to visualise a process that a person goes through to accomplish a set goal. In its simplest form, it compiles the actions that the user takes into a timeline. The timeline can then be expanded upon with thoughts and emotions of the user as well as decisions taken at certain stages. This mapping realizes the process into easily digestible information that can aid the design team into pinpointing distinctive, frustrating or delightful moments which can result in productive discussions. (Gibbons, 2018)

Additionally, it helps develop a shared vision of the user's behaviour in its actual context. Typically, alongside of a User Journey Map, a persona is created to illustrate the user and their goals. This is often based on the customer who use the product or service and is derived from information from interviews. (Hanington & Martin, 2012a)

This method will be useful for our thesis to map out what picking implies, as well as to use as a foundation for finding possible solutions. As picking strategies vary, it can also be used to map out differences to find pros and cons with each.

4.4 Ideation

In the ideation phase of the design processes the focus will be on quantitative generation of ideas. The following, proposed methodologies have been chosen to effectively complement each other through their differing approaches to idea generation.

4.4.1 Brainstorming

Brainstorming is a method used to generate a large amount of ideas, concepts and possible solutions regarding a defined objective (Hanington & Martin, 2012b). Frequently used in a group setting, the intention of the method is to create a safe environment, by welcoming every idea without any inhibition from other participants (Harley, 2017). Additionally, working in a group often produces a greater number and variety of ideas, and also encourages ideas to build off each other (Lawrence, 2022). A brainstorming session should not stretch further than 60 minutes to keep it productive (Kelly, 2000). While noting ideas down in words is a common approach, the goal is to capture the idea in any way, shape or form, as long as the idea is able to be reminisced once the evaluation stage proceeds (Harley, 2017).

4.4.2 How Might We

How Might We (HMW) is a technique in which questions are constructed in "how might we" fashion, to create a clearer scope of the problem to solve (Rosala, 2021). HMW's can usually be defined once enough insight of the root problems are uncovered. The difficulty with the method lies with the balance of the question. The HMW should maintain a certain level of ambiguity, as it opens up the possibility for the ideas to take any direction (Friis & Yu, 2020). At the same time, it cannot be too broad as it defeats the purpose of focusing on the root problem. When correctly executed, it will result in a question that is non-suggestive towards a solution, focused on the desired outcome and that becomes a cornerstone in the ideation process (Friis & Yu, 2020).

4.4.3 Worst Possible Idea

Worst Possible Idea is a method where idea generation is based on finding explicitly bad ideas regarding a certain objective (Interaction Design Foundation, n.d.-e). The intention is, by identifying preposterous and silly ideas, that one can deconstruct them and find powerful insights that may create a foundation for a good solution elsewhere. Using the bad properties of each idea, one can analyze what makes them bad, and find the opposite of them to establish valuable insights. The strength with this method lies in the execution of the method. While traditional brainstorming sessions encourage all ideas, stating absence of prejudice or judgment, it is not always the case that each participant opens up and contributes, concerned that this still might happen (Interaction Design Foundation, n.d.-e). Worst Possible Idea instead sets the expectations low, relieving pressure and anxiety of presenting ideas. This makes this method a powerful tool to explore the problem in a different perspective, possibly yielding unique insights (Interaction Design Foundation, n.d.-e).

4.5 Prototyping

The prototyping phase entails the creation of the designs proposed as ideas in the ideation phase. These can range from low fidelity wireframes to fully functional, visually appealing prototypes. The following methods are the primary methods chosen to be used in this thesis.

4.5.1 Sketching

Sketching is an effective method to externalize ideas and mental models, providing a tangible representation of abstract concepts. It can serve as a powerful ideation and problem-solving tool, allowing designers to explore alternative solutions, iterate on designs and communicate ideas effectively. Whether through traditional techniques or digital tools, the purpose of sketching is to facilitate quick visualisation, feedback and refinement of design concepts (Buxton, 2007). Additionally, sketching has a vital role in collaborative design processes, as the use of it becomes a common language, and facilitates co-creation of meaningful design solutions. Sketching has the ability to capture user needs, visualize interactions and informing the design of intuitive features (Koskinen et al., 2012). Sketching will be a necessary tool for us to ideate in the problem space, as well as to initiate the prototyping stage.

4.5.2 Research through design

Research through design is a research methodology that aims to produce new knowledge through the design process. Through iterative cycles of design, implementation and evaluation, the design process itself becomes a way of generating knowledge and understanding. The iterative cycle enables reflective practice in which designers must reflect and evaluate their design decisions in order to discover new insights. By combining design and inquiry, it allows researchers to investigate complex questions by using the design artifacts as a tangible manifestation of them. They aid in facilitating dialogues, invite critique as well as create enriched discussions. (Zimmerman et al., 2007)

4.5.3 Devils advocate

The Devil's Advocate is a method often utilized on large scale projects and in businesses to evaluate decisions in order to make sure any consequences comes to light before it is too late. This can be done by raising difficult questions in constructive manners. Mui argues that there are three important rules to making this method work. Firstly, the process must begin before any sides to the ideas has been taken, otherwise there is a risk of biased decisions. Secondly, it is important to frame the activity correctly by making it about learning instead of simply breaking down ideas. Finding out about uncertainties should be the focus. And lastly, the devil's advocate should operate throughout the process and not only in the end. (Mui, 2014)
During this thesis, this method is used mostly in combination with brainstorming and sketching to quickly rule out problematic scenarios.

4.6 Evaluation

The final phase of the design thinking process involves evaluating the prototypes from the previous phase. For this thesis, the following evaluation methods were chosen.

4.6.1 Usability Testing

Usability testing is an observational method used to evaluate a product using representative users (Rubin & Chisnell, 2008). The users are asked to perform realistic tasks, usually combined with a "Think-aloud" protocol, where they are encouraged to continuously verbally communicate their thought process throughout the tasks (Hanington & Martin, 2012c). The facilitator ensures that the tests are performed without influencing the participants behavior, to assure that the resulting data is of high quality (Moran, 2019). The goals of usability testing usually include:

1. Identify and rectify problems in the design of the product.
2. Discover opportunities to improve.
3. Learn and understand the target user's behavior and values. (Moran, 2019)

The gathered data allows the facilitator to recognize usability problems, usually indicated by certain behavior expressed by the test user (Hertzum, 2022). This can be frustration, impatience or uncertainty indicating confusion with the design. Surprising expressions can indicate a mismatch between the product and the user's expectations. If a user needs assistance or several actions before completing the right task, it is another usability problem in regards to priority.

4.6.2 Heuristic Evaluation

Heuristic evaluation is an inspectional method used to assess an interface according to a set of defined usability guidelines and principles (Hanington & Martin, 2012d). It is commonly performed using established heuristics such as Nielsen's ten general principles (Nielsen, 2022a) or Jordan's seven principles of usable design (Jordan, 2020). Heuristic evaluation lets a few expert evaluators examine an interface, focusing on different individual aspects, to find usability issues and conclude its impact on the user experience. As the result depends on the choice of heuristics, it is important to consider them carefully according to the project's characteristics (Interaction Design Foundation, n.d.-c). Additionally, it is recommended to involve multiple evaluators to receive results with higher quality, and that the tests are performed individually to ensure unbiased results (Nielsen, 1994). Conducting heuristic evaluations are often advised, as it requires less advance planning compared to usability evaluations with real users, can deduct a majority of the usability problems and can be used early in the process to inform the continuation of the development (Nielsen & Molich, 1990).

5
Planning

The initial plan for this project was to follow a design process according to section 4.1 along with the majority of the methods and theories described in section 3 Theory & 4 Methodology. The plan was to divide the project into two major parts where the first part consisted of mainly researching and understanding the problem space. The second half would be of innovative nature, where a design would be implemented, evaluated, iterated upon and finally result in a high fidelity design in accordance with the results from the first part. These parts would answer research question one and two respectively. The initial time plan for the project can be seen in Figure 5.1.

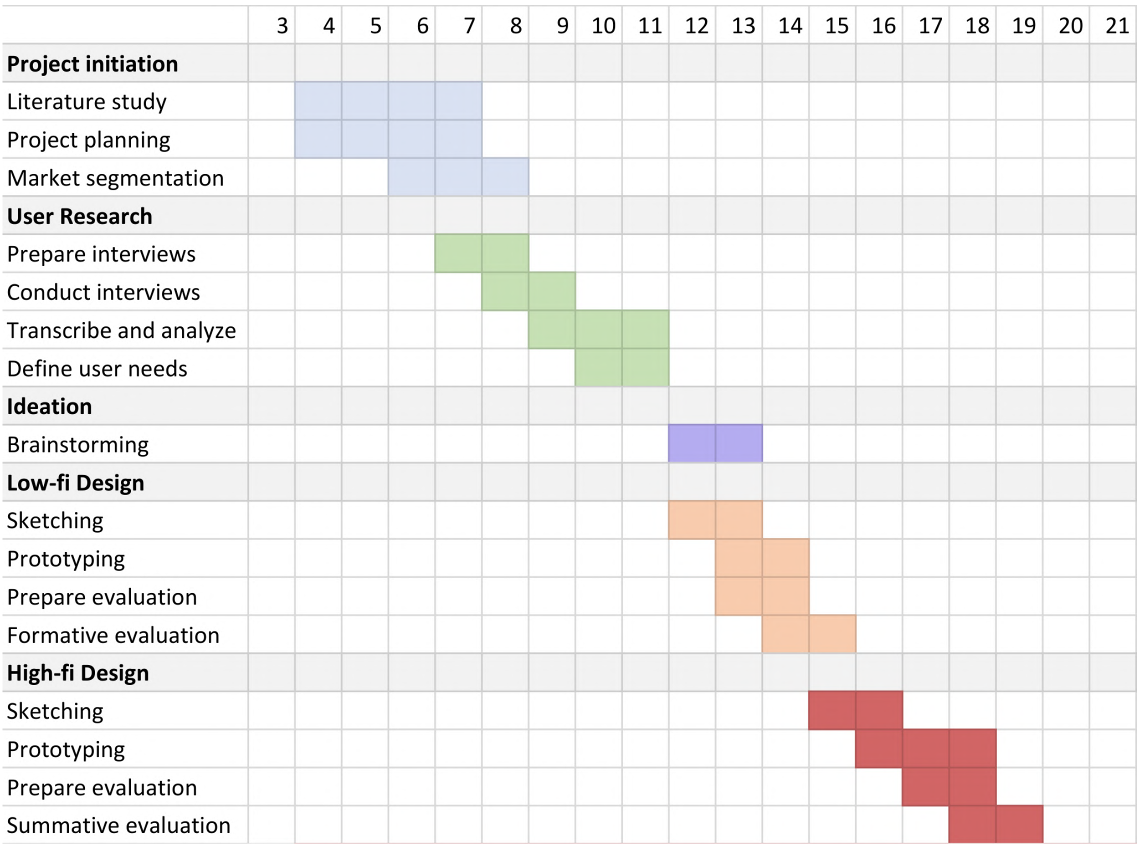


Figure 5.1: Overview of the initial time plan for the project.

6

Execution and Process

In this chapter, the project execution and process is described, iterated through four different phases. Each phase represents a new significant alteration and direction to the project. The phases loosely follow the design process, described in the Methodology 4 chapter. The first three phases compiles the interviews and visits, and describes the main insights gathered to inform our first research question. The fourth and final phase delves into our design implementation, aiming to answer the second research question. See Figure 6.1 for a brief visualization of the four phases.

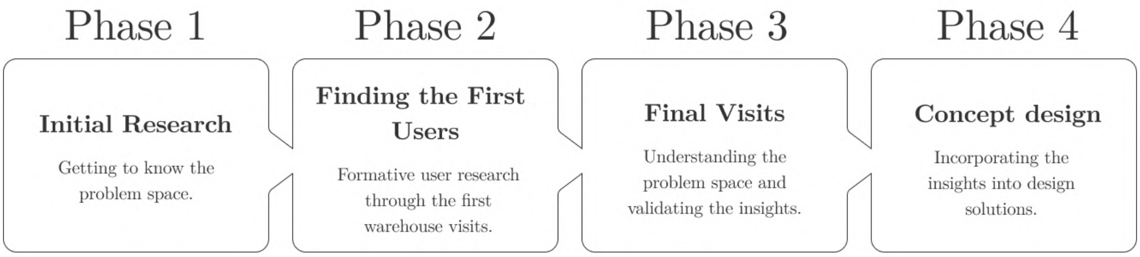


Figure 6.1: Descriptions of the different phases.

6.1 Change of Scope

Initially, the scope of this thesis was to explore potential graphical user interface designs for an *Automated Guided Vehicle* (AGV) mounted screen to be utilized for order picking. As the research phase proceeded, it became evident that solving picking using an AGV mounted screen was not as clear of a solution as it first might have seemed. As we came to know the complexity of warehouse layouts in the context of their physical and digital constraints, it became clear that each warehouse and their corresponding order picking process is quite unique, with solutions tailored specifically to fit their needs. Along with this insight, the systems and methods in use for fulfilling order picking is also quite diverse, which led us to consider approaching the challenge of effectivizing order picking in a more fundamental manner. We decided to take a step back and adjust the scope to focus more on uncovering the underlying needs and criteria for successful manual order picking. This decision led us to focus more on exploring the different ways in which order picking is actually performed. More weight was therefore put on user research, where warehouse visits for interviews and observations were essential for finding out the pains and gains of manual order picking. This was done in order to reach insights on how this activity should be performed, and how we could improve upon it for the people working with it. With this new scope, we decided to (1) reach conclusive insights on successful order picking and (2) how we would approach innovating on this process through interface design based on the findings.

6.2 Phase 1: Initial Research

The first step of this thesis was to get a good understanding of the area in question. In order to better understand what order picking actually entails and how AGVs are used today, an extensive research phase was initiated. This included meetings with several stakeholders at Toyota, including project managers and UX experts, reading up on existing resources within Toyota as well as performing relevant online research. The most important findings during this initial phase was in relation to (1) the ways in which order picking is performed, either through Goods-to-Person or Person-to-Goods, (2) the systems associated with successful order picking within these two approaches (such as Pick-by-Voice, Pick-to-Light, etc.), as well as (3) the different methods associated with optimizing order picking for different warehouse setups, such as zone picking and wave picking, among others. Furthermore, we looked into the existing solutions in use today. Most of the information gathered in this stage is summarized in chapter 2 Background.

During our initial research, Toyota made a visit to a customer of theirs (coded "Company A" among all of the data gathering sources available in table 6.1) in order to research how they are performing manual order picking. The information gathered was in the form of interviews and video clips of an order picker in action, utilizing Pick-by-Voice in combination with an AGV carrying two pallets. We had the fortune of being able to take part of the information gathered from their visit. It quickly became clear to us that the benefits of working hands-free with no screen was very effective, especially as the route was pre-planned and the AGV drove by itself to each and every pick location. The voice technology allowed the picker to simply confirm the pick by saying a check number related to the specific pick location, as well as the quantity and on which pallet the picker placed the pick. It was clear that these three attributes related to each pick was sufficient for successful order picking within this setup.

Furthermore, the picker was able to pick two separate orders simultaneously due to the use of two pallets, which further strengthens the value of Pick-by-Voice as a sequential information provision system.

The main take-away from this visit, however, was the placement of the order picker at all times. Seldomly was the picker close to the front of the forklift, and was almost exclusively located next to the pallets instead. This proved efficient as there were nothing for them to control on the AGV, so they had no reason to walk further than where the AGV automatically drove. This was an important finding as it shed light on the question of whether a screen should be placed on the AGV and in such

a case, for what purpose.
Summarized, the main take aways from this visit was:

- The picker could stay close or next to the pallets most of the time. This meant that no time was spent on walking further than the AGV automatically drove.
- Is there really a need for a screen on the AGV for picking purposes?

6.3 Phase 2: Finding the first users

During and following the initial research, we reached out to a number of different companies, which we expected were performing order picking to some extent, in order to book a visit to their warehouse as well as to conduct interviews with their staff. The insights from the visit to Company A described above provided a foundation for the initial interview questions (see Appendix B).

In order to make the visits as meaningful as possible for our investigation of manual order picking, we set out a number of preferences for which company to visit, and how to approach that visit. It was preferred that the company (1) utilized a Person-to-Goods order picking process, that they (2) utilized some type of vehicle for the manual picking process (e.g. a forklift or roller cages, etc.) and (3) that the warehouse was located within a reasonable geographical radius from us to allow for reasonable travel opportunities. We realized the difficulty of knowing which companies fulfilled these requirements, as they seldom advertise their specific order picking methods.

The initial approach to find potential users was mainly looking at Google Maps finding names of companies around Gothenburg and researched to see if they appeared relevant for us. Searching through job postings from companies that looked for warehouse workers was another approach. These methods yielded visits to two companies, both of which mainly utilized Goods-to-Person processes. However, these visits aided with the insight of how unique and different each solution is. This process was time consuming, and mainly a guessing game which led us to seek other means of finding users. We sought out experts in the business, both within the company as well as acquaintances who might have information about the industry, to find potential companies with the relevant order picking processes.

6.3.1 Interviews & Visits

Due to the focus on the order pickers and their needs, it was concluded that a qualitative method for data gathering would be the most effective choice. The interviews were conducted both online and in person on-site if combined with a visit. When possible, the interviews were recorded when such an agreement was made and the circumstances allowed for that type of setup. In these cases, the interview questions (see Appendix B) were followed semi-strictly in order to distinguish the differences between answers from different interviewees. However, we made sure to allow for a more semi-structured approach for several reasons, including the fact that we needed to get to know the business and order picking, both broadly and in depth, which led us to let the discussions during the interviews allow for a more natural flow.

These interview sessions were often held in the beginning of the visits with warehouse managers, before going down to see the warehouse. This setup allowed them to present their processes, as well as us to get to know how they have set up their warehouse in terms of the layout, their choice of *Warehouse Management System* (WMS), their methods and systems utilized presently and historically, as well as if they had managed to identify any specific pain points related to these aspects. These interview sessions provided us with important information from the perspective of management, not directly related to the activity of order picking. Most managers, however, had worked as order pickers earlier in their careers which made their perspectives even more relevant.

When this setup was not possible, or when we were walking around the warehouse with order pickers or other staff, the interviews were more spontaneous and the questions often in relation to the context in which we were at the time. During the visits on the floor of the warehouse was when the most of the observational data were gathered. The focus of our observations were on how order picking was performed, what the picking process and flow looked like, how the order pickers utilized their order picking systems in combination with their vehicles, etc.

As a natural consequence of finding users and planning visits over a longer time span than just during the initial exploration, we had the opportunity to iterate on the questions and observational methods as each interview and visit taught us more. This led us to sharpen the questions and focus of the interviews as the project went on. This allowed us to seek new insights related to previously learned ones and it allowed us to verify the information we received. All of the visits are compiled into Table 6.1 below.

	Operation	OPS	Pick-by-systems and solutions	Interviewee Positions	Data collection methods
A	Groceries	PTG	Pick-by-Voice, AGVs, Manual forklifts	Picker	Videos, Photos
B	E-commerce, clothes and sports equipment	GTP	AS/RS, Wearable Screen, Roller cages	Team leader	Interviews, Observation
C	Tailored grocery delivery	GTP	Pick-to-light, Conveyor belt	Production- and warehouse manager, Systems manager	Interviews, Observation
D	E-commerce, clothes and sports equipment	PTG	Mounted display, Scanner, Manual forklifts	Picker	Interview, Photos
E	Vehicle manufacturer	PTG	Paper picking, Manual forklifts, Magnetic lifter	Picker	Interview
F	E-commerce	PTG	Portable display, Scanner, Manual forklifts	Picker	Interview
G	Wholesale for food, groceries and restaurant equipment	PTG	Paper picking, Manual Forklifts	Warehouse manager, Picker	Interviews, Observation
H	E-commerce	PTG	AS/RS with Pick-to-Light, Wearable display, Scanner, Manual forklifts	Group manager, WMS/IT Manager	Interviews, Observation
I	Wholesale for consumables, work clothes and equipment for businesses	PTG	Mounted display, Manual forklifts	Warehouse manager	Interview, Observation, Photos
J	Wholesale for food, groceries and daily goods.	PTG	Pick-by-Voice, Manual forklifts	Warehouse manager, Supervisor, Picker	Interviews, Observation, Photos, Videos

Table 6.1: Table over company visits and interviews.

6.3.2 First visits

The first visits were to the companies we found during our initial user finding activity. Both of these companies utilized a Goods-to-Person setup as their main order picking process.

6.3.2.1 Company B: The Automated Warehouse

The first company (B) was an e-commerce retailer for clothes and sports equipment utilizing an *automated storage and retrieval system* (AS/RS) for 95% of their stock (see table 6.1). However, as they had what they called *uglies*, a common name for large and bulky items unfit for AS/RS systems, they still had to perform manual order picking for five percent of their stock. Apart from learning that AS/RS is difficult to compete with when it comes to handling items up to a certain size, we did glean some useful insights.

The manual order picking was clearly performed inefficiently, but as a consequence of the major focus put on maximizing efficiency in the AS/RS system. Uglies were largely placed in shelves, rather than on pallets as regularly seen, and each of the items were only rarely picked. This allowed the manual order picker to handle several (up to as many as 24 separate orders, as indicated by the largest roller cages with 24 separate compartments) during a single route. The picking system in use was a digital picking list in the form of a mobile device, with a strap making it possible to wear on the back of their hand. The device was also used for confirming the pick by scanning the location. Interestingly, even though the device was wearable, it was clearly disruptive to the order picker's routine as it was often left behind when they needed to lift larger, more cumbersome items. Clearly, when designing order picking systems to be worn, it is important to allow for full freedom of movement and to not let the system disrupt the most frequent task presented to order pickers, which is lifting.

We noticed the fact that almost everyone working with order picking, either manually or with the AS/RS, had earphones in one ear only. We learned that safety rules prohibited the use of two earphones as that might cause them not to be able to hear potential hazards, such as forklifts in movement, or the fire alarm in case of a fire. However, the need or want for listening to music or podcasts during order picking, both automatic and manual, was evident.

Therefore, the main takeaways from this visit was:

- The AS/RS system is very efficient.
- The handheld device was disrupting the picker's routine, as it made it more difficult to lift larger items.
- There is a need or want for listening to music or podcasts during order picking.

6.3.2.2 Company C: The Pick-to-Light Warehouse

The second visit was to a grocery home delivery service where the orders are tailored after recipes. Here, a Pick-to-Light solution was adopted along a moving conveyor belt. Along this belt, pickers stood with approximately two-three meters as their zone. They had totes of specific food in front of them, on the other side of the belt, lighting up according to what is to be put into each box travelling down the belt. After seeing their warehouse, we sat down with the warehouse manager and their assistant for a recorded interview.

It quickly became clear that ergonomics was of high priority for Company C. Since the pickers had to stand up, and reach over the belt, they had put in soft carpets to stand on and lined the side of the belt with soft material to alleviate any physical pain resulting from this work. They had also managed to optimize the placement of the products to be picked so that about 90% of all picks was in the first few meters of their zone, so that they rarely had to reach very far.

Furthermore, most order pickers had varied tasks so they would not have to stand up their entire shifts.

We learned that it was of utmost importance to place the products neatly in the boxes. This was due to the fact that badly placed products may damage other products in the transport, which might hurt their sales as their customers are private.

The order pickers were allowed to wear one earphone for the same reasons as in the previously visited warehouse, namely due to security risks. They did play loud music in one end of the conveyor belt, which made us quite aware of the noise level. This made us even more interested in how noise and sound pollution in general might impact the working environment.

6.3.2.3 General findings

When it comes to manual picking, it seems important to be able to handle all kinds of orders simultaneously (either large orders to few customers, or orders to many different customers), especially when the manual order picking operation is as small as it was at Company B.

Furthermore, ergonomics seems important. The process at Company C was very labor intensive, with many pickers at the belt simultaneously. Despite the sheer size of their order picking force, they displayed very low order picker turnover. Arguably due to good physical and mental ergonomics, with padded floor and belt, and good reach, as well as task variability and other benefits such as cooked food some days, and breakfast every day.

The main take-aways from this visit were:

- Ergonomics is of high importance, many measurements are done to empower this.
- Since ear-covering devices were prohibited due to security reasons, it created a significantly louder environment due to speakers being used instead.
- Each warehouse is different, and implement strategies and technology fit for their specific requirements.

6.3.3 Exploratory Sketching

The fact that relevant companies were difficult to find and book visits to at their availability left us with gaps in our time plan where we initially would have wanted to perform user research. Due to this fact, we had to solve this problem creatively. We realized that we would have to extend the period for data gathering in accordance with the cadence with which we came into contact with relevant companies, and thus modified our plan accordingly. Instead of an initial exploration phase, we adopted a continuous data gathering phase to accompany us throughout the thesis. This new approach to data gathering would provide novel benefits such as allowing us to modify each and every visit according to previous insights.

Furthermore, we capitalized on the scheduling opportunities we were given by trying to gain insights through design activities. With the most relevant inspiration coming from Company A, as gathered by the UX team at Toyota, we focused on how to alleviate picking with the use of an AGV. One of the most important insights from that visit was the fact that the picker always walked next to the pallets on which they would place the picks. We decided to do digital sketching, utilizing the simplicity of FigJam[1], to produce low-fidelity visualizations of scenarios and ideas based on our visits at that point. Since the sketching was produced digitally, we could change the sketches according to new ideas, which was pivotal as we incorporated the devil's advocate method into the activity. During this activity, we decided to produce all of the ideas we came up with, regardless of feasibility. We encouraged each other to find potential problems with each sketch through the devil's advocate approach, after which it was either iterated upon into something useful, or discarded.

With ergonomics in mind, these methods provided us with several new ways of alleviating order picking when performed with an AGV, most notably the scanner approach (see top middle and top right in figure 6.2). This way of performing picking would allow for the picker to wear a screen on their arm which could be utilized for scanning the items to be picked, while also allowing the AGV to scan the handheld device in order to confirm the pick. The benefit of such a system would be in the form of visual information provision, but it also comes with the risk of obstructing the lifting. The rightmost image in Figure 6.2 displays how such a screen could be magnetically detachable to be placed on the AGV, which would provide high flexibility on where to place it to be viewed from different angles. However, it is

[1]https://www.figma.com/figjam/

difficult to see how this solution can compete with Pick-by-Voice unless the visual information provision potential is utilized beyond the efficiency with which order picking is performed with Pick-by-Voice.

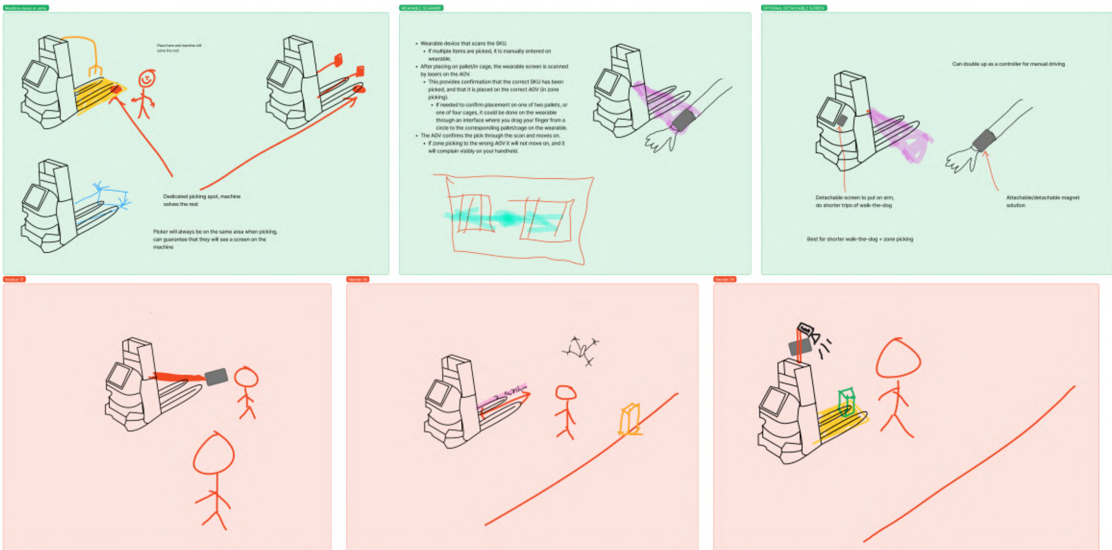


Figure 6.2: Some of the solutions from the Exploratory Sketching activity.

One such potential feature that we experimented with was the ability to guide the order picker to where they should put each item that they picked, by displaying it on the pallet, either digitally on a screen, or by displaying it through the use of light projections on the pallet. We had no indication that this might be needed as of yet, but we quickly realized that such a system would provide quite the challenge in technological terms. Firstly, the WMS would need to know the dimensions, weight and structural integrity of everything to be picked in order to be able to build high pallets securely, without the risk of fragile things breaking in the bottom. Secondly, the order picker would have to follow the orders of the machine, diminishing their agency and expertise for one thing. Additionally, it might be difficult for the system to rectify the change introduced by an order picker who places an item incorrectly in relation to the instruction. Given a flawless execution of this idea, it might still be difficult to beat the efficiency with which Pick-by-Voice is utilized, simply due to its simplicity. It is probably more important for an order picker to know that they put the picked item on the correct pallet (in the case of several) or compartment rather than on a predetermined precise spot.

6.3.4 Interviews with order pickers

Following the change in scope, two interviews were held with order pickers who worked in warehouses operated with manual Person-to-Goods processes. Both of the interviews were held online and were recorded. The interviewees got to read through a consent form (see Appendix C) and verbally agreed to being recorded and having their recordings be transcribed for analysis. Both of the interviews were semi-structured, and follow-up questions were asked when the interviewer found it relevant.

6.3.4.1 Interview with order picker at Company D: The Scanning Warehouse

The first interviewee worked at an e-commerce warehouse for clothes and sports equipment. Apart from the interview, we were provided with photos of a typical order picking routine, detailing each step as well as what information they have available during their route.

Their picking route started with them getting a forklift, and assigns an order to themselves among others in a digital list of orders. The order is then visible at all times on a screen mounted on the forklift. When the they got to an item to be picked, they checked that the location number on the shelf corresponded with the one on the screen, they picked up an item and scanned it with a handheld scanner, after which they confirmed number of items to pick using the screen. Thereafter they were shown into which box to place the items. This information was always visible, but following the scanning it was shown more clearly. Thereafter, the box were scanned and then fed the item.

We learned that they enjoyed having varied tasks at work, and that they were allowed to listen to music with one and sometimes two earphones. The main source of errors were regarding the amount of items to pick, partly due to the fact that they had to manually enter how many to pick, but also because they had to manually count the amounts of items to put in, a number which could at times be rather large (up to a hundred items at a time, were mentioned).

However, important to note was that beside the quantity errors, the process provided great accuracy due to the many scans required. It is therefore likely relevant, when choosing which order picking system to use, to take into account how much time each pick takes to perform and to put that in contrast with the error rate. It is likely that some may tolerate a higher error rate when, for example, the efficiency is high enough to outweigh the cost of errors.

Relevant to note, as well, was the fact they had gloves available to use when picking if they wanted, although this person decided against them most of the time. This is relevant to take into consideration when designing order picking systems so that they may provide efficient interactions while wearing gloves.

6.3.4.2 Interview with order picker at Company E: The Vehicle Manufacturers & F: The Digital Device Warehouse

The second interview was held with a person who had been working as a manual order picker at two different warehouses: Company E were related to vehicle manufacturing and Company F were related to e-commerce.

At Company E, they utilized paper picking. They expressed liking towards always being able to see the paper when driving between each picking location. They were instructed to make sure that they placed the items neatly. It was more important to pick the correct item than the correct quantity. They were provided with the opportunity to wear gloves, which again strengthens the need to design interactions with gloves in mind. They also expressed a liking towards driving forklifts.

At Company F, they were not allowed to wear earphones at all, but they were allowed to have a portable speaker on their forklift. They expressed how this raised the noise level in the warehouse quite significantly, which again might be worth taking into account when thinking about the security risks with wearing earphones in the first place. The order picking list was digital and displayed on a handheld device, which they had to bring with them to many of the picks when leaving the forklift. They were required to scan the items in order to proceed to the next item, which again provided a means to make fewer errors.

Finally, some of the items were expressed cumbersome to lift and/or to place on the pallet. The interviewee described how they sometimes decided to take a detour just to avoid picking up something they knew would be problematic to place on the pallet in that point of the route, such as a large framed painting. Unless the detour was taken, they would sometimes have to tape the item on the outside of the forklift in order to bring it with them until they would be able to place it on the pallet in an acceptable manner. They were, notably, not required to place the items neatly, as that would be performed by a packaging area after the picking route was completed. However, the detours might still be avoidable, and if they are compromising efficiency, there should be solutions to avoid them.

6.3.4.3 General Insights

One of the main insights to press on from these interviews was the type of information they had access to. They clearly had to know where to go, what item to pick and how many of it. The type of information displayed to them varied, and sometimes it was important to distinguish between shelf levels, for example. When picking clothes, size was an important informational addition, of course, and they expressed that it sometimes was nice to know the stock status of certain items beforehand.

Another very important insight from these interviews were the placement and accessibility of the information they had access to. Both of them had access to the list of items to be picked, one on a screen mounted on the cart, and the other on a paper attached to the forklift. This raises the importance of steady and continuous information provision. Providing the correct information at the correct time, seems important regardless of placement.

Furthermore, worth noting is the observation that the second order picker had to carry the digital device by hand, and place it on the forklift in between picks. While it may not necessarily be negative, it is easy to imagine not being hands-free to become problematic when lifting larger or heavier items.

Based on the fact that the second order picker had to work around cumbersome picks, we realized that it might be worth looking into providing options for order pickers to deal with situations like these.

Although it was difficult to truly grasp the environment and context in which they worked, having made the interviews over the internet, this was alleviated by the provision of the pictures taken at one of the interviewees place of work.

6.3.5 Data analysis

After each visit and interview, relevant facts, observations and interviewee opinions were extracted onto post-it notes in FigJam. Additionally, the notes were grouped in accordance to thematic analysis, resulting in themes such as sources of frustration, contextual information, ergonomics, etc.

What was important to understand for this project was the flow of actions pickers took, all from receiving a forklift to finishing an order. Therefore, user journey maps were created after each visit, or interview, in order to try to get to some general insights about the routes, where they were flawed and what about them that could be improved. An example of this mapping is displayed in Figure 6.3. This would aid in our understanding of similarities and differences between different processes.

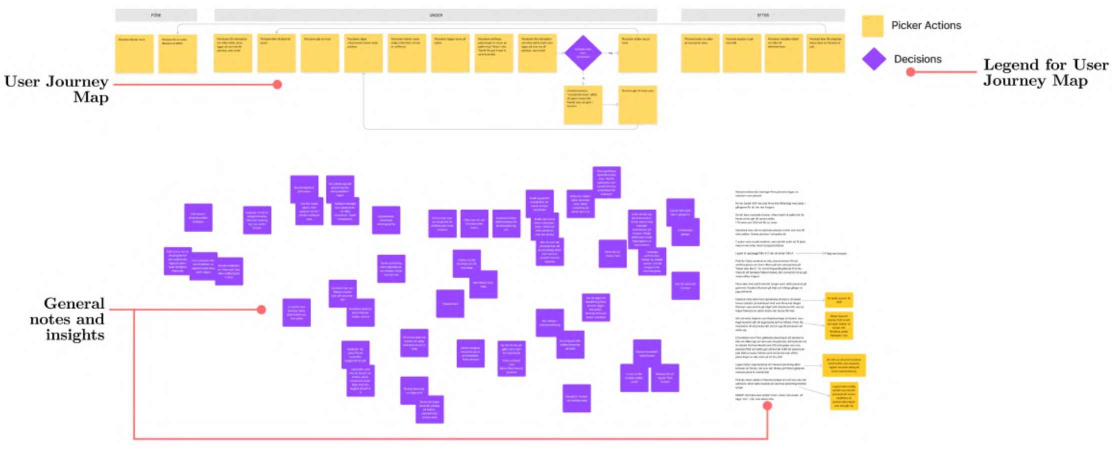


Figure 6.3: An example of how a company visit was managed.

When analyzing these different processes, we came to the realization that they are very difficult to map out in ways that highlight their differences in actionable ways, meaning that it was just as difficult to generalize the optimization of one process to another. This was due to the fact that each warehouse is simply too unique in its layout, systems and vehicles in use, as well as their major priorities as businesses.

Following this, we started to utilize our insights from the analysis of our visits and interviews to create the requirements list of essential factors for successful order picking. We noticed that the factors were more or less important to successful order picking, while some were more related to efficiency, some to ergonomics and some more related to the warehouse setup in general. For this reason, we split the list into four different categories, as follows:

1. Successful order picking, i.e. must-haves,
2. Efficient order picking, i.e. should-haves,
3. Pleasant order picking, i.e. nice-to-haves for order pickers, and
4. General insights and limitations.

This turned into what we called our *living draft* of important factors for order picking. Even though focus could be put simply on the first and second category (essentials and efficiencies), we agreed that the third category was important not to leave out. It seemed likely that pleasant order picking could have an indirect impact on efficiency through order picker retention and general health, both physical and mental. Lastly, the fourth category were unlikely to provide much basis for the planned concepts but were deemed relevant to warehouse operations in general.

Figure 6.4 displays how the requirements were informed by the insights gathered from the visits. Each color of the post-it note refers to a specific company of which the insight was gathered from. Related notes were put next to the proposed requirements, strengthening or weakening the arguments for them. This enabled us to view the requirements holistically, and understand the needs better. The entire mapping of the requirement list can be seen in Appendix A.

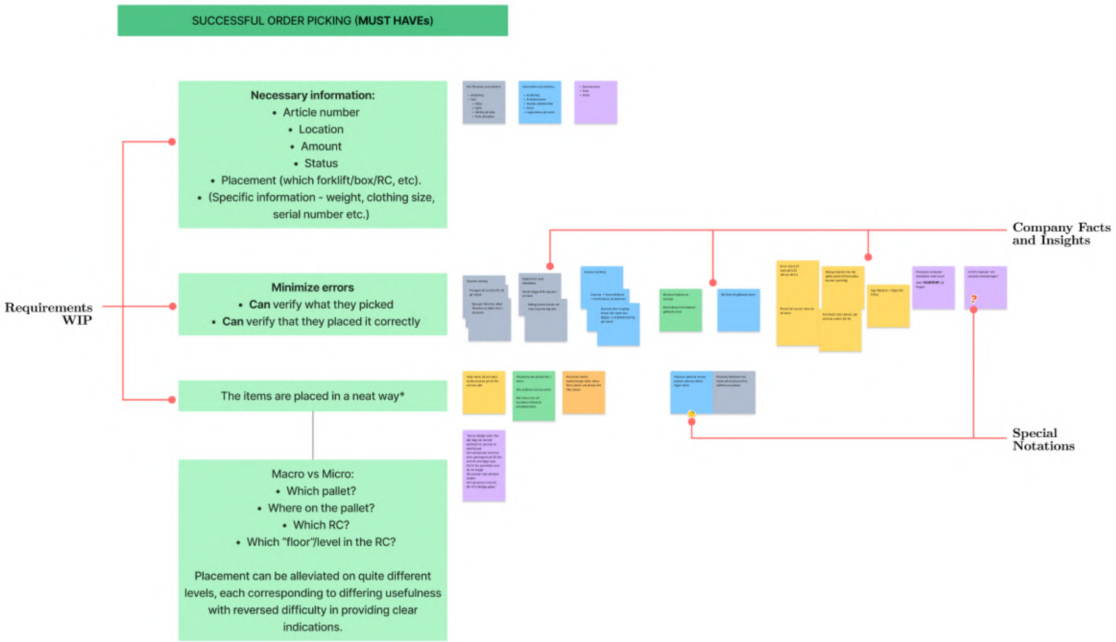


Figure 6.4: An image displaying how insights were coupled with the requirements.

6.3.6 Workshop with Toyota

The following week, we were privileged to join Toyota for a creative workshop spanning several days, investigating different concepts. We started by imagining three separate scenarios for order picking using an AGV with a mounted screen to explore in which areas and cases this might be used. The initial focus was put on whether an AGV with a screen would be useful for manual order picking, without any other auxiliary equipment. To test this, we built a forklift out of material we had at hand (pillows, stools and training equipment) and acted out a scenario of an order picker, in a walk-the-dog situation (as the one observed at Company A), see Figure 6.5.

Figure 6.5: Image of one of the authors acting out a scenario with the furniture-made truck.

The order picker were imagined to walk alongside the AGV to each pick location, pick an item and put it on the pallet and then confirm the pick on the screen. The scenario was repeated with the placement of the screen at different places on the AGV. While no specific measurements were taken, it was concluded that having to walk towards the screen was disruptive to the activity, especially when it was required of the order picker after every pick. Some placements of the screen did alleviate this activity, such as having it on the side of the AGV, facing the order picker. However, this would be problematic for two reasons. The screen would have to be indented into the AGV for it to not protrude, since that could be a source of injuries or accidents. This in turn would limit the angles with which the screen could be tilted. The second, and more glaring problem, is that even if the side-mounted screen could be used for picking from that particular side, you would need an additional screen on the opposing side of the AGV for when items were picked on that side of the aisle. Additionally, it was unclear whether it would be ergonomic to interact with a screen at the height provided by the AGV for extended periods of time, and especially so if the order picker is tall. In short, this seemed unlikely to compete with Pick-by-Voice, by any means.

Our next focus landed on exploring AGV assisted zone picking. This scenario had the most unknowns and were hypothesized to provide the best use of a screen mounted AGV. To try this concept, one of us played the role of the order picker while the rest of us were AGVs. We were holding papers indicating what to pick next, and in which order they were to be served. We devised an order beforehand and investigated how the order picker would potentially have to act in this situation.

The main insights from this activity was that the screen was useful for displaying information as long as the order picker was facing it. If one AGV had been picked to, then moved forward to the next pick location within the same zone, then the order picker would no longer be able to see the screen and find prioritizing which AGV to serve, as well as what item to serve it. Furthermore, we realized that, unless the aisles were quite wide to allow for overtaking and/or the system for optimizing the routes of the AGVs to only be served sequentially, they would get stuck behind each other. In such a case the zone picking method would have no benefit other than serving multiple AGVs in a walk-the-dog fashion, but with less order pickers, resulting in slower and less effective order picking.

6.4 Phase 3 - Final visits

The third phase would prove the most valuable due to the amount of insights we had reached up until this point. Additionally, the warehouses visited during this phase were all utilizing a Person-to-Goods process, providing the best foundation for verification of prior insights and the most legitimate basis for new ones.

6.4.1 Company G: The Paper Pickers

The next visit we managed to book was to a company with a focus on wholesale for food, groceries and restaurant equipment. They utilized paper picking with manual forklifts. For increased efficiency, each picker carried multiple orders at the same time, attached to a board across the front of the truck so it was visible while standing in the truck. Most of the trucks carried one to two roller cages, and each could be divided to support orders for up to four different customers at the same time. This meant that the pickers could sometimes pick to up to eight customers simultaneously. The warehouse manager expressed a concern for the amount of errors that occurred with the multi-order workflow, especially since each pick had to be manually verified. According to the warehouse manager, many pickers had previously worked with a scanning system, and appreciated the system due to the easy verification of picks and fewer errors as a result. On the other hand, pickers liked the simplicity of the paper picking system. Additionally, each order had to be printed at a specific station in the warehouse, which caused a bottleneck when it was crowded. These two issues combined spoke for the need for a digital solution.

The warehouse layout was sorted so the heavy and large items were closer to the printing stations. Experienced pickers, who knew the layout, statistically performed better and did less mistakes. Therefore, warehouse managers prioritized maintaining personnel, or otherwise hire experienced pickers. Furthermore, the aisles were as wide as two trucks could fit side-by-side and to conserve space, they also stored items vertically in several levels. Picking on a level higher than floor level evidently slowed down the picking process significantly, due to the raising and lowering of the truck. Lastly, due to to the tight space in the aisles, it was clear that this layout would not be able to support AGVs, especially if they collaborate with order pickers. Additionally, from the insights gathered from the workshop mentioned previously, the compact aisles would impact the AGV traffic within the warehouse, possibly counteracting the efficiency gained from the technology.

The main take-aways from this visit was:

- The capacity of paper picking is limited, and there is a clear need for a digital solution. It is clear that they would need a system for verification and confirmation of picks.
- Picking higher than floor level slows down the picking process significantly.
- It is important to be able to handle several orders at the same time.
- Scanning is effective in minimizing error rates.
- A lot of space is needed if one wishes to implement AGVs.

6.4.2 Worst Possible Idea

During this phase, we initiated an exploration of different perspectives of order picking by using the "Worst Possible Idea" approach. In its initial implementation, we posed the question, "How can we solve the issue of picking?" However, we realized that this question was too broad, lacking constraints that would enable us to focus on generating unconventional and imaginative ideas. Consequently, we decided to tweak our approach in the second iteration, framing the question as, "How can we make the order picker's experience as miserable as possible?" This revised formulation proved to be more effective in identifying potential pain points for the pickers.

We used Thematic Analysis as a method to map out the resulting ideas. Through this process, it became evident that aspects related to ergonomics and well-being could potentially pose problems. If the pickers are dissatisfied with their working conditions or encounter inefficiencies due to the risk of injury, frustration with the technology, or similar factors, the overall efficiency of the entire process is significantly impacted. This result made us analyze our visits and interviews with an increased focus on ergonomics to validate our hypothesis.

6.4.3 Company H: The Arm-Mounted Screen Solution

The first out of the three last visits was to Company H, which is a warehouse managing e-commerce items and electronics. The company uses manual trucks for handling bulkier and heavier items, and were equipped with spotlights to indicate their location, to warn other people in the vicinity. Alongside this, they were using a unique system based on Pick-by-Voice. This system uses a wearable phone attached to the picker's arm, which translates the instructions given by the Pick-by-Voice system into text format. In other words, instead of receiving the picking information through an auditory medium such as headphones, the pickers receive the information in written form on the device. This means that they maintain the same workflow as with a Pick-by-Voice system, but interact with it differently. To verify each pick, they utilize a wearable scanner, that was connected to the wearable phone. Alongside the manual picking, they utilize an AS/RS system where smaller items are handled.

What we learned was the motivation behind the unique Pick-by-Voice system was the concern over maintenance costs associated with a complete Pick-by-Voice system. This cost consideration translated to other parts of their operation, particularly regarding the fragility of the wearables they used. They reported frustration regarding the life span of the scanners, resulting in a constant search for sturdier options. When discussing future alternatives, they wished for more robust solutions. Consequently, this highlighted a different aspect of picking, namely the cost, both for integrating the solution and ensuring its ongoing maintenance.

Another challenge in their operation they acknowledged is the inefficiency of stacking the pallet. Their inventory includes items that vary in size, ranging from 75 inch TVs to small memory cards. The pickers faced difficulties in planning the pallet stacking due to being unaware of the coming items in the order until they arrived at them. If the item could not fit on the pallet, they had to transport the partially filled pallet and return with an empty one and continue their picking route. This produced significantly more unnecessary trips. Consequently, this meant that there was a need to inform the picker with necessary information that might have an impact on their picking route.

Lastly, during this visit we gained valuable insights regarding the usage of a wearable phone screen, as well as its impact on user interactions. One observation, as pointed out by the warehouse manager, was the clumsiness of the hardware. As it required touch input, the picker had to fixate their arm with their other hand in a lifted state in order to accurately press the correct buttons on the screen as well as preventing weight induced fatigue. Furthermore, it was reported that the phone was restricting the pickers' range of motion, particularly impacting their lifts of larger items.

The main take-aways from this visit was:

- The cost of implementing and maintaining picking technology is an important factor.
- There is a need for informing future picks, to aid the picker in planning.
- A wearable screen as a technology is clumsy and difficult to interact with.

6.4.4 Company I: The Minimalist Warehouse

The second of the final visits was made to a company handling consumables, work attire and equipment for businesses. They employ manual trucks in combination with a cart-mounted screen. Similarly to previous warehouses we visited, there was a strict policy that prohibited the use of headphones to keep both ears free, primarily due to security risks. In addition to this, the trucks were equipped with front-facing spotlights shining a clear light on the floor in front of the forklift. The purpose was to indicate their intentions as a visual warning to people in their vicinity.

The management expressed contentment with their current system, particularly due to its simplicity. They appreciated the added functionality that was offered by a screen, such as the ability to view previous picks or the of use buttons for functions such as label printing. The company had previously experimented with alternative systems, such as Pick-by-Voice or even AGVs. The main criticism towards Pick-by-Voice was the reliance on auditory memory which posed inconveniences for the pickers who had to memorize numerous commands and comprehend auditory information provision. Comparatively, the cart-mounted screen solution had a shorter learning curve, according to the warehouse manager. Furthermore, the management emphasized the importance of robust technology over fragile wearables, as a broken device could impact an order picker's work potential.

The primary issue found with the use of AGVs was the significant space investment required to implement the technology. Although the warehouse was already spacious, measuring aisles three metres wide, the manager expressed that even more space would be required. Expanding the floor space, as well as limiting the picks to floor level only would mean a reduced storage capacity within the warehouse. This trade-off – less items for a potentially more efficient picking strategy - was deemed not worthwhile for the company. Additionally, the manager pointed to the fact that any warehouse meaning to change their existing order picking strategy introduces a risk in terms of both time and money, and that such a shift would require a substantial investment.

The main take-aways from this visit was:

- Simple and sturdy technologies are preferred.
- AGVs require a lot space.

6.4.5 Company J: The Complete Pick-by-Voicers

Our third and final visit we made was to a warehouse managing wholesale for food, groceries and daily goods. The company utilize a comprehensive Pick-by-Voice system and relied exclusively on manual trucks for their operations. These trucks were capable of carrying two pallets simultaneously. During our visit, we had the opportunity to shadow a picker throughout a picking order, from receiving the truck to pallet delivering.

The picker initiates by receiving information about the first pick through their headphones. Additionally, the picker could receive details such as order volume and the customer specifications. This allowed them to plan the numbers of pallets to bring, as well as determine if any specific height restrictions applied. Once the pallets were loaded, the picker starts the picking order. Information about location, amount and where to place each item was given for each item.

One notable efficiency of the Pick-by-Voice system was that the picker's ability to multitask. While loading the item onto the pallet, the picker could simultaneously receive information about the next pick, after confirming the current one.

This enabled the picker to plan their next pick, while completing with the current pick, eliminating any unnecessary movements associated with receiving information. Moreover, for shorter distance picks, the picker could move the truck using buttons instead of entering the vehicle, providing additional time savings. Furthermore, the picker we observed utilized both pallets to ease the stacking of the pallet. Items with shapes which might compromise the stability of the stack, were placed on the second empty pallet to be addressed later, as seen in Figure 6.6.

Figure 6.6: An image of the pallet stacking at Company J.

There was some criticism towards the Pick-by-Voice technology. Occasionally, it would experience connectivity issues, causing the picker to lose access to the necessary information and preventing them from proceeding with their order. Additionally, it produced uncomfortable sounds as it tried to reconnect, and posed as an annoyance. Another drawback was the need to learn specific commands to interact with the system. They had to familiarize themselves with around 40 unique commands, which the picker said was a significant initial challenge starting this job. To overcome this, each truck was provided with a list of the commands to assist the picker. Furthermore, there was no ability to rectify mistakes that occurred. If the picker realized they responded incorrectly, there was no option to correct it, and would mean that the item would be dispatched with incorrect information. If the picker discovered an error a few picks later, they had no means of accessing the details of that specific pick. The system only allowed them to view the previous pick. This limitation could prove detrimental, especially in environments where a picker manages multiple different customers at the same time. As a result, we saw a potential benefit in using a graphical interface to address this issue.

Moreover, when verbally interacting with the system, the picker mentioned that they occasionally forgot what they said when verifying picks. Due to the unavailability to receive this information, it caused frustration and uncertainty, often leading the picker into making mistakes.

Regarding the picking order, the pickers expressed a desire to view the whole order beforehand. This would allow them to identify potentially difficult and cumbersome items early on, preventing difficulties with pallet stacking.

Moreover, the warehouse had previously experimented with the use of AGVs, but found that the warehouse layout could not support it due to the tight aisles. Nevertheless, the warehouse management mentioned that other facilities within the same company had successfully implemented fully automated solutions. They meant that they would prefer to transition towards a similar automation direction in the future.

The main take-aways from this visit was:

- The Pick-by-Voice technology allows for a multitasking workflow, and minimize time wasted on information transmission.
- The Pick-by-Voice technology introduces many commands that the picker has to learn, and poses as an initial difficulty.
- There is no possibility to rectify mistakes using the Pick-by-Voice technology.
- Due to the unavailability of viewing previous picks, it can cause frustration when pickers want to access detailed information about a certain pick.
- The pickers want to be able to view the whole order beforehand to allow planning of the picking order.
- Moving towards automation is preferred.

6.5 Phase 4 - Concept Design

With the list of essential factors completed as a result of the first research question, we set out to approach an answer to the second research question, *How might the resulting insights be conceptually implemented in order to innovate on manual order picking?* In this section, we will present our reasoning for choosing the design materials to be used for our concepts as well as our reasoning for each specific feature. This is then followed by our iterative design activity of research through design and lo-fi prototyping resulting in the final results, and our answer to the second research question, all of which can be seen in section 7.2, Results, Part 2: Order Picking Design Concepts.

6.5.1 Design Materials

At this point, it was clear to us that Pick-by-Voice is very efficient, as seen both at Company A and J, and it was clearly more efficient than any of the other methods and systems utilized at the other warehouses we had the opportunity to visit. It does have the clear benefit of allowing information to be provided to the picker regardless of their location, meaning that they could walk beside a pallet with seamless information provision and verification, or drive a forklift with no screen with the same efficiency. The focus becomes the next pick, and not a hunt for information. Additionally, it provides the order picker with both of their hands free for driving, lifting and a voice input system yields the freedom to wear gloves when needed.

However, some facts remain to question the certainty of Pick-by-Voice as the sole system to be used for manual order picking. The sequential nature of information provision inherent in an audio based system, receiving information about any other pick than the current one is unfeasible. Likely, it would impact the order pickers ability to focus on the current pick, or even force the information regarding the current pick out of their memory in favor of information that may not be relevant yet. Therefore, it is unlikely that a system relying solely on auditory feedback would be able to provide richer information during the picking route. This was evidently problematic at several warehouses (F and H) where reaching a picking location where the item to be picked was unsuitable for stacking at that time, which forced them to either end the route early to begin it anew with an empty pallet, or otherwise keep said item improperly (and potentially dangerously) fastened to the forklift. The same problematic unpredictability were seen and solved at Company J by bringing an additional pallet on which they could place items temporarily.

Furthermore, the sequential approach to order picking is not necessarily a bad thing; after all, only one location can be reached at a time, and driving the shortest calculated route would be the most efficient as long as no item pick may hinder the rest of the sequence. This type of optimization is, of course, almost always performed, although with differing success. The layout of the warehouse is often planned in a way that allows for heavy, large or very common items to be placed early in the route in order to alleviate the problem of encountering hindering picks. This is, however, never fool proof, as evident at F, H and J.

Furthermore, as previously mentioned, the order pickers are said to be the route experts in the end, and several managers and order pickers were positive towards the idea of them being able to customize the picking order. This was something that we wanted to experiment with, and thus decided that in order to provide the ability for order pickers to customize their order, they would need access to a screen.

6.5.1.1 Enhancing Pick-by-Voice

We saw no reason to try to compete with Pick-by-Voice. Instead, we decided to keep what works well with Pick-by-Voice and to expand on that concept further. The addition of an auxiliary screen has the potential to make the order picking activity more complex, hindering what makes Pick-by-Voice so efficient, so it was important for us to keep the flow of actions to a minimum, and to keep them contextually relevant.

As we identified benefits to add a screen to the Pick-by-Voice system, we discussed what type of screen it should be and where the screen should be placed. The discussion touched on wearable screens but ultimately disregarded them as an option due to the fact that they always has the potential to hinder lifting and physical movement. Similar reasoning were concluded regarding handheld devices; they could work, but having to pick it up and put it down, store it somewhere for such a small screen seemed unimaginative and limiting. We finally decided that there are two screens that has great potential to improve Pick-by-Voice: (1) cart-mounted displays and (2) *augmented reality* (AR) through head-mounted displays.

(1) Cart-mounted displays was chosen as one of our concepts to improve upon for several reasons. Firstly, many manual forklifts already sport a display on which our concept could be utilized. Secondly, the future of forklifts are likely to incorporate autonomous solutions in higher extent, and placing a screen on an AGV for operational and communicative purposes as proposed by our employer lends its use to enhancing order picking as well. Additionally, we wanted to experiment with how to utilize such a screen within the setting of zone picking. With this type of display in combination with Pick-by-Voice, the voice system would continue to operate at its current level, providing both voice inputs and feedback. The screen would be an extension of this system to make up for features which are unfeasible to operate purely by voice. Therefore, order picking is not to be contingent on the screen, but would benefit from its existence.

(2) Augmented Reality was chosen, however, as a means to improve upon Pick-by-Voice and the lack of simultaneous information available, and the need for auditory information provision. Hearing is clearly controversial. It is important for safety reasons, to hear a fire alarm, to quickly get someone's attention or to hear an oncoming forklift. Furthermore, we wanted to free up hearing for the order picker to allow for a more customized experience during their shifts, allowing for music or podcasts to be listened to in accordance with safety regulations instead of a voice. The efficiency of voice communication would be kept as an input medium, but due to the above reasoning, the information provision would be performed entirely through visuals.

Seeing as augmented reality as a technology is steadily improving (Makarov, 2022) and the market size expected to increase significantly (Fortune Business Insights, n.d.), as well as the potential it has for contextually relevant, and ubiquitous information provision, choosing to go forth with this system was a given.

Furthermore, as evident by the development of the industry into intelligent manufacturing as part of Industry 4.0 (SAP, n.d.) and the fact that augmented reality is the only technology as part of the fourth industrial revolution which aims to improve the HCI (Egger & Masood, 2020), this technology provided relevance not only in terms of future applications, but also academically.

6.5.2 Design Process

We began our design process by outlining what we envisioned augmented reality picking, or vision-picking, to be. We took inspiration from computer games in how certain elements are highlighted and visually presented, and we looked at existing solutions of vision-picking.

6.5.2.1 Vision-picking Competitors

Deciding to utilize AR in one of our proposed solutions, we sought out additional information regarding existing solutions for vision-picking. Three of the solutions through which AR is utilized today can be seen in figure 6.7. Picavi[2] (see Figure 6.7(A) provides information through a small window at the corner of the top right *field of view* (FOV). There, information regarding the current pick is displayed, as well as an image of the product. The pick-by-system shown here utilizes an accompanied scanner to confirm each pick. LogistiVIEW's (see Figure 6.7(B)) solution[3] mimics Pick-to-Light in their vision-picking system. Here, the order picker scans an item after which the order picker receives visual information of where the scanned item should be placed, through what they call Put-to-Light.

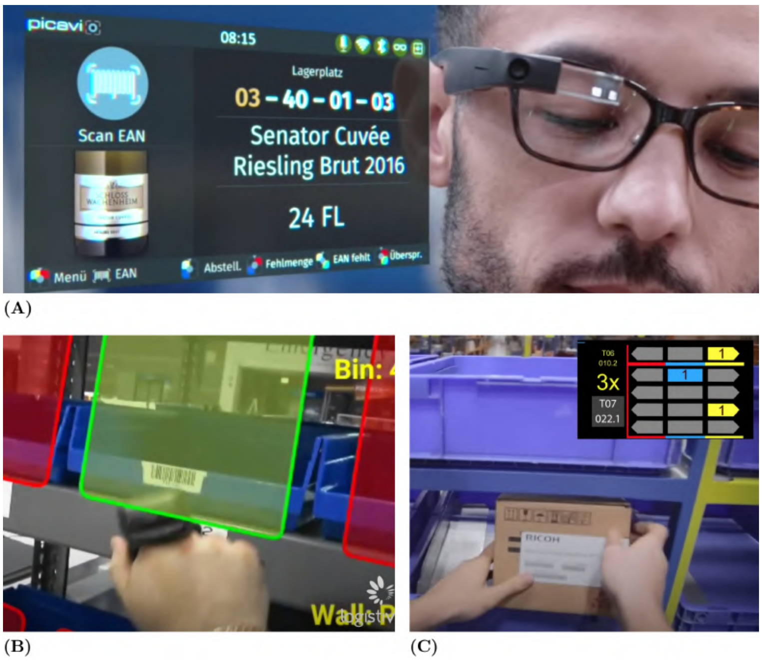


Figure 6.7: (A) Picavi, (B) LogistiVIEW, (C) DHL.

After placing the item, the box is scanned and they may scan the next item. In the third image[4] (see Figure 6.7(C)), the placements of each item is displayed in the top right corner of the right eye's FOV. The pick begins by scanning the item to be picked with the scanner mounted on the glasses. Thereafter, the display shown in

[2]https://www.youtube.com/watch?v=ePrReQhteIg
[3]https://www.logistiview.com/vision-pick-and-put-wall.html
[4]https://www.youtube.com/watch?v=I8vYrAUb0BQ

Figure 6.7(C) provides a visual guidance of where to place the items through color coding as well as vertical and horizontal mapping corresponding to the cart holding the boxes.

6.5.2.2 Envisioning Augmented Reality Order Picking

Since AR has the potential to provide both static and dynamic information, we started outlining which information should be placed where, and why. An early sketch of what the AR user interface might look like can be seen in Figure 6.8. Here, the designs revolved around the fact that the most essential information must be available at all times, namely location, quantity and placement. Therefore, we decided that it ought to be displayed statically in one of the corners of the FOV. Additionally, to aid in navigating to where the pick is located, we decided to experiment with highlighting as inspired by the visual guidance offered by Pick-by-Light; one type for the current pick, and another for upcoming picks. We argued that this would aid in planning where to go next as well as indicate how many picks are left in the current aisle. Furthermore, we argued that a picture might be useful in order to gain additional information about the product, such that the order picker can plan how to place it etc. For this reason, we also decided to include a size comparison where the item is to be outlined, here supposedly in comparison to a pallet. We eventually decided against using size comparison this way since it might be confusing as to whether it is supposed to indicate where on the pallet to place the items, which was never our intention.

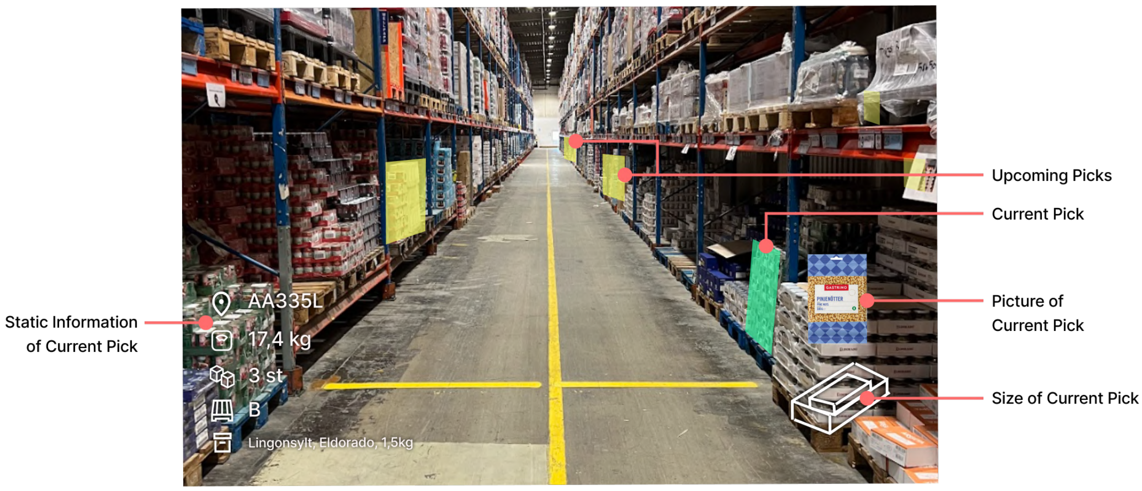
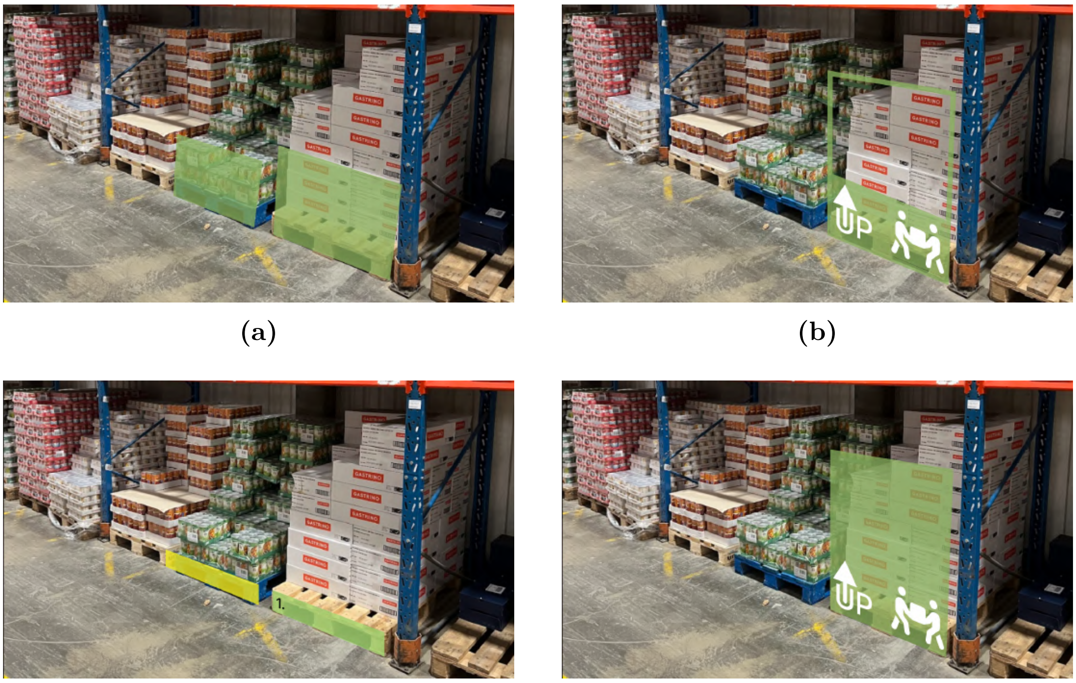


Figure 6.8: Early sketching of the AR interface.

Thereafter, we looked at different ways to display the item location once facing it, see Figure 6.9. The challenge was to clearly display which item to pick without it being obstructive. We wanted the information to be persistent to avoid any uncertainty regarding which item is the correct one, hence shrinking it so that the items are clearly visible. Figure 6.9(b) and 6.9(d) also provide an example of ways to provide information about the item being cumbersome in some ways, for example that it has to be placed in a certain orientation or that it is particularly heavy.



(a) (b) (c) (d)

Figure 6.9: Different concepts of highlight displays.

Next we decided to tackle the challenge of providing an order list overview, as well as the ability to customize and modify the order of the list, see Figure 6.10. A pick list needs to display quite a lot of information, and we quickly realized that the format of displaying this much information directly within the FOV, as well as obstructing it entirely, was suboptimal. Therefore, we decided to switch our focus to how this can be displayed on a cart-mounted display first, to then begin adapting that design to the vision-picking concept.

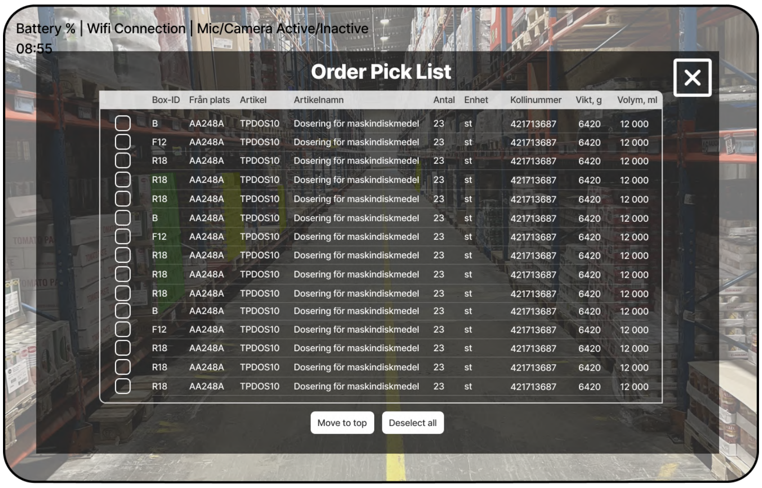


Figure 6.10: Initial design of pick list in the vision-picking concept.

6.5.2.3 Designing for Cart-Mounted Displays (CMD)

When switching focus to designing for cart-mounted displays (AGVs and manual forklifts, alike), we specifically wanted to answer two major questions: How could the pick list be utilized before the picking route even started, and how would it be used during a picking route. We imagined that preparing the route would offer slightly different interactions than during the pick route. For example, a larger focus before the route starts would be to make sure the item order is good and that no particularly challenging picks would surprise the order picker in the middle of the route. This allows them to plan for these picks either by changing when in the sequence to pick them, or when to finish up an active pallet and start picking to a new one.

Regarding changing the sequence, we bumped into a discussion of whether or not it would be worth it to change the sequence when it comes to the risk of impacting the efficiency, since driving to and back from a challenging pick might take longer than just finishing up a pick in the middle of the route and start with a new pallet. However, this would be subject for evaluation and we reasoned that the functionality would still provide useful benefits in certain circumstances. For instance, before the route can start, they may need to drive to aisle A to start the route optimally; during that drive, a short detour to pick up a large quantity of an item that would provide a good base to stack on would likely be less detrimental than envisioned above.

Additionally, in the case of picking a large item such as a TV, it might be nice to know beforehand that a 75" TV will be in this picking route, hence allowing the possibility to move the item to the end of the pick might be preferable. Knowing that the large item is coming towards the end might result in the order picker leaving enough room on the pallet to make sure that last item fits. This last example is taken from Company J where a TV would have to be fastened to not fall over, making a route more difficult to perform if the TV is early in the route.

Preparation round. This pick sequence changing feature was coined the *preparation round*, and is primarily supposed to be used before the picking route starts. This would separate the veteran order pickers from the novice order pickers, and thus allow for a more competent system in the right hands. The knock-on effect of this is that the data collected over time by the *Order Management System* (OMS) about the modified sequences may be used to change the layout of the warehouse in a way that suits more order pickers.

When modifying the order of items, we argued that it might be useful to see the same type of additional information as was presented in figure 6.8 regarding product type and size. This would provide more information regarding each pick which would alleviate the job of discerning the difficulty of the pick. This train of thought sparked the idea of a feature to automatically identify which picks are likely to be especially cumbersome. Taking into consideration the weight, size and whether the picks must be facing upwards, for instance – information that the OMS provides – the feature coined *Outliers* came into being. Outliers would be a part of the preparation round interface to highlight and flag certain rows which might prove especially challenging. Along with this came the addition of the "Attributes" column for allowing this information to be visible for each item. See Figure 6.11 for how this interface was taking shape.

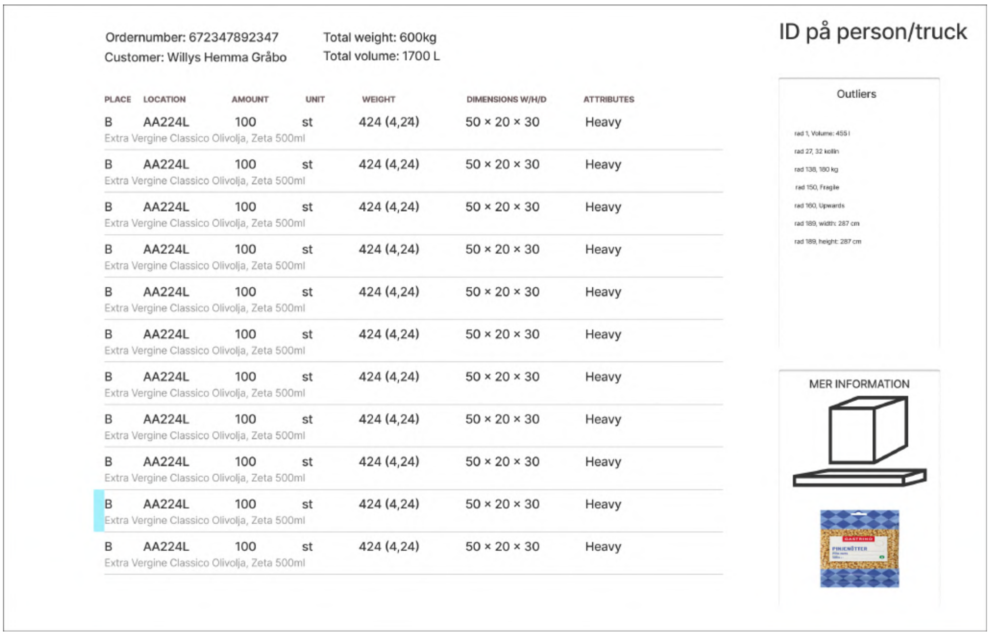


Figure 6.11: Early iteration of CMD interface, including Outliers.

6.5.2.4 Flexibility and Versatility of the Interface

Considering the potential for utilizing the screen on different types of vehicles, from manual to automated, and in different picking methods, such as Walk-the-Dog or Zone Picking, we realized that all of these might demand different informational foci. As the CMD concept is planned to be used together with Pick-by-Voice, we set out to provide a conceptual interface which could provide adequate information regardless of method, vehicle or combination thereof. We argued that the most relevant time to be utilizing a special interface were during zone picking, and modified the original screen slightly to accommodate the nature of picking in zones. Therefore, two screens were designed for CMD usage and can be seen in Results, Concept 2: CMD Interface 7.2.2.

6.5.2.5 Adapting the CMD Interface to AR

With a close to finished design for CMD, we went back to adapting the information from that interface into one for AR. A few sketches were drawn outlining some potential solutions. They also served as a way to try to assess what is needed from this point on as well as how interactions could be designed, see Figure 6.12.

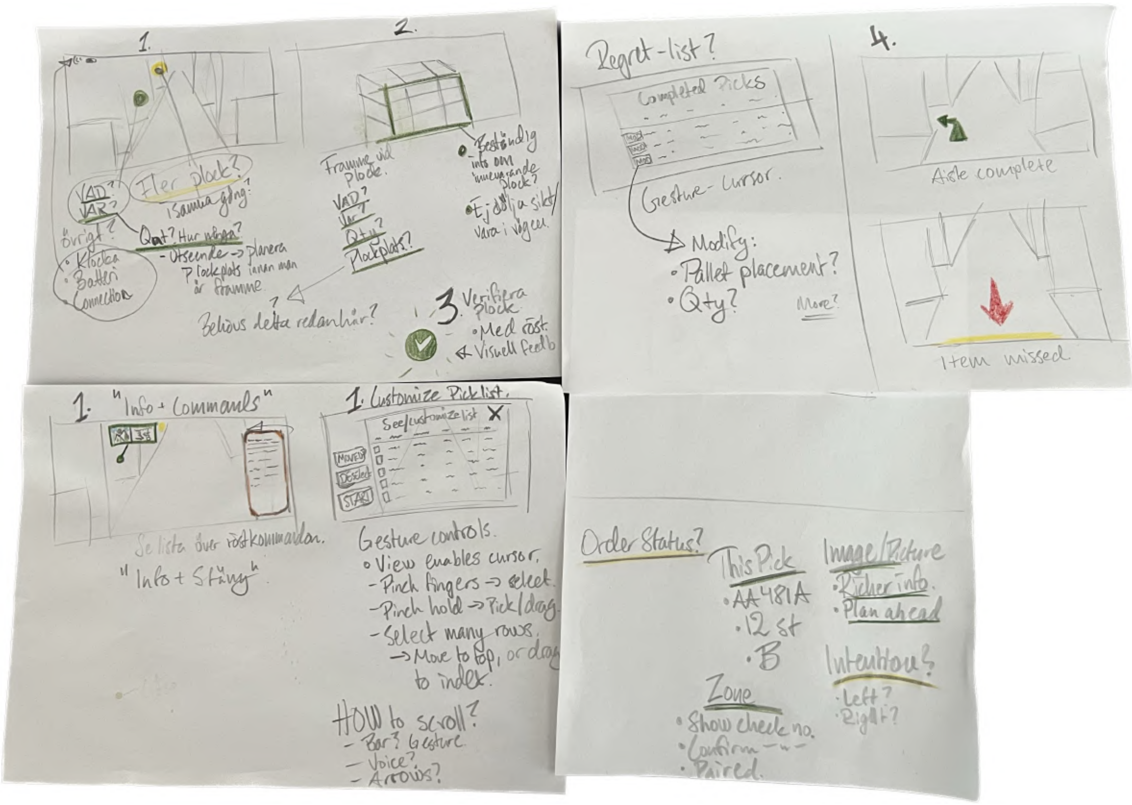


Figure 6.12: Pen and paper sketching of potential AR solutions.

Gestures. One imminent question arising from this was how to provide controls over a list of items which is only seen virtually. As one of us had experience with utilizing *Virtual Reality* (VR) where hand gestures can be utilized, this felt like a reasonable way to allow interacting with a list without having to carry peripheral devices. Meta provides gesture controls through pinching the index finger and thumb[5], which may be quite sufficient for this purpose as well.

[5]https://www.meta.com/sv-se/help/quest/articles/headsets-and-accessories/controllers-and-hand-tracking/hand-tracking-quest-2/

Commands. Pick-by-Voice, to be utilized for uttering commands to this interface, is the main way of interacting. During one of the visits, we got to see a cheat-sheet of the commands available to the order pickers (see Figure 6.13 below). This yielded some insights into which commands would be reasonable to integrate in this new interface. It also provided the valuable insight about the fact that such a cheat-sheet was necessary in the first place. This led to the inclusion of such a list in the interface, but also the conception of *voice buttons*. These would afford both pressing through gestures as well as simply speaking the text on the button.

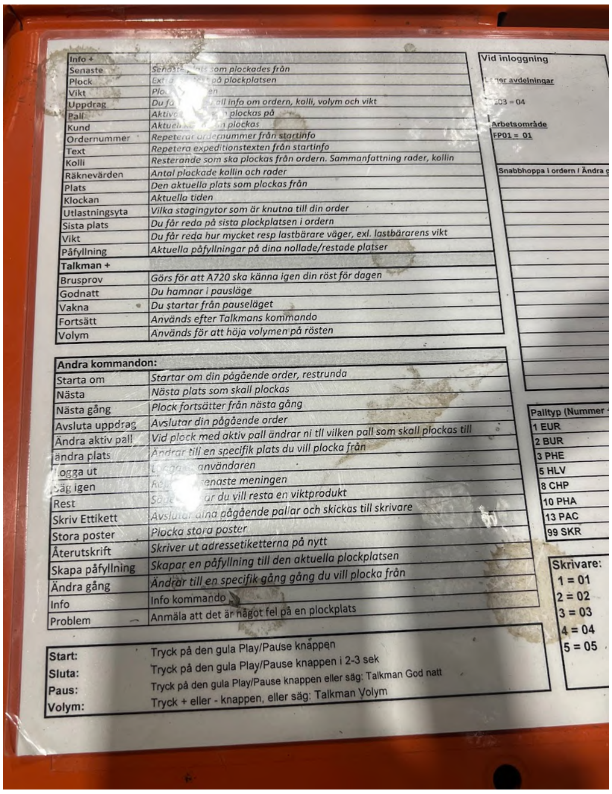


Figure 6.13: Pick-by-Voice commands available to order pickers at Company J.

Interface Layout. As evident from before, fitting the pick list interface in the order picker's FOV was challenging for several reasons. Since the environment in which they work may present dangers in fast moving forklifts, it was imperative not to obscure their vision at any point.

The inclusion of technology for allowing gestures was argued to be able to provide additional functionality. One such functionality was to involve displaying the palm of your hand to bring up the list interface, see Figure 6.14, (A). This was argued to provide the order picker with the ability to bring up the list at any point, and would allow for them to just as quickly stop viewing the list by lowering their hand again. The major problem with this concept would be that they are no longer completely hands-free, a highly valued feature.

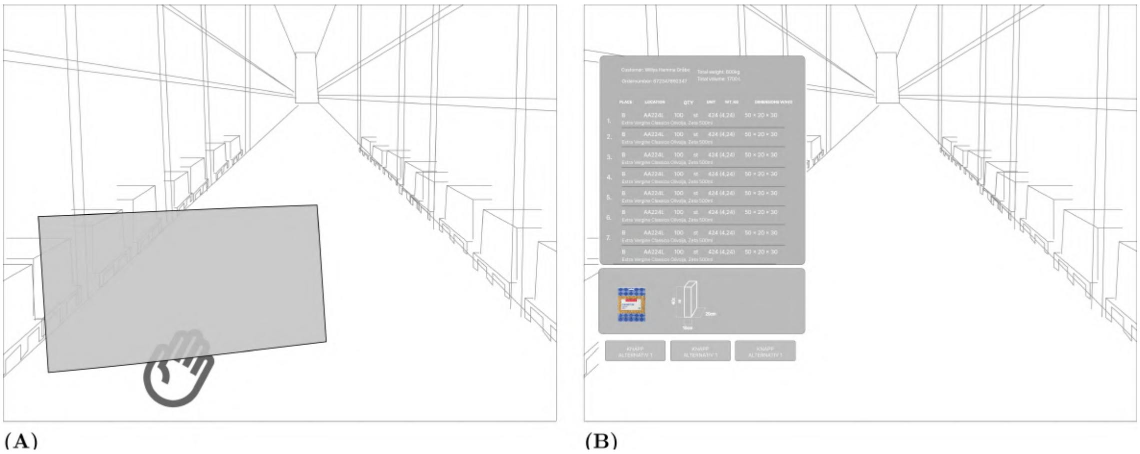


Figure 6.14: (A) Concept sketch of palm up interface. (B) Mockup of interface statically placed leftmost in the FOV.

The next iteration saw the placement change to the left side of the interface in a static manner, see Figure 6.14(B). This was done mainly due to the importance of being hands-free. It would also allow for visibility in the middle of the screen. The problem with this view, we speculated, was however related to peripheral vision and the dangers inherent to that. Furthermore, the multi column list may not be properly displayed in such a narrow portrait mode.

We came to the conclusion that regardless of where the order picker is standing, and what they are doing, they need clear vision of their surroundings at all times. Furthermore, many order pickers are already used to looking at a screen mounted on their forklift, placed in the bottom of their FOV. We wanted the list to be able to provide ample information horizontally, so a wide list would be needed. The list should disappear instantly should danger present itself. The order picker should also be able to glance at it regardless of their location, stationary or in motion. Thus we decided on an interface where the list is placed at the bottom of the screen. It can be opened with voice, and closed with both voice and gestures. The behaviour we wanted to emulate was inspired by the map interaction in the computer game Minecraft (see Figure 6.15). Here, the map can be viewed either in its entirety (A) or as held lowered in the FOV (B). The difference with our concept is that the order picker can choose the perspective of the interface simply by tilting their head forward, making the interface take up more and more space in the FOV depending on how much they tilt. When they look straight ahead, the interface would still be there for them to glance at, and tilt for a better view, but would be mostly out of view when they need to focus on their surrounding environment.

Figure 6.15: (A) Minecraft map in full view. (B) Minecraft map lowered to allow for vision of surrounding environment.

This would emulate how a screen is viewed on forklifts today, while still providing the list interface to be brought with the order picker regardless of their positioning on the forklift or in the warehouse.

6.5.2.6 Error handling

The final piece of the puzzle was to not only allow the order pickers to change their order lists, but to change their actions and rectify any mistakes. As we learned during a visit (J), it was (1) difficult to remember what has been said during voice-picking, and (2) very difficult to change what was said and done once the mistake was a fact.

In order to alleviate this problem, the voice-commands and the expected information related to the pick would have to correlate. If the order picker provides confirmation that the pick has been done to pallet B, then the system would either confirm or deny the correct placement to the pallet, depending on whether pallet B was the goal placement. Furthermore, it should be clearly visible to the order picker, without cluttering the interface, whether this correlation is valid or not. That is, whether the pick has been completed successfully or if there is a mismatch in the expected pick information and the information received by the system.

To solve both the first and second aspect raised above, we introduced a voice log. This log would be displayed somewhere on the screen and provide information about what has been recorded by the system, as well as provide information regarding whether the pick was successfully completed or not. A mismatch would count towards an error in the system, and should be easily corrected then and there; a principle of high importance as an item placed in the bottom of a pallet is practically impossible to change in a later stage.

This voice log would save and display each recorded command uttered during that pick. Anything not recognized as a valid command or valid information regarding the pick would not be recorded.

6.5.2.7 Vision-picking and AGV assisted zone picking

To address the potential for allowing zone picking to be utilized with vision-picking and AGVs, an example of communicating the status of incoming vehicles were produced. As seen in Figure 6.16, four color coded status highlights were introduced.

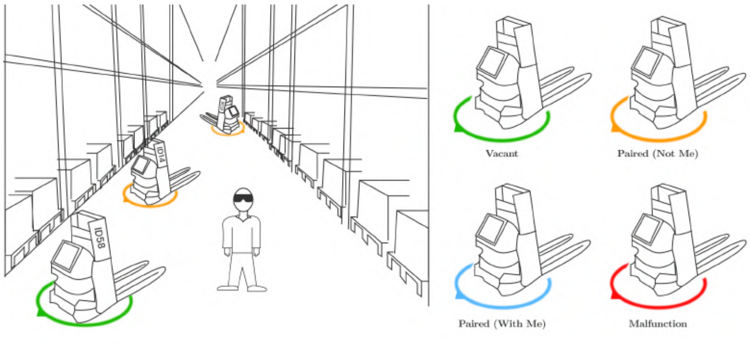


Figure 6.16: Status highlights within the context of AR and AGV.

The colors are supposed to communicate the following:

- Green: Vacant, meaning it is free to be paired with.
- Orange: Paired with another order picker.
- Blue: Paired with the order picker, from their own perspective, and
- Red: Malfunction.

This was later iterated upon to eliminate a color in favor of clearer communication with the addition of symbols, as can be seen in Figure 7.6 in chapter 7 Results.

The initial inspiration for this visualization comes from computer games, where circular highlights are often used to display information such as targeting and hostility, for example. See Figure 6.17 for an example of this from the computer games Old School Runescape[6] and World of Warcraft[7].

[6]https://oldschool.runescape.com/
[7]https://worldofwarcraft.blizzard.com/

(A) (B)

Figure 6.17: Circular highlighting in (A) Old School Runescape and (B) World of Warcraft.

7

Results

In this chapter, the final results of the thesis will be presented and described. The chapter will be divided in two main sections, each corresponding to our two research questions. The first part will describe the list of essential factors for successful order picking as a result of the continuous data gathering activity. The second part will consist of two concepts for potential order picking systems as proposed by us, based on the list of essential factors.

7.1 Part 1: Essential Factors for Order Picking

The list of essential factors as collected through visits, observations and interviews, is our initial answer to the first research question, *What are the essential factors for successfully performing the activity of manual order picking?*

The list of essential factors is divided into four categories:

(1) **Successful order picking**, which describes the vital factors for activity completion.
(2) **Efficient order picking**, which describes the factors which may impact the efficiency of the activity, and thus should be considered.
(3) **Pleasant order picking**, which describes the factors which may directly or indirectly impact efficiency and task completion from the perspective of the order picker with their well-being in mind.
(4) **General insights and limitations**, which describes insights we found throughout our thesis which may or may not directly relate to order picking, but may still be relevant to consider for warehouse management.

Please note that while the lists below are numbered, it is not necessarily the case that they are numbered in terms of descending importance. The full list can be seen in Appendix A.

7.1.1 Successful Order Picking

The list of factors that are vital to completing the activity of order picking is short, yet invaluable.

1. Successful Order Picking (Must-Haves)

(1.1) The order picker needs sufficient information:

- Location
- Quantity
- Placement

(1.2) The order picker needs to be able to verify each pick.

(1.3) The order picker needs to be able to place items neatly.

(1.4) Ability to correct mispicks and errors.

(1.1) The order picker needs sufficient information: Location, Quantity & Placement. The first requirement relates to the basic information that is needed for a manual pick to be completed. The three sufficient and necessary pieces of information for order fulfillment was identified to be location, quantity and placement. The location relates directly to each item with information about aisle, aisle placement and shelf level, such as AA248A, which would correspond to the aisle ("AA"), aisle placement ("248") and level from the floor ("A"). The order picker also needs to know how many items to pick, hence the inclusion of quantity. Finally, placement relates onto which pallet or compartment to place the items after picking them. This information may be left out when performing single order picking with a single pallet or bulk compartment for later packaging, but these instances were deemed as rare occurrences as this is rarely the most efficient way of completing order fulfillment.

This is the least amount of information necessary for general usage of any system, but the information must necessarily have the potential for expansion with additional attributes, such as size, weight or serial numbers (such as at Company H) in cases where these are necessary for completing the pick.

(1.2) The order picker needs to be able to verify each pick. The second requirement relates to order pickers' ability to verify each pick. By providing order pickers with the opportunities to confirm and/or otherwise verify that each pick has been performed correctly by taking the correct item, the correct amount and placed it correctly, you also provide a level of certainty into the process which is vital to success.

(1.3) The order picker needs to be able to place items neatly. The third requirement relates to the order pickers ability to place, and stack, items neatly. This might not necessarily impact the work performed by the order picker directly, but an unsuccessful stacking of large and heavy pallets does pose the risk of damaging the plastic wrapping during the eventual transportation from warehouse to customer. Additionally, improperly stacked pallets may risk falling over, injuring people, or at the very least the products to be shipped. These risks were deemed high enough that proper stacking of items is of vital importance.

(1.4) Ability to correct mispicks and errors. The final requirement relates to the fact that order pickers inevitably makes mistakes, and should be able to correct them. It is most often possible to correct errors made by order pickers after the fact, but it often requires significant effort. For example, at Company J, the order pickers could go to the warehouse inventory management after their route was finished and report the mispick. However, this was almost never done since most of their orders were going to the same customer. The problem, however, was transferred to their customers who often customizes their orders such that when unpacking the pallets, the items stacked on each pallet will be relevant to unpack in a certain part of the store, for example. This would result in them having to potentially travel to unpack some items which would be better placed on another pallet in the same order. More problematic are the mispicks at Company H, where mispicks could constitute quite expensive wares, such as computers, TVs, etc.

Regardless of what harm or cost an error may pose, an incorrect pick does not constitute a successful pick.

7.1.2 Efficient Order Picking

While the previous list items might be vital for success, these might be considered vital for efficiency in the order picking activity.

2. Efficient Order Picking (Should-Haves)

(2.1) Access to clear and relevant information at all times.

(2.2) Minimization of additional actions and movements.

(2.3) Ability to customize pick lists.

(2.4) Access to easily retrievable items.

(2.5) Ability to easily verify the pick.

(2.6) Intuitive systems with simple learning curves.

(2.7) Ability to easily place items neatly.

(2.8) Ability to easily correct mispicks and errors.

(2.1) Access to clear and relevant information at all times. The first requirement relates to the ability to always have clear and contextually relevant information available. An expertly built system as an example of this is Pick-by-Light as utilized at Company C. The only information provided was a light shining at the item to pick, which goes out when the item is picked. Furthermore, having contextually relevant information, i.e. limiting the information available at certain times, may serve several purposes. For one, at G, H, I and J, the order pickers were observed driving the forklifts quite fast. Displaying too much information in such a case might pull their attention from the driving which might lead to accidents. Lastly, having to sift through large amounts of information is likely to take longer than smaller, directly relevant pieces of information, impacting efficiency directly. This was evident at Company G, where several simultaneous paper lists were competing for the order picker's attention.

An additional example was at Company H, where they received information about quantity of the items by displaying each item ten times on separate rows, instead of displaying one item with the quantity of ten instead.

(2.2) Minimization of additional actions and movements. This calculates directly into increased efficiency. This can relate to how the information is presented to the order picker. Putting down and picking up a digital list in order to lift bulky items, as seen in Company B and F, are examples of superfluous actions. Similar arguments can be said regarding stationary lists such as cart-mounted displays or paper lists fastened to the truck. Should several picks occur within a small vicinity, having to check the stationary lists between each may diminish efficiency.

Furthermore, at Company H, the confirmatory actions required several button presses which could clearly be optimized to save time.

(2.3) Ability to customize pick lists. Order pickers should be able to customize their pick lists in order to avoid having to take detours or pick fragile items before heavier items, which might impact stacking stability. Even though order picking lists ideally should be, and most often are, algorithmically optimized through the *Order Management System* (OMS), the optimization is never perfect. Several companies (G, I and J) expressed how pickers do know best when it comes to item prioritization, and several reacted quite positively when queried regarding the option for order pickers to modify their pick lists on demand.

List customization (2.3) also ties into (2.7) and (1.3), both of which relates to neat item placements.

(2.4) Access to easily retrievable items. Being able to easily retrieve items improves efficiency when contrasted against difficult placements. Examples were seen in several warehouses where the item locations were almost empty, leaving only a few items which was difficult to reach, and required ducking. Additionally, when needing to pick from the second level up from the floor, efficiency was clearly diminished due to longer time per pick.

(2.5) Ability to easily verify picks. Verification should be quick and easy. As evident from the use of Pick-by-Voice, the flow of information integrates verification of said pick and immediately provides information about the next pick. However, one order picker (J) expressed wanting for an improvement on Pick-by-Voice since it was difficult to get certain information about previous picks.

(2.6) Intuitive systems with simple learning curves. The pick-by-systems in use should be intuitive and provide a simple learning curve. This is especially true when order picker turnover is high, since training drains efficiency.

(2.7) Ability to easily place items neatly. Lastly, it should be easy to place items neatly on the pallet. As observed by the visit to Company J where the order picker were able to bring two pallets, while picking only to one at a time. They chose to utilize the empty pallet to bring certain items with them until the items could be stacked better, they then moved the items to the correct pallet and were able to stack neatly. Many order pickers may not have this luxury, whereupon customization of the list (2.3) prior to the start of the picking route could yield better efficiency in their cases.

(2.8) Ability to easily correct mispicks and errors. As a continuation of (1.4), it should not only be possible, but easy to correct mispicks and errors. By providing contextually relevant and intuitive ways to understand the problem and correct it quickly, this option may provide higher efficiency as a result of fewer errors.

7.1.3 Pleasant Order Picking

These factors were identified as important from the perspective of the order pickers themselves. Not all of the following items are easily managed, but may provide value indirectly when properly managed.

3. Pleasant Order Picking (Nice-To-Haves)

(3.1) Minimization of frustration through:
- Trustworthy equipment.
- Clear information.
- Meaningful interactions.

(3.2) Ability to control or adjust sound and/or noise.

(3.3) Minimizing task monotony or offer task variability.

(3.4) Access to adequate lifting ergonomics and equipment.

(3.5) Access to choice of transportation.

(3.1) Minimization of frustration through: Trustworthy equipment, Clear information & Meaningful interactions. The first point regards mental ergonomics through minimization of frustration. One source of frustration is faulty equipment, as described at J. They experienced spots in their warehouse where their Pick-by-Voice systems could not connect to their Wi-Fi, providing them with an unhelpful beeping sound until the connection was re-established. This drives frustration and drains the attention of the order picker. Furthermore, aside from the cost of changing out equipment that breaks or wears out, providing equipment that is reliable and robust should be considered in order to provide a reliable working environment.

At Company H, unclear information provision lead to frustration. Their system provided information about quantity by displaying the same item ten separate times, instead of displaying that ten of said item was to be picked. The problem was exacerbated by an interface that forced a button to be pressed several times, allegedly entirely redundantly. These two sources of frustration were compounded when combined, and should be pruned from any process.

(3.2) Ability to control or adjust sound and/or noise. We believe that it would be beneficial for order pickers to be able to control and adjust sound and noise. Every warehouse we visited displayed the want or need for music or podcasts during the order pickers' routes. At Company H, the order pickers managing the AS/RS system only worked for shorter periods due to the high sound volume. Whether due to the monotonous nature of order picking or the sound pollution inherent to warehouse settings, this is an area which could be improved.

(3.3) Minimizing task monotony or offer task variability. Monotony is inherent in manual order picking, and it may be difficult to change. However, many order pickers (at C, G and H) expressed frustration and found it tiresome to listen to the same voice all day when utilizing Pick-by-Voice, something that could be improved.

(3.4) Access to adequate lifting ergonomics and equipment. Many order pickers have to lift heavy or otherwise cumbersome items at times (observed at B, E, F, and H). Company E had a magnetic lifter for some heavy lifts, which is an approach to alleviate this problem. One order picker mentioned that they could ask a colleague for assistance (H). This was, however, seldom utilized.

Gloves were offered at all warehouses in our sample, but most order pickers rarely used them, and one (J) mentioned the summer heat in the warehouse made using gloves unbearable. However, the same order picker mentioned that they preferred to use gloves, especially when handling cardboard packaging as the material had a tendency to cut into the skin.

Two warehouses (A and H) had quite spacious pallets to pick from, which allowed the order picker to move in between each item location to have a better lifting position, especially when the stock was thinning out and the items were placed far from the aisle.

(3.5) Access to choice of transportation. Being able to access different types of vehicles would provide the opportunity for each order picker choose their preferred picking method. At Company A, the order pickers were allowed to choose between manually driven forklifts and AGVs. Those who enjoyed driving manually could have that luxury while those who preferred walking next to an AGV could walk up to as much as 20 kilometers per day. One order picker (F) we spoke to expressed especial liking towards driving forklifts, while another (J) found none of that excitement; they did however really want to try walking next to an AGV, something they didn't even know existed before queried about it.

7.1.4 General Insights & Limitations

This final list consist of insights which might be relevant to consider for warehouse management in general when it comes to decisions about processes, optimization and choice of systems.

4. General Insights & Limitations

(4.1) Warehouse setups are unique, complex and dynamic.
(4.2) Piece rate salary may impact error rate/efficiency/etc. substantially.
(4.3) Order picker turnover may negatively impact efficiency.
(4.4) Picking one level up slows down the route significantly.
(4.5) AGV usage is highly dependant on context and environment.

(4.1) Warehouse setups are unique, complex and dynamic. The combination of warehouse layout, managed items, methods, systems and equipment leads to unique and highly complex problem spaces for each company. This multitude of contingencies makes pinpointing general points of efficiencies difficult and needs to be done at a warehouse specific level. However, this sheds light on the potential need for future systems to provide high flexibility in their services.

(4.2) Piece rate salary may substantially impact error rate/efficiency/etc. Some companies offered monetary bonuses for more picks per hour. One company (G) even provided a flat bonus when no errors and mispicks were made. Some companies shied away from these kinds of incentives altogether, afraid of what effect it would have (B, J). It is easy to imagine what effects these policies might have. Providing money per item picked may lead to more errors, which may net the order picker more money but hurt the company. On the other hand, providing bonuses for less errors may benefit the company image and customer retention, but may result in lower efficiency overall. It is beyond us to provide any recommendations on this, but the subject seems to be controversial within the business.

(4.3) Order picker turnover may negatively impact efficiency. Most of the companies visited valued order picker retention highly, and especially regarding veteran order pickers. Veterans are better at optimizing the picking list than new hires (G), which allows an order to be fulfilled more efficiently. Furthermore, new hires require some training time to get up to speed, and depending on which pick-by-system in use, from the more intuitive Pick-by-Voice system to the more labor intensive and manual list picking systems, training time will vary as a result.

(4.4) Picking one level up slows down route significantly. As observed at several warehouses (D, G, H, I & J), order picking involving even just one level up from the ground floor slows down the route significantly. This was due to having to raise and lower the forklift, often while holding an item which may or may not be cumbersome to carry, and then leaving the forklift to place the item, to then again enter the forklift. Keeping all manual order picking activities on the ground floor would be a general recommendation when possible.

(4.5) AGV usage is highly dependant on context and environment. Some warehouses had quite narrow aisles (G, H, I & J) which may prove challenging when implementing AGVs because of the inherent safety radius they require. Furthermore, combining AGVs and manual forklifts within the same zones may provide additional challenges since the AGVs move quite a lot slower than manual forklifts. This would hinder the flow of traffic and likely reduce the overall efficiency. One company (H) would like to try using AGVs for automatic replenishment.

7.1.5 Summary

The lists above and their accompanying reasoning are the results of our visits, observations and interviews with warehouse managers and order pickers. While it is clearly difficult to generalize findings from one warehouse to another due to the complexity of each unique setup, there were several important findings upon which to base the following concept proposals.

7.2 Part 2: Order Picking Design Concepts

This section will describe the design concepts resulting from utilization of the list of essential factors for order picking as described in Part 1 as well as general insights gathered from our different data gathering activities.

The following are the resulting answers to the second research question, *How might the resulting insights be conceptually implemented in order to innovate on manual order picking?*

7.2.1 Concept 1: Vision-Picking

The concept for vision-picking include two different modes; (1) picking mode and (2) list mode. Picking mode (see Figure 7.1) is the state where the order picker will receive all the relevant information needed to complete each pick, while keeping the interface as clean as possible. Most interactions in this mode will be made using voice commands, but unlike Pick-by-Voice, the order picker will receive no information through audio. The list mode is the mode where an order can be modified and customized to the order pickers liking. This mode provides all the information relevant to the entire order, including the information provided during picking mode, albeit somewhat differently.

As the main mode for interaction for this proposed concept is through utilization of the voice, there are elements which are coined to be called *voice buttons*, effectively constituting a button with their inherent affordability (Norman, 2013) with the voice command to be used in order to activate the button. The secondary mode for interaction is gestures which alleviate the activity of modifying the order picking list. Gestures can also be used to press buttons within the interface.

7.2.1.1 Picking Mode

This view (see Figure 7.1) provides the three established essential factors (see requirement 1.1)) regarding the current pick, as well as the name of the product, a picture, and any additional attributes important to the specific item, such as fragile or orientation requirements, etc. The information is displayed at the location where it will be relevant, namely at the place for the next pick.

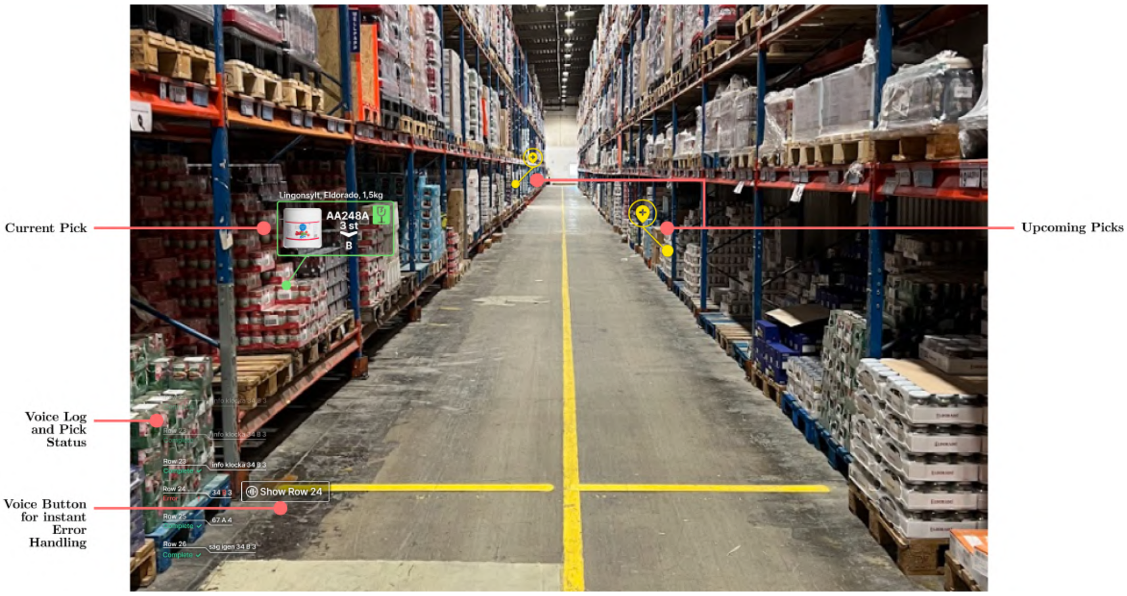


Figure 7.1: Concept illustration of picking mode active.

Yellow markers will be shown to indicate upcoming picks to allow for planning of where to drive or walk without the need to process the number of the aisle location. As soon as a pick is completed, the next pick in line will become active, changing the yellow marker into the green with the relevant information.

Seen in the bottom left of Figure 7.1 is the voice log. This system will provide the order picker with continuous information regarding the registered commands in the near past. This list will also provide visual confirmation regarding pick status, yielding instant feedback for completed picks as well as display when there is a mismatch between the registered command and the order, suspecting a mispick or error. This instantaneous feedback for errors is accompanied with an option to just as quickly rectify any mistakes. This is done via the voice button which becomes available as soon as an error has been recorded.

Activating the voice button for error handling opens up a box in the bottom middle of the *field of view* (FOV) (see Figure 7.2) which provides information regarding the error in question, as well as the possible actions. These actions affords the following actions:

- *Ignore*: Removes the error entirely from the list. This action should be used if the system incorrectly records a mismatch in the system, or when the error is not possible to rectify.
- *New Place*: Provides the ability to choose a new place for the picked item, should the placement be incorrect.
- *New Count*: Provides the ability to update the said amount.
- *Rest*: If the error is in regards to too low quantity, this option is available. Choosing this will add the rest of the items to the rest round, which is an

additional round occurring after the original route to pick up items which were unavailable before.

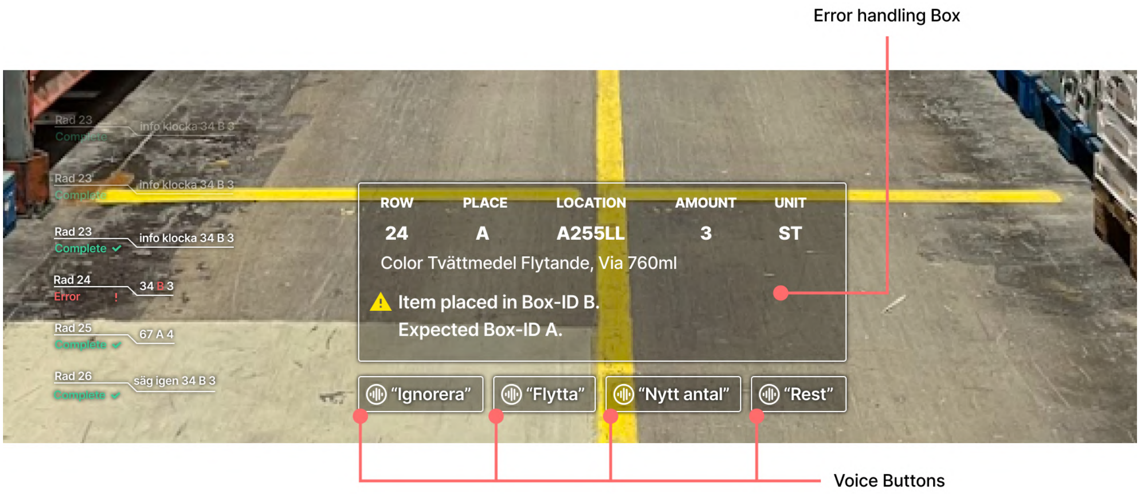


Figure 7.2: The modal view after requesting to view the error.

When the item to be picked is not in the FOV the information box will be placed in the bottom middle of the FOV. An arrow indicator will guide the order picker to the location of the pick relative to where the order picker is looking. See Figure 7.3.

Figure 7.3: Order picker view when pick location is out of view.

7.2.1.2 List mode

The list mode (see Figure 7.4) provides all the relevant information regarding the entire order. The bottom of the list interface house the voice buttons. The button *Show Row #* is the command for selecting a row and viewing the additional information about it available in the far right of the interface. The *Outliers* are located directly above it to provide ease of access to show the relevant potentially challenging picks.

The *Modify* button will unlock the list items, presenting the order picker with the ability to move around rows into new positions. Moving rows would be performed using gestures through directing a cursor by moving the hand and pinching to grab, hold to move and let go of a row in a new location. A signifier (Norman, 2013) for movability through the use of three horizontal lines at the end of each row will become visible when entering the *Modify* state (not visualized here although displayed in Figure 7.7). Additionally, the voice button *Commands* can be accessed to switch the view of the list to instead display all available voice commands.

Furthermore, the current selection is marked at the beginning of the row. The selection defaults to the current pick unless another row has been specifically requested.

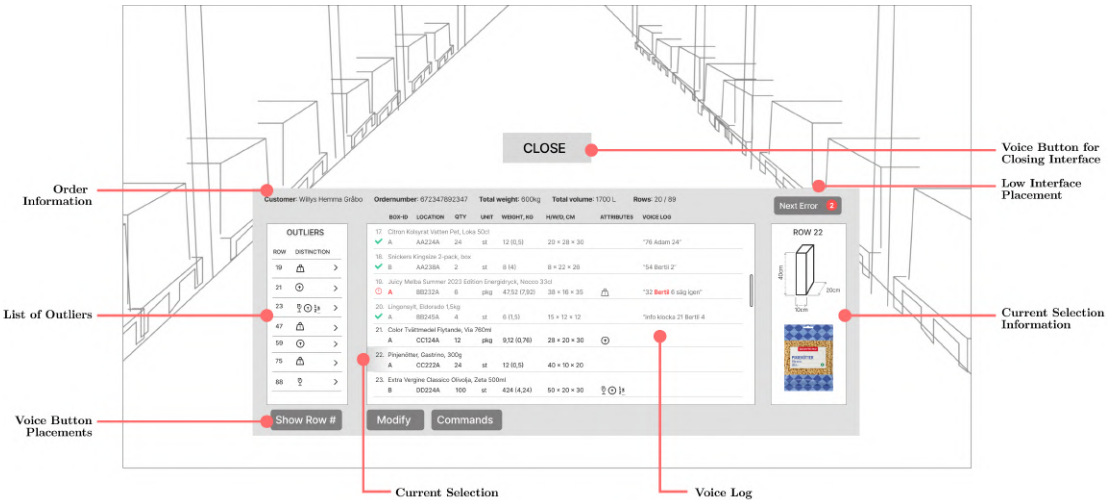
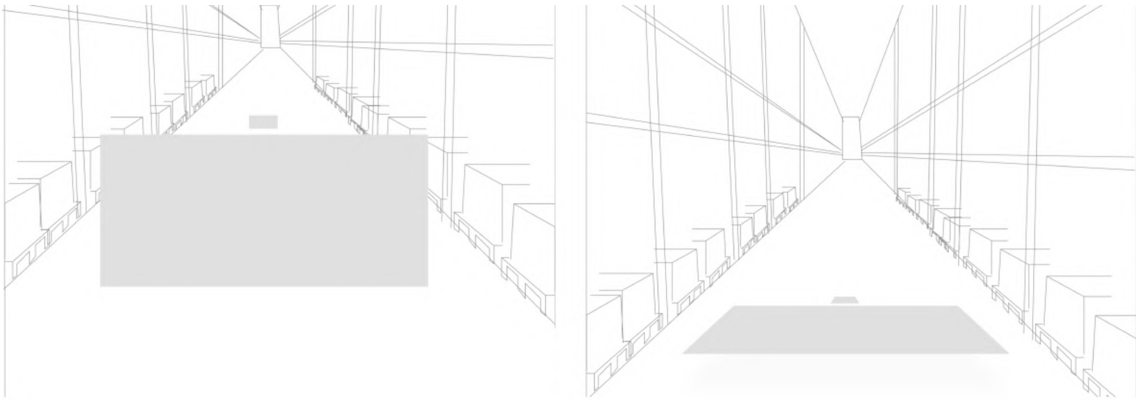


Figure 7.4: List mode interface.

Completed picks, successfully or not, are signified through a slightly lighter coloration of the information. Along with this change, the status of the completion as successful or not are marked with a green check mark or a circled exclamation point. The latter is accompanied with the information which the system deemed incoherent, resulting in the identification of said error. Management of errors would be performed by selecting the row, presenting the same voice buttons for rectifying the error as presented in Figure 7.2 although within this interface. An example of this can be seen in Figure 7.8, depicting the same behaviour within the CMD concept.

Error management, furthermore, is facilitated through the use of the recorded voice lines, available in the *Voice Log* column of the list. The information which deviates from the expected values will be highlighted in red for ease of identifying the problem. Additionally, a voice button for error management is presented in the top right corner of the interface, displaying the number of presently existing errors. The voice line "Next Error" would instantly select the most recent error in the list for instant rectification.

The behaviour of the interface, as depicted in Figure 7.5, allows the order picker the same list information provision as a screen on a forklift would. This is done through tilting of one's head. Tilting it down, as the order picker would to view the screen on a forklift, would simultaneously raise the interface to make it more visible. Tilting the head back up to a forward facing view would lower the interface into a less visible mode. This functionality will work on a spectrum, allowing for seamless transitioning between all the possible angles between full view and low view. This provides the order picker with the hands- and voice free interaction for displaying the relevant parts of the list at a glance.



(A) **(B)**

Figure 7.5: Vision-picking interface behaviour when (A) head is tilted down and (B) when facing forward.

Furthermore, the placement of the voice buttons in the lower part of the interface are those non-vital to the success of the route, while the functionality of the error handling is vital, hence placed higher up in the FOV. The error button placement is intended to provide the fastest at-a-glance view while face-forward and the interface is lowered. The voice buttons in the lower part of the interface will likely quickly be remembered, requiring them to be less visible at most times. However, tilting ones head down will still make them quite visible and interacted with through gestures.

Lastly, the list can be opened or closed through the commands *Show List* in picking mode, or *Close* when in list mode.

7.2.1.3 AGV Assisted Vision-picking in Zones

To aid in zone picking, the concept includes highlighting functionality for status information provision. The proposed functionality would display a symbol, here a waving hand representing a vacant AGV, namely one requesting assistance. An order picker would approach it and pair with it to receive the pick list associated with the order to be picked to that specific AGV. The pairing is done by saying *Pair* followed by the AGV ID number. The symbol would disappear, the highlighting color change to blue and with the word PAIRED below. The red highlighting would be accompanied by a warning symbol to communicate AGV malfunction.

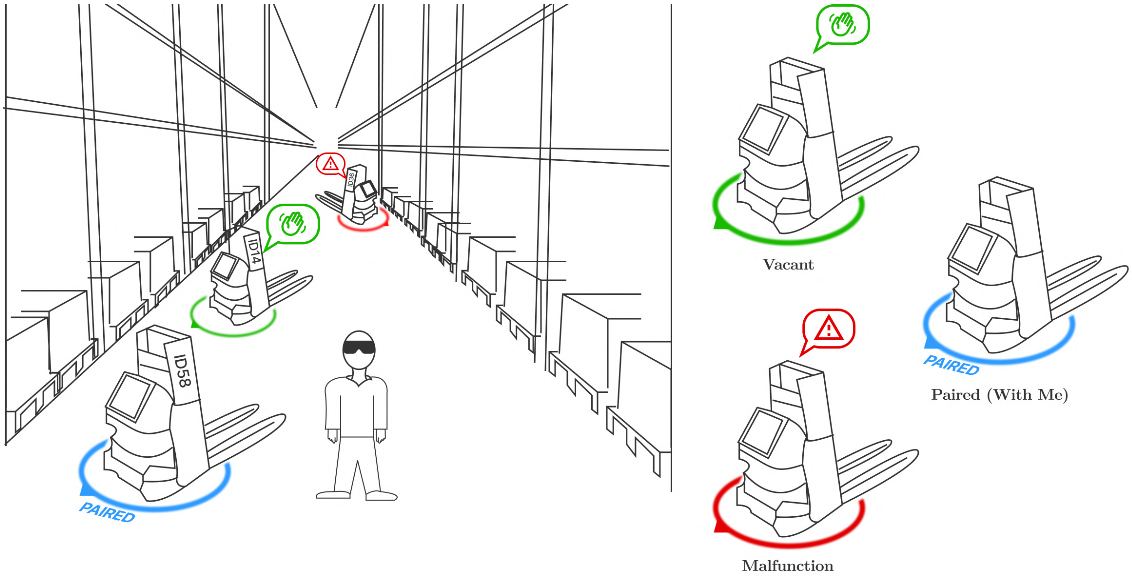


Figure 7.6: AGV status highlighting during zone picking, as seen through the proposed vision-picking glasses.

7.2.2 Concept 2: CMD Interface

The proposed concept solution regarding *cart-mounted displays* (CMD) has a large focus on the list mode with picking mode integration rather than the separation of the two modes as seen in the concept for vision-picking. The main mode for interactions, as well as information provision, will be made through Pick-by-Voice. The focus of this concept is, rather than replacing any functionality of Pick-by-Voice, to enhance the already potent Pick-by-Voice.

The interface is to be displayed on screens mounted on either manual forklifts or on AGVs. Together with Pick-by-Voice and by utilizing voice buttons, digital command lists, error handling and list modification, this concept may provide an significantly enhanced order picker experience with decreased error rates and higher effective efficiency.

7.2.2.1 List Modification

The list modification can be entered through interacting with the *Modify list* button, either through pressing it with touch screens or by activating it through voice. This is the mode previously referred to as *preparation round* in chapter 6 Execution and Process, although no separate mode for preparing the order is ever entered.

Activating list modification allows items to be dragged and dropped. The Outliers list can be pressed to reach the relevant row, or the voice command *Show Row #* can be spoken for the same result. The Outliers list, visible by default at the start of a new pick route, can be closed either by pressing the bottom of the list, or by saying *Close Outliers*. This causes the current pick to become larger and provide more value during the actual picking route, as seen in Figure 7.8.

The currently selected row is highlighted with blue and the top of the interface displays the current pairing of forklift and order picker. The right side of the screen displays customer information, numbers of rows picked of the remaining total and additional visual information in the form of product dimensions and an image.

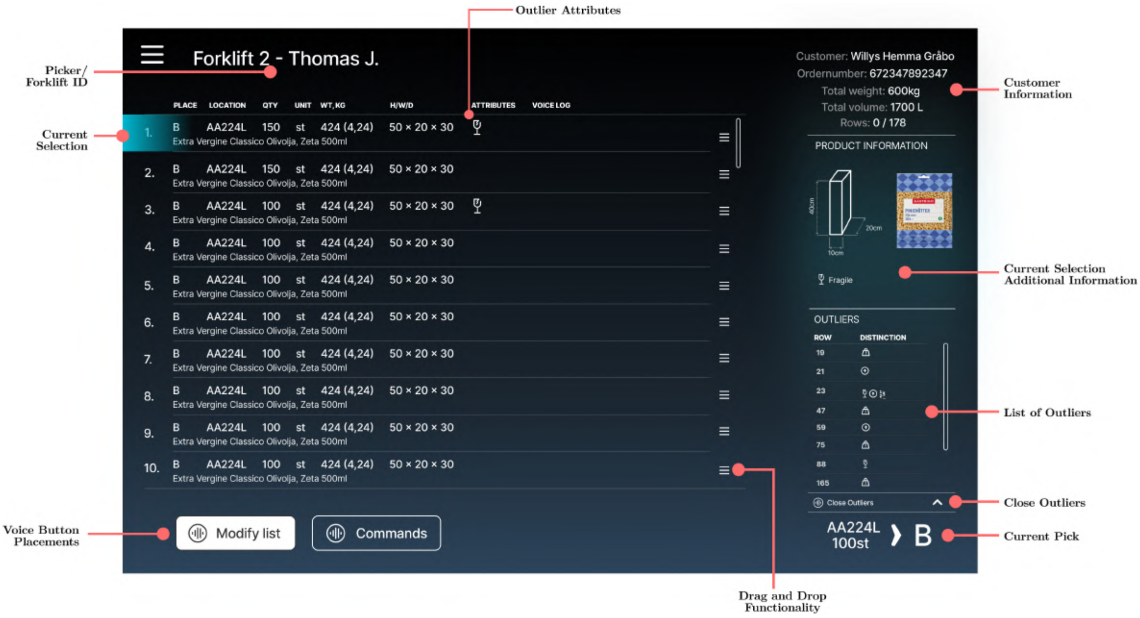


Figure 7.7: Mockup of pick list modification in the CMD interface.

7.2.2.2 During Picking

During picking as seen in Figure 7.8, the completed list items are grayed out. Erroful picks are, however, marked with red for clear visuals of the information inconsistency culpable for the error. These errors can be entered in four different ways, (1) by pressing the button *Next Error* which selects and expands the most recent error, speaking the phrase (2) *Next error* or (3) *Show Row #* for the associated row for the same result, or (4) by pressing the down arrow at the end of the row. Expanding the error handling area reveals information about the error accompanied by four voice buttons offering the same functionality as in concept 1, namely:

- *Ignore*: Removes the error entirely from the list. This action should be used if the system incorrectly records a mismatch in the system, or when the error is not possible to rectify.
- *New Place*: Provides the ability to choose a new place for the picked item, should the placement be incorrect.

- *New Count*: Provides the ability to update the said amount.
- *Rest*: If the error is in regards to too low quantity, this option is available. Choosing this will add the rest of the items to the rest round, which is an additional round occurring after the original route to pick up items which were unavailable before.

Additionally, as can be seen in Figure 7.8, the right bottom area occupies the information regarding the current pick when the Outliers list is closed.

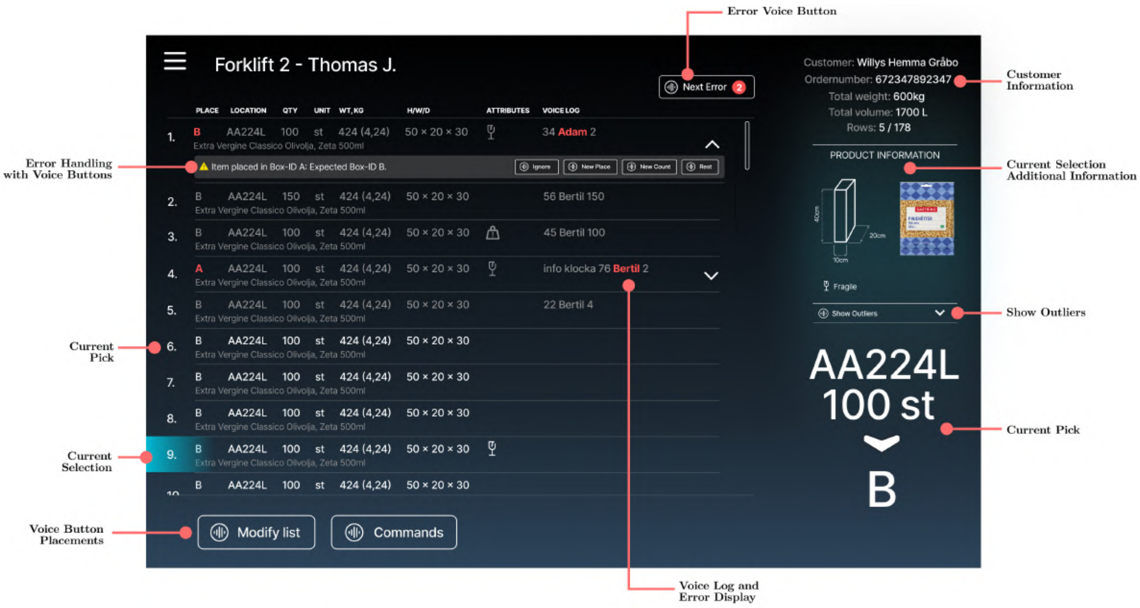


Figure 7.8: Mockup of an active picking route in the CMD interface.

7.2.2.3 CMD Assisted Zone Picking

An early concept illustration of information provision during zone picking can be seen in Figure 7.9. The most important conceptualizations to note here is the enlargement and relocation of the current pick information. Regardless of combining the CMD with Pick-by-Voice or not, this is the most important information to display to the picker being approached by an AGV.

Additionally, all the items to be picked by the currently paired order picker are highlighted simultaneously to provide information regarding both the last pick to be picked for this AGV, as well as how many more are left to pick.

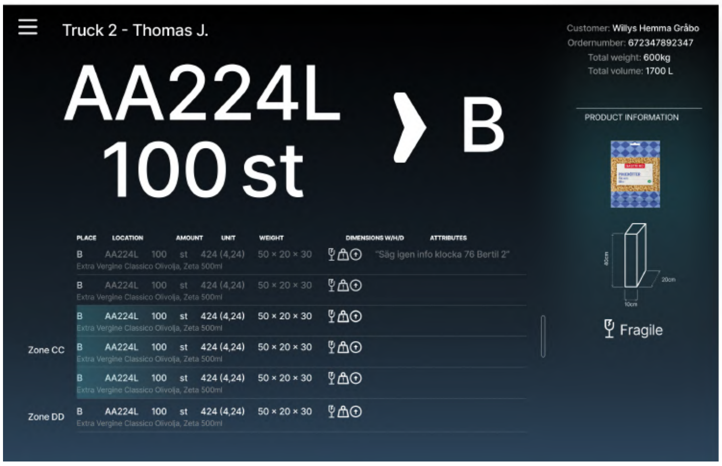


Figure 7.9: Mockup example of how the CMD interface could be adapted to support AGV assisted zone picking.

7.2.3 Concept Design Adherence to Essential Factors

The following section outlines the essential factors which has been taken into account when designing the concepts, and outlines the two concepts' adherence to the respective lists. Please note that since no concept has been evaluated, the adherence may change following future testing of the concepts.

7.2.3.1 Concept Adherence to Successful Factors

1. Successful Order Picking (Must-Haves)	Concept 1: Vision Picking	Concept 2: CMD Interface
(1.1) The order picker needs sufficient information: • Location • Quantity • Placement	✓	✓
(1.2) The order picker needs to be able to verify each pick.	✓	✓
(1.3) The order picker needs to be able to place items neatly.	✓	✓
(1.4) Ability to correct mispicks and errors.	✓	✓

Concept 1: Vision Picking:

- The order picker has access to the necessary information in a persistent manner (1.1).
- Each pick is possible to verify through the use of voice (1.2).
- The order picker has good ability to place items neatly through planning the route and receiving information about item specifics, such as weight, fragility

and orientation requirements (1.3).

- The order picker has the ability to correct mispicks and errors through the voice button interface and persistent pick status feedback (1.4).

Concept 2: CMD Interface

- The order picker has access to the necessary information in a persistent manner through voice information (1.1).
- Each pick is possible to verify through the use of voice (1.2).
- The order picker has good ability to place items neatly through planning the route and receiving information about item specifics, such as weight, fragility and orientation requirements (1.3).
- The order picker has the ability to correct mispicks and errors through the CMD interface (1.4).

7.2.3.2 Concept Adherence to Efficiency Factors

2. Efficient Order Picking (Should-Haves)	Concept 1: Vision Picking	Concept 2: CMD Interface
(2.1) Access to clear and relevant information at all times.	✓	✓
(2.2) Minimization of additional actions and movements.	✓	✓
(2.3) Ability to customize pick lists.	✓	✓
(2.4) Access to easily retrievable items.	N/A	N/A
(2.5) Ability to easily verify the pick.	✓	✓
(2.6) Intuitive systems with simple learning curves.	?	?
(2.7) Ability to easily place items neatly.	✓	✓
(2.8) Ability to easily correct mispicks and errors.	✓	✓

Concept 1: Vision Picking:

- The order picker has access to clear and relevant information at all times through visual, persistent information (2.1).
- The order picker can minimize their additional actions and movements through good planning of picks, both before and during the route through clear visual highlighting (2.2).
- The order picker has access to customizable pick lists (2.3).
- Factor (2.4) is not applicable to interface design.
- Pick verification can easily be performed through voice, with visual confirmation (2.5).

- Factor (2.6) has been taken into account during design but is especially dependent on evaluation due to the highly subjective nature of the factor.
- The order picker can plan their pick which contributes to better ability for neat placements of items (2.7).
- The order picker receives instantaneous feedback regarding errors directly visible in their FOV and has access to quick error rectification through voice (2.8).

Concept 2: CMD Interface:

- The order picker has access to clear and relevant information when needed through Pick-by-Voice, (2.1).
- The order picker can minimize their additional actions and movements through good planning of picks, (2.2).
- The order picker has access to customizable pick lists, (2.3).
- Factor (2.4) is not applicable to interface design.
- Pick verification can easily be performed through voice, (2.5).
- Factor (2.6) has been taken into account during design but is especially dependent on evaluation due to the highly subjective nature of the factor.
- The order picker can plan their pick which contributes to better ability for neat placements of items (2.7).
- The order picker has access to error information through the CMD interface and has access to quick error rectification through voice (2.8).

7.2.3.3 Concept Adherence to Pleasant Factors

3. Pleasant Order Picking (Nice-To-Haves)	Concept 1: Vision Picking	Concept 2: CMD Interface
(3.1) Minimization of frustration through:	✓	✓
• Trustworthy equipment.	?	
• Clear information.		
• Meaningful interactions.		
(3.2) Ability to control or adjust sound and/or noise.	✓	✗
(3.3) Minimizing task monotony or offer task variability.	✗	✗
(3.4) Access to adequate lifting ergonomics and equipment.	N/A	N/A
(3.5) Access to choice of transportation.	N/A	N/A

Concept 1: Vision Picking:

- The system contributes to minimization of frustration through clear information and meaningful interactions. No conclusion can be drawn at this stage regarding the trustworthiness of the equipment required for vision-picking as proposed in this thesis (3.1).
- Elimination of the need for picking related sound contributes to the order picker's ability to control what they hear to the extent with which they are allowed by their employer (3.2).
- Nothing can be concluded regarding task monotony or task variability. The former is highly subjective and requires evaluation while the latter is not applicable to the specific activity of manual order picking (3.3).

Concept 2: CMD Interface:

- The system contributes to minimization of frustration through trustworthy equipment, clear information and meaningful interactions (3.1).
- The order picker cannot control or adjust the sound through the use of the CMD interface any more than what Pick-by-Voice systems already allow.
- Nothing can be concluded regarding task monotony or task variability. The former is highly subjective and requires evaluation while the latter is not applicable to the specific activity of manual order picking (3.3).

Additional Notes: Access to adequate lifting ergonomics and equipment (3.4) and access to choice of transportation (3.5) is not directly related to the specific concepts proposed in the thesis and are thus not applicable.

8

Discussion

This chapter will cover the answers of the proposed research questions and discuss challenges and limitations regarding our process, our proposed design concepts as well as what future work might be proposed as a result.

8.1 Reflections on Results

1. What are the essential factors for successfully performing the activity of manual order picking?

The first research question relates to the needs for order pickers regarding information provision through different technological solutions, their vehicular access and equipment, as well as investigating which factors might lead to frustration and challenges for order pickers.

Due to the larger focus put on user research through visits to warehouses, interviews with managers and order pickers alike, as well as observing the activity and environment through different means (videos, photos as well as in person), the resulting list of essential factors proposed by the authors should prove accurate to a high degree.

While all factors are based on insights gained from end users and the relevant environment, the list is likely to have room for additional factors. The reasoning behind this statement is based on the major general insight regarding the complexity and uniqueness of each warehouse. The insights gathered early in the process were sometimes either confirmed or denied at later visits, likely due to the fact that different warehouses operate significantly differently. However, the factors that remain are ones that survived such scrutiny, which lends credibility towards their accuracy, while further factors, unknown to the authors, may also prove relevant additions should future research reveal them. As such, the list in its current form can be considered a viable answer to the first research question.

2. How might the resulting insights be conceptually implemented in order to innovate on manual order picking?

During the thesis, a comprehensive understanding of each pick-by-system was gathered, most of which were later observed in action and investigated through user research with expert users. Additionally, several different existing solutions in the world of automated material handling was investigated. Along with these, the essential factors uncovered as a result of the first research question resulted in two design concepts which innovate particularly in the space of order picker expertise when it comes to the optimal route. Both of the proposed concepts include ways of changing which items to pick in which order, a feature currently not offered to the extent of the authors' knowledge. This feature furthermore evoked significant interest among several expert users queried about its potential. Together with the fact that most experts also agree that order pickers are the best when it comes to pallet stacking and that the unquestionably efficient Pick-by-Voice system homogenize the skill of order pickers due to the lack of features its simplicity and intuitiveness require, this feature was relevant to introduce.

Additionally, with the necessary visual medium inherent to the ability to properly manage digital lists came further benefits, such as the ability to handle errors quickly and efficiently. Another benefit involves innovating on information provision from the sequential nature inherent to Pick-by-Voice to a more non-sequential information provision through perpetual visibility of vital information. However, as Pick-by-Voice was deemed a highly proficient system, the need to replace it entirely never arose. Instead, the decision was made to keep it as is in when combined with cart-mounted screens regarding voice both input and auditory feedback. However, the auditory feedback system was left out when voice was combined with AR in the proposed vision-picking concept.

The two resulting design concepts, as reached through an iterative research through design process, aim to provide value both in the near future with easily implementable additions to existing systems within the cart-mounted screen concepts, and provide a basis for future implementation and continued research in the augmented reality vision-picking concept.

Note that images provided in the chapter 7 Results are still images of dynamic and moving elements. Therefore it is difficult to assess the effective visibility of the elements in this state, and evaluation with the proper technology would be necessary.

8.2 Reflections on Methodology

As initially proposed in Chapter 5, this thesis was expected to follow a more traditional design process. The decision to change the focus of the report came quite late as a result of the need for more data through user research and warehouse visits had the unintended consequence of removing time from the traditional design phases. Consequentially, as a more rigorous data gathering activity was performed in order to put emphasis on the first research question, proper evaluation of the design concepts were unable to be done. However, while the end results of the design concepts are still in need of user testing and further iterations, the fact that the essential factors have been iterated upon, that part of the thesis has utilized several of the methodological elements missing from the second part.

Due to the lack of user testing of the concept designs, nothing can be concluded regarding their intended benefits for the order pickers.

8.3 Technological Feasibility

The vision-picking design concept raises uncertainties regarding the possibilities for their implementation with existing technologies. While there are a multitude of existing AR glasses today (Allison, 2023), few of them seem to offer gesture controls since that solution requires additional cameras to assess and analyze the movements of the order picker's hands. Furthermore, AR glasses are likely to introduce a higher cost to purchase and maintain.

The use of AR technology in warehouse settings may also require additional systems to function correctly, such as establishing a digital twin of the warehouse (Globecon Freight Systems, 2020) with enough sensors to accurately display the correct information within a digital world and thus augment the real world through the glasses. This requires investments in IOT enabling hardware, which further raises the technological risk of breakage. It is important to take into consideration what happens when sensors need to be replaced, or if the network connection is lost, and what consequences these things might have for the warehouse operations. A sufficiently long outage may erode the benefit of any incremental improvements proposed with utilizing the proposed fidelity of vision-picking. However, as has been displayed, the market size for AR is supposed to grow severalfold (Fortune Business Insights, n.d.), and with the development of Industry 4.0, we are likely to see major improvements in both hardware and software to aid in the realisation of the proposed vision-picking concept.

Another challenge is the integration of the technology in existing warehouse systems. Due to the uniqueness of each warehouse and the diverse use of systems for operation, it will be undisputed that the solution has to be tailored to meet each specific requirements. However, achieving this customization creates a complex task, as the solution will have to be flexible to adapt to different systems without sacrificing generalizability.

8.3.1 Complexity and Usability

One important aspect to highlight is the want for complex systems. A system that has many moving parts are more vulnerable to breakage. This was a viewpoint from one of the warehouse managers with which we spoke. They valued simplicity over anything else and even shied away from Pick-by-Voice for this reason, among others.

They would likely not be the target audience for the vision-picking concept, at least not at the current state of the art in regards to connectivity and available glasses.

Another manager mentioned a strong dislike towards having to buy more of the same equipment when it eventually worn out. This cost increasing aspect of any product is always relevant and especially in terms of cutting edge technology such as augmented reality. This aspect might present challenges in regards to how widespread the system has potential to become unless industrial durability is taken into serious consideration.

8.4 Accessibility

The technology have to be suitable for all levels of technological experience. People are quite diverse and their technological experience range from tech-savvy to the polar opposite. It is therefore important that the proposed concepts are evaluated properly to ensure a reasonable learning curve regardless of user, and iterated upon to allow for wide adaptation.

While the concept designs have taken color and contrast into consideration during development, it is necessary to point out that evaluation of the success with which this has been accomplished should be performed.

8.5 Comparison with existing solutions

While there are several different vision-picking solutions in use today, our proposed solution provides functionality which is evidently unavailable elsewhere to the extent of the authors' knowledge. The ability for the order pickers to change how their pick list is ordered, and the ability to quickly see which rows and items are likely to present themselves as difficult picks in order to easily identify which rows to move, is novel. Furthermore, this feature arose significant interest when queried about.

Another important feature which might be novel is the ability to instantly identify picking errors, and to quickly rectify the mistake using voice. The hands free nature of this approach allows the order pickers to keep good pace during their route while maintaining a high certainty of their ability to successfully perform their job with high efficiency and low error rate.

Furthermore, being able to bring up the pick list at a moments notice provides ample opportunity to gain quick insights regarding the rest of the picking route. This allows for better planning of the current pallet on which they are stacking and provides knowledge regarding when they should wrap the active pallet and start stacking a new pallet.

The CMD concept resembles the functionality of the existing screens mounted on displays, but with updated visuals and with the integration of Pick-by-Voice. This combination provides novel functionality in regards to how they could interact with the interface with the use of voice buttons. Additionally, the aforementioned pick list modification and error rectification features provide even greater utility and competition.

8.6 Ethical considerations

One significant aspect of AR technology is the potential impact on privacy and security. AR often involve the use of cameras to track and analyze the real world, which can be concerning regarding the collection and usage of personal data. Companies and developers must therefore implement robust privacy policies and transparency with the data handling to protect user information. Additionally, AR technology also raise the question about the potential for misinformation or manipulation which is combated by clear regulations in terms of the accessibility of the data.

While AR technology has the potential to increase production and efficiency in order picking, it is important to find a balance between technological assistance and worker autonomy. Order pickers should be able to maintain control over their tasks, and have the ability to override or adjust the technology when necessary. Therefore, it is important to ensure that the order pickers are not seen as passive participants, but active decision-makers in the order picking process.

Another important ethical consideration of AR technology is its visual pervasiveness and what effect this might have on the users' physical and mental well-being after prolonged usage.

8.7 Future work

Given the wicked problem nature of the research questions, the final products would ideally have been iterated and evaluated multiple times, in order to establish comprehensive and usable solutions. Therefore, the next step to this project would be to initiate an evaluation using these versions of the concepts. In addition, more study visits to warehouses would have to be conducted, to revise and build upon the guidelines from the first research question.

However, the concepts enable opportunities to expand with additional features that could potentially improve the order picking experience. Firstly, more security measures could be integrated in the AR concept. For example, as noted from warehouse I and J, in addition to the trucks shining spot-lights on the ground to indicate their location, this information could be provided through the AR glasses by highlighting the forklifts in their vicinity. For example, an outline of the forklift or AGV could be displayed that would make it visible through shelves giving order pickers a complete image of their surroundings. Moreover, communication between warehouse staff could be improved through interconnected devices, allowing a quick way to warn each other or ask for help. These features could potentially eliminate the need for prohibiting the use of ear wear, and could improve the quality of life for the pickers.

Moreover, several additional security features could be implemented into the order picking integrated technologies in order to improve the quality of life for the order pickers. For example, flashing red light could be shown in the entire FOV for communicating that there is a fire, of course accompanied by the fire alarm. However, providing visual security information would allow the order picker the benefit of using ear wear of their own choosing to suppress noise and to allow for their own leisurely listening during work. While this topic might be controversial in regards to how much the technology could ever be trusted in regards to communicating danger, freeing up the ears for order pickers through the vision-picking concept does provide a new business opportunity. Ear wear could be developed that could be used in accordance with safety regulations while still contributing to increased well-being and quality of life for the order pickers.

As the final products are intended to be able to be interacted with entirely through voice, a future improvement could be to introduce smarter speech recognition. Instead of fixed commands, the system would be able to recognize various expressions. This would reduce the numerous commands the pickers would have to familiarize themselves with.

9

Conclusion

Order picking is the most costly and time consuming activity that is performed in warehouse operations. Part of this activity can be automated as seen with systems such as automated storage and retrieval systems which fall in line with the expected movement of the industry towards the forth industrial revolution. Another part of this activity, however, is difficult to automate. In order to provide means of making manual order picking more efficient, Toyota is working towards providing Automated Guided Vehicles with a focus on order picking, and the focus of this thesis has been to aid in providing a foundation for the requirements of order picking as well as proposals for its innovation.

Two research questions were put forth:

1. *What are the essential factors for successfully performing the activity of manual order picking?*

2. *How might the resulting insights be conceptually implemented in order to innovate on manual order picking?*

The extensive initial research into the area of order picking became the foundation on which the methodologies of interviews and observations were based. These were performed during visits to warehouses with operations ranging from almost fully automated to fully manual, each with different systems for order picking. This extensive data gathering phase, which due to difficulties in reaching the relevant users, provided invaluable data on which to base the answer to the first research question. This resulted in a list of essential factors for order picking, divided into four categories:

1. **Successful Order Picking**, describing the factors which are vital for the success of the activity.

2. **Efficient Order Picking**, describing the factors which make the activity more efficient.

3. **Pleasant Order Picking**, describing factors related to the perspective from

which the activity is performed, and

4. **General Insights and Limitations**, describing factors which may indirectly impact the activity of order picking.

The list of essential factors bundled with invaluable insights from each visit, interview and observation laid the foundation on which to begin answering the second research question regarding how the activity could be innovated upon. This resulted in two design concepts, both incorporating voice technology as input method:

1. **Concept 1: Vision-Picking**, which focuses on how to incorporate a fast growing technology into the picking process and how to innovate on information provision.

2. **Concept 2: Cart-mounted Display Interface**, which focuses on providing additional benefits through the use of a screen not possible simply through the use of Pick-by-Voice.

These two design concepts both incorporate novel functionality through features allowing the order pickers to modify their order picking lists to their own expert liking, direct error handling and new interactivity through voice buttons. Both of these concepts are designed with strong adherence to the list of essential factors where applicable.

The main limitation with this study is the lack of concept evaluation. The exclusion of said phase was decided upon the revision of the initial scope as it became clear that further user research would be needed. This forced the thesis into a non-linear working method, which despite the intention of following the Design Thinking method, provided adequate answers to the research questions eventually finalized.

Due to the above limitation, future work would be advised to include prototype development and evaluation of the proposed design concepts.

The potential for innovating on manual order picking is evident throughout this thesis, and the continued high cost of manual order picking demands it. The activity is evidently repetitive and labor intensive, which fosters a future focus on how the activity can be made more pleasant to perform.

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A

Living Draft

B

Interview Questions

Thanks for taking your time to do this interview! We are two students from Chalmers doing our master thesis, and we are investigating order picking and how to effectivize it. This is going to take around 15-20 minutes.

Order picking

- What does a normal work day look like for you?
- Could you tell us about your experiences with order picking?
  - How long have you been working with this?
  - Can you describe a typical order picking session, from start to finish with an order? *Like, how do you get the initial information, and where do you go from there?*
  - In what part of the process do you meet most resistance? Which part is the hardest/most annoying?
  - How do you receive information about your picking order?
  - What information do you need to be able to complete a picking order?
    - Do you feel that you get the information you need when you need it?
- Error prevention?
  - What are the risks with misplacing goods?
  - What measures do you have in order to prevent making picking errors?
- **Extra:** Are there any rules on how much you are allowed to lift per day?
- **Extra:** Do you get paid extra the more you pick per day?
- There are several different technologies for delivering picking information, such as paper list, pick-by-voice and pick-by-light.
  - Which technologies have you worked with?
  - What are some of the benefits of each?
- What would you like to improve about your daily tasks?

AGV experience

- Do you have experience working with AGVs?
- How does the AGV aid you in your work?
- How does the AGV communicate with you?

Personal

- Do you find yourself physically tired after work?
  - What are the most tiresome activities?
- Are you allowed to listen to music/podcasts during work?
  - Do you do that?
- Do you wear gloves or similar when you work?
  - Would you prefer the opposite?
    - Why / Why not?

- If all order picking trucks were autonomous, how would you like to approach order picking?
- What would be the optimal way to perform order picking in 10 years time?

C

Consent Form

CHALMERS
UNIVERSITY OF TECHNOLOGY

Interview Consent form for participation in Master Thesis on Order Picking Innovation

The purpose of this interview is to get a better understanding of warehouse logistics and order picking. This data will strictly be used for this master thesis in order to innovate on solutions for order picking in collaboration with AGVs.

All data will be anonymized, meaning that your name will never be mentioned in the report or anywhere else post-interview.

By signing this document, I consent to the following:

- My participation is entirely voluntary.
- I may choose to end my participation at any time.
- I have the right to revoke my consent at any time.
- The data produced may be used in the final report of this thesis.

☐ I agree to have this interview recorded and later transcribed for the purposes described above.

Today's date:

____

Participant's information:

Name:

____

Signature:

____

Moderator's information:

Name:

____

Signature:

____