Master's thesis

NTNU
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Faculty of Engineering
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Eirik Halle

Design Decision's Impact on the Order Pickers' Human Factor Aspects in Order Picking Systems

Master's thesis in TPK4930 - Production Management
Supervisor: Fabio Sgarbossa
Co-supervisor: Vivek Vijayakumar
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Special thanks to my Supervisor, Fabio Sgarbossa, Full professor of Industrial Logistics at the Department of Mechanical and Industrial Engineering(MTP) at NTNU, for guiding me through the writing process of this thesis.

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Finally, I would like to thank my family for giving me all the necessary support to allow me to continue my studies. This thesis is the culmination of many years of hard work, and it makes me very proud to have come to this stage despite the extra limitations I've had to navigate because of a diving accident in 2014, which has left me wheelchair bound. Here are some words that have kept me going and epitomize the attitude I have tried to adopt during this research process.

"Life's battles don't always go
To the stronger or faster man,
But sooner or later the man who wins
Is the man who thinks he can."

Walter D. Wintle

Trondheim, 3rd August 2022

Eirik Halle

Abstract

The European Commission's introduction of Industry 5.0 in January 2021 has placed humans front and center in industry production and logistical research. One of the main avenues of Order Picking(OP) research development is focused on getting practical and holistic OP models in modern warehouse logistics and OP tasks. One such area of interest is providing an empirical understanding of Design Level(DL) decision-making and its impact potential on Human Factor(HF) aspects.

This research empirically investigates how variations in system settings & technology configurations could impact HF aspects in warehouse logistics and OP tasks. In addition to exploring what new Industry 4.0(I4.0) assistive technologies can do for order pickers operating in these system setting & technology configurations. The research evaluates two different system settings & technology configurations: Picker-to-parts OP(SS1) and parts-to-picker OP(SS2).

The chosen research approach was a mixed model method to support the findings by a case study consisting of two semi-structured interviews and a questionnaire. One interview from the management and one from the order pickers on the ground floor Bring AS in Jönköping. Then a thematic analysis provided the order picker's beneficial and challenging dynamics concerning HF aspects when performing OP tasks. The questionnaire consists of a workload intensity assessment and a weighting of the workload subcategories through a two-way Analysis of Variance (ANOVA) to provide the quantitative findings. Then a literature review provided the human-technology interactions necessary to discuss the potential impact of introducing new assistive technology to the order pickers concerning HF aspects and define the hypothesis evaluated during the research process. Findings consist of two hypotheses and the identification and cataloging of many human-technology interactions with the potential to impact HF aspects for order pickers. A qualitative understanding of what order pickers faced of beneficial factors & challenges in SS1 and SS2. A quantitative understanding of the order pickers' workload profile and the overall workload and intensity of workload sub-categories while performing OP tasks.

The findings suggest that variations in system setting & technology configuration have a significant impact on the HF aspects of order pickers performing OP tasks. These variations also encourage different strategies when deciding what technologies to prioritize in each system setting & technology configuration.

This thesis reinforces the lack of practical, holistic, and empirical research on how HF aspects impact the OP process' readjustment to Industry 5.0(I5.0) priorities. Researchers could also use the findings to direct future research efforts to quantify the cost-benefit ratio of introducing a specific new assistive technology.

Management can use the proposed analysis of the workload intensity to evaluate their system setting & technology configuration to find where the order pickers are experiencing unreasonable high workload and make appropriate adjustments. Management can use the catalog of human-technology interactions to evaluate a technology's impact on HF aspects. One potential use of the research is as a framework for assessing different system settings & technology configurations in warehouse logistics and making educated recommendations as to what assistive technologies management should prioritize to address HF aspects.

Sammendrag

Europakommisjonens introduksjon av Industri 5.0 i januar 2021 har satt mennesker i sentrum innen industriproduksjon og logistisk forskning. En av hovedgreinene for forskningsutviklingen innen vareplukking er fokusert på å få praktiske og helhetlige modeller av vareplukking i moderne lagerlogistikk og vareplukkeoppgaver. Et slikt interesseområde er å gi en empirisk forståelse av beslutningstaking på designnivå og innvirkningspotensialet det har på menneskelige faktorer.

Hensikten med denne forskningen er å empirisk undersøke hvordan variasjoner i systeminnstillinger og teknologikonfigurasjoner kan påvirke menneskelige faktorer i lagerlogistikk og vareplukkingsoppgaveroppgaver. I tillegg til å utforske hva nye hjelpeteknologier (Industri 4.0) kan gjøre for ordrevelgere som opererer i disse systeminnstillingene og teknologikonfigurasjonene. Forskningen dreier seg om å evaluere to forskjellige systeminnstillinger og teknologikonfigurasjoner: Vareplukker-til-Varer Plukking(SS1) og Varer-til-Vareplukker Plukking(SS2).

Den valgte forskningstilnærmingen var en blandet modell for å støtte funnene ved hjelp av en casestudie bestående av to semistrukturerte intervjuer og et spørreskjema. Et intervju fra ledelsen og et fra ordreplukkerne hos Bring AS i Jönköping. Deretter ga en tematisk analyse vareplukkernes formening om fordelaktige og utfordrende faktorer angående menneskelige faktorer ved utførelse av vareplukkingsoppgaver. Spørreskjemaet består av en vurdering av arbeidsbelastningsintensitet (NASA TLX) og en vekting av arbeidsbelastnings underkategorier gjennom en toveis variansanalyse (ANOVA) for å gi de kvantitative funnene. Deretter ga en litteraturgjennomgang av de menneskelig-teknologiske interaksjonene som var nødvendige for å diskutere den potensielle effekten av å introdusere ny assisterende teknologi for ordreplukkerne på menneskelige faktorer og definere hypotesene som ble utforsket under forskningsprosessen.

Resultatene ble to hypoteser og en katalog av menneske-teknologiske interaksjoner med potensialet til å påvirke menneskelige faktorer for vareplukkerne. En kvalitativ forståelse av hva vareplukkerne sto overfor av gunstige faktorer og utfordringer i SS1 og SS2. En kvantitativ forståelse av ordrevelgerens arbeidsbelastningsprofil, den totale arbeidsmengden og intensiteten til arbeidsbelastningen erfart under vareplukkingsoppgaver. Konklusjonen er at resultatene tyder på at variasjoner i systeminnstilling og teknologikonfigurasjon har en betydelig innvirkning på de menneskelige faktorene hos vareplukkere. Disse variasjonene oppmuntrer også til forskjellige strategier når du bestemmer hvilke teknologier som skal prioriteres i hver systeminnstilling og teknologikonfigurasjon.

Det manglende grunnlaget for praktisk, helhetlig og empirisk forskning knyttet til hvordan mennneskelige faktorer påvirker vareplukkerne justeringen til Industri 5.0-prioriteringer forsterkes av denne avhandlingen. Forskerne kan også bruke funnene til å argumentere fremtidig forskningsinnsats for å kvantifisere nytte-kostnadsgraden ved å innføre en spesifikk ny assisterende teknologi. Ledelsen kan du bruke den foreslåtte analysen av arbeidsbelastningsintensiteten til å evaluere systeminnstillingen og teknologikonfigurasjonen for å finne ut hvor vareplukkerne opplever urimelig høy arbeidsbelastning og foreta justeringer. Ledelsen kan bruke katalogen over menneske-teknologi interaksjoner for å evaluere hvilke menneskelige faktorer som kan påvirkes av hvilken teknologier i ønsket retning. Forskningen kan brukes som et rammeverk for å vurdere ulike systeminnstillinger og teknologikonfigurasjoner innen lagerlogistikk og gi veloverveide anbefalinger om hvilke assisterende teknologier som bør prioriteres for å håndtere menneskelige faktorer.

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Acronyms

AI Artificial Intelligence. 20

ANOVA Analysis of Variance. 50, 54, 56, 60, 62, 68

AR Augmented Reality. 19–24, 27, 28, 35–37, 39, 71, 78–80, 84

AS/RS Automated Storage and Retrieval System. 3, 34, 80

B2B Business-to-Business. 48

B2C Business-to-Customer. 48

BD Big Data. 23

DL Design Level. 1–3, 5, 6, 9, 14, 32, 40, 50, 62

HF Human Factor. 1–4, 6, 7, 9, 13–16, 19, 27, 29–34, 36, 37, 39–45, 47, 51, 52, 54, 56, 58–60, 62, 69, 73, 74, 76–78, 80–84

HUD Head-Up Displays. 21, 24, 27, 28, 36, 54, 79, 81

I4.0 Industry 4.0. 2, 3, 34, 44

IoT Internet of Things. 22, 28, 35, 37, 78

MCS Motion Capture System. 59, 78, 81

MSD Musculoskeletal Disorders. 32–34, 77

NASA TLX NASA Task Load Index. 40, 41, 43, 50–54, 56, 59, 60, 62, 67, 73–76, 79, 82, 83

OP Order Picking. 1–7, 9–16, 19–45, 48, 50–52, 54, 56–60, 62, 63, 67–69, 71, 73–84

OP4.0 Operator 4.0. vii, 1, 7, 13, 14, 19, 28, 34, 42, 43, 82

OPS Order Picking System. 2, 5, 6, 10, 12–16, 19, 22, 24, 34, 36, 37, 40, 50, 83, 84

PbVi Pick-by-Vision. 21, 22, 25, 27, 28, 71, 78–81

PbVo Pick-by-Voice. 25, 79

PRISMA Preferred Reporting Items for Systematic Reviews and Meta-Analyse. 45

PtL Pick-to-Light. vii, 22–26, 63, 73, 78

RFID Radio Frequency Identification. 19, 23–25, 37, 77–79

SKU Stock Keeping Unit. 17

SLAP Storage Location Assignment Problem. 17, 23

SLS Smart Lighting Systems. 26, 28

SS1 System Setting 1. 4, 41, 43, 63, 64, 67, 72–77, 79–83

SS2 System Setting 2. 3, 4, 41, 43, 63, 64, 67, 72–77, 79–83

UI User Interface. 21

VR Virtual Reality. 19, 22, 28, 36, 39, 54, 78, 81

WMS Warehouse Management System. 21–24, 27, 63

Glossary

Human Factors and Ergonomics The scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design to optimize human well-being and overall system performance.. 2, 34

Industry 5.0 Industry 5.0 is the term used for EU's renewed efforts of putting humans in the center of logistic and production design and development to face the future challenges of sustainability, aging workforce etc.. 1

Logistics 4.0 the logistical system that enables the sustainable satisfaction of individualized customer demands without an increase in cost and supports this development in industry and trade using digital technologies. 1

Order Picking 4.0 Order Picking 4.0 is a sociotechnical OPS where the individual or heterogeneous customer orders are compiled efficiently and sustainably into small batch sizes from a large variety of goods in a warehouse. Additionally, Operator 4.0 considers automation of supportive and substitutive technologies to a large degree along with HF objectives simultaneously. 1, 6, 14

Sociotechnical Systems Sociotechnical systems in organizational development is an approach to complex organizational work design that recognizes the interaction between people and technology in workplaces. The term also refers to the interaction between society's complex infrastructures and human behavior. 2, 12–14, 84

1 Introduction

1.1 Background & Motivation

In January 2021, the European Commission coined the term Industry 5.0 as the new mission statement to ensure a more sustainable, resilient, and human-centric industry production and warehouse logistics(EU, 2022). This development was an extension of Industry 4.0 (Kagermann et al., n.d.) which introduced a trend of digitizing more aspects of life and society in general, including Order Picking (OP). Consequently, terms like OP4.0(Romero et al., 2016), Logistics 4.0(Winkelhaus and Eric H Grosse, 2020), and Order Picking 4.0(Winkelhaus, Eric H Grosse and Morana, 2021) has emerged. They all have their basis in a vision of enabling sustainable satisfaction of individualized requirements from order pickers and customers using digital technologies.

Figure 1: Industry 5.0

Source: EU, 2022

In OP the automation and supportive technologies have received more widespread attention in production and logistics, and there is a consensus that humans will remain a vital component of operational procedures(B. A. Kadir et al., 2018; Sgarbossa et al., 2020).

One significant consequence of this development in logistics is the renewed focus on the integration of Human Factor (HF) aspects in OP at the Design Level (DL). Allowing management to ensure sustainable, human-centered, and resilient OP processes through system settings & technology configuration management and further innovative use of new technologies.

Even manual picker-to-parts OP alone is a worthy target for such efforts, since it is the most labor-intensive warehouse operations (Bartholdi and Hackman, 2011, p.24) and represents as much as 55% of warehouse operational cost (Koster et al., 2007;

Tompkins et al., 2010). In 2018, logistic costs represented approximately 10% to 20% of a country's GDP depending on whether the logistic efficiency is on the low or high end and denote the economic significance of OP (Winkelhaus, Eric H Grosse and Morana, 2021). Additionally, manual OP represents up to 80% of the picking systems used in warehouses (Koster et al., 2007).

The high degree of human order picker OP interactions suggests that not accounting for human characteristics(e.g., learning and forgetting, workload, body posture, etc.) when planning OP activities is equivalent to managerial failure (Eric H Grosse et al., 2014). Human system interactions in OP have, for some reason, been ignored or assumed constant and independent of the OP process in planning problems. The result is a gap between problems studied in literature and those observed empirically in practice. This gap indicates that incorporating HF into planning models of OP has unrealized potential.

Deviations from optimized decisions at the DL(i.e., system setting, technology) concerning HF aspects are likely to affect performance outcomes(i.e., productivity, quality, and well-being) (Eric H Grosse et al., 2014).

The factors that motivate the research are related to the identified gaps in OP's literature foundation and are there are four of them(Karlsson, 2010, p.68). Firstly, Winkelhaus, Eric H Grosse and Morana, 2021 describes the lack of research focusing on novel Order Picking System (OPS) holistically or from a Sociotechnical Systems perspective. Secondly, Boysen et al., 2019 identified that good analysises on system selection(system settings), ergonomics, and holistic models were limited. Thirdly, Eric H Grosse et al., 2014 finds that HF aspects are neglected in OP planning and Koster et al., 2007 notes that picker-to-part OPS have received less attention than parts-to-picker. Finally, Bzhwen A. Kadir et al., 2019 reveal an obvious need for empirical evidence and collaboration between the academic fields of Human Factors and Ergonomics, Industry 4.0 (I4.0), and HF aspects along with its practitioners(i.e., order pickers). Together these author's findings illustrate the need for engaging in this exploratory and empirical research.

Since neglecting to consider the HF aspects in OP planning is equivalent to managerial failure (Koster et al., 2007) HF aspects should be considered early at the DL in the decision-making process to avoid adverse performance deviations. Identifying the affected stakeholders is also essential for effective management. Bad choices at this stage are typically costly and time-consuming to remedy.

There are several contributions to consider. System setting & technology configuration decisions are strategic decisions. Therefore, theoretical and practical contributions benefit early decision-making at the DL when HF aspects are the priority.

The contributions are fourfold. Firstly, an empirical understanding of the significance of system setting & technology configuration decision-making. Secondly, it is to consider the total workload of OP tasks for manual picker-to-part OP, and picker-to-parts OP and understand how order pickers are impacted. Thirdly, is identifying and cataloging human-technology interactions in a OP tasks context. Managers can then use this catalog to evaluate new technology potentials for HF aspects in different system settings & technology configurations. Finally, managers could use these findings to identify the relevant stakeholders to enable early involvement and increase the likelihood of optimal decision-making.

OP management can use the contributions to avoid HF-related pitfalls in their decision-making for OP tasks and warehouse-related issues. Consequently, reducing work-related illness, absenteeism, and presenteeism, along with higher workplace quality and safety in the OP tasks, thus reducing long-term costs.

1.2 Problem Description

The issue at hand is the lack of holistic and empirical assessments of how significant DL decisions can be to order pickers' HF aspects in warehouse logistics. The problem is about empirically assessing the consequences of variations in system settings & technology configurations for picker-to-parts and parts-to-picker OP and finding out what role new assistive technologies can play to empower the order pickers' HF aspects.

The purpose of DL decisions is to address the long-term perspective in logistics. Solving this problem requires two core aspects of the DL to be researched:*system settings & technologies.*

In system settings, the focus is on the decisions made regarding the layout and storage location assignment since these are the primary OP planning decisions addressed at the DL (Boysen et al., 2019). In the last decade, many new technologies have been introduced into production and logistics through the implementation of I4.0 (Kagermann et al., n.d.). Hence, to make the discussion of the human-technology interactions manageable, only manual picker-to-part OP related technologies are included in the problem(Winkelhaus, Eric H Grosse and Morana, 2021). The existence of Automated Storage and Retrieval System (AS/RS) in picker-to-part OP is an example of technology exclusive to System Setting 2 (SS2).

Empirically differentiating between two system settings & technology configurations is required to solve the problem, and at a Bring AS-owned warehouse in Jönköping, these requirements are satisfied. The two different system settings & technology configurations are assessed separately through workload analysis allowing the makeup of the workload to be used to gauge the impact on the order picker's HF aspects. The technology recommendations

Solving this problem matters for several reasons. One, it provides managers with an empirical foundation to improve decision-making that impacts the order picker's HF aspects as Eric H Grosse et al., 2014 highlighted the need for their consideration. Two, it gives managers a way to evaluate the technologies that help manage order pickers' workload when choosing new technologies.

Decisions made for system setting & technology configurations are considered strategic (figure 3), meaning they are made with a long-term perspective at an early stage. Consequently, poor decision-making here would be expensive to remedy.

1.3 Aim, Research Questions, and Objectives

This thesis aims to understand how the decision-making in system settings & technology configurations will impact the order pickers' HF aspects. Additionally, find out how new assistive technologies can impact the order pickers' HF aspects while performing OP tasks. The research questions/hypotheses represent the goals for reaching this aim, while the objectives represent the step-by-step playbook to guide the research. The research questions and the corresponding research objectives are summarized in table 1.

Table 1: Research Questions and Research Objectives

Research Questions	Research Objectives
RQ1: How does variations in system setting & technology configurations affect the order pickers' HF aspects?	**RO1.1:** Develop and find literature support for the hypotheses and motivate the methodology. **RO1.2:** Understand the system settings & technology configuration of a real life case company **RO1.3:** Understand the impact of various system settings on HF aspects of the order pickers
RQ2: How does different system settings & technology configurations(System Setting 1 (SS1), SS2) impact assistive technology recommendations seeking to improve HF aspects?	**RO2.1:** Identify and catalog the technologies and the relevant human-technology interactions for manual picker-to-parts OP tasks. **RO2.2:** Assess human-technology interactions that hold potential when improving the OP process in terms of HF aspect.

1.4 Research Scope

This section aims to define the exact scope of the thesis. Firstly, is a presentation of the main areas of the research. Finally, a presentation of the considerations made to limit the scope of the research.

This thesis' primary research areas is a comparison between manual picker-to-parts OP and parts-to-picker system settings & technology configurations effect on HF aspects. Figure 5 show the research scope of three main areas where the intersection of the three represents the research scope. By combining these three areas, this study will focus on problems concerning the impact of variations of system settings & technology configurations on order picker's doing OP task in terms of HF aspects.

The emphasis on picker-to-parts OP is justified by the labor-intensity, immense cost(50% operating cost), and wide use(90 % of warehouses)(Koster et al., 2007) .

Another valid reason to limit the scope here is the lacking research on manual picker-to-parts OP. (Koster et al., 2007) found that only 30 out of 114 research articles on OPS address picker-to-parts OP and the rest parts-to-picker OP. Improvements here could help the majority of logistical operations.

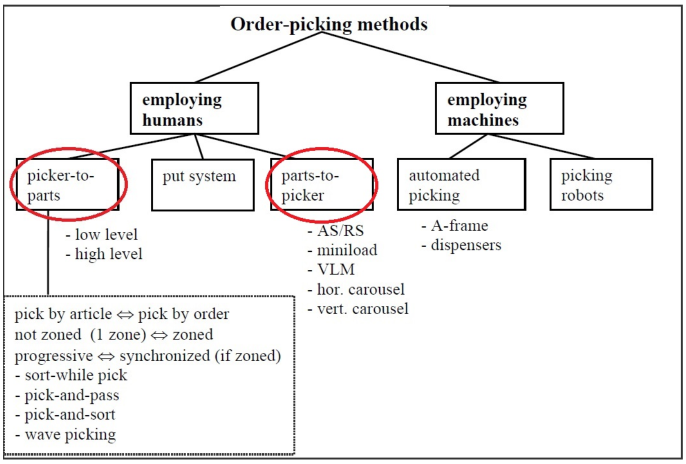


Figure 2: Classification of Order Picking Systems

Source: (Koster et al., 2007)

The scope is further limited by focusing on systems settings at DL include primarily strategic concerns like layout, storage location assignment and technology decisions, as illustrated in figure 3, making decisions concerning OP planning problems like routing, zoning, and batching are tactical and operational decisions. Good strategic decisions will prevent costly modifications to layout and storage later by keeping the human needs of order pickers central to the decision process early.

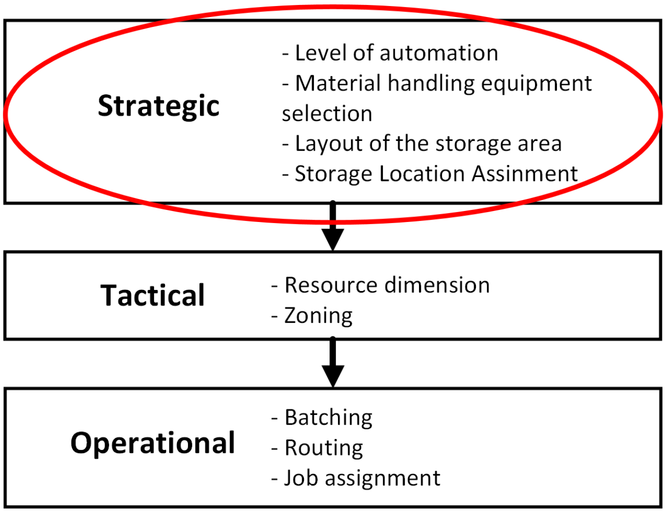


Figure 3: Strategic, Tactical and Operational Decisions

Source: Gils, Caris et al., 2019

There is a large number of technologies and potential human-technology interactions.

The number of included technologies needs to be limited to make the research more manageable. Therefore the primary focus in the research process is on manual picker-to-part OP related technologies(figure 2) and the supportive technologies that can affect the order pickers performance during OP tasks. A table of the technology overview is in table 16.

Winkelhaus, Eric H Grosse and Morana, 2021 introduced the comprehensive concept of Order Picking 4.0 to evaluate the impact of new technology illustrated in figure 4. As illustrated the technology interactions related to human reduced OPS and hybrid OPS are left out of scope.

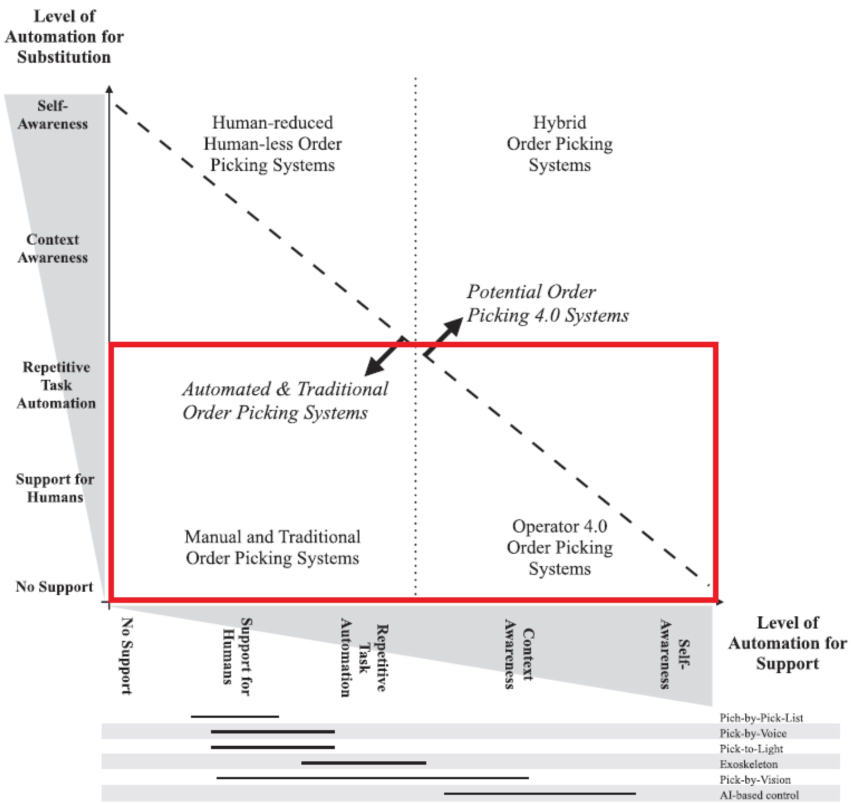


Figure 4: Manual Traditional and OP 4.0 OPS

Source: (Winkelhaus, Eric H Grosse and Morana, 2021)

The determination of how to shape the scope considers the intersection between system settings & technology, and the impact on order pickers' HF aspects from a DL perspective. A graphic illustration of the scope is completed in figure 5.

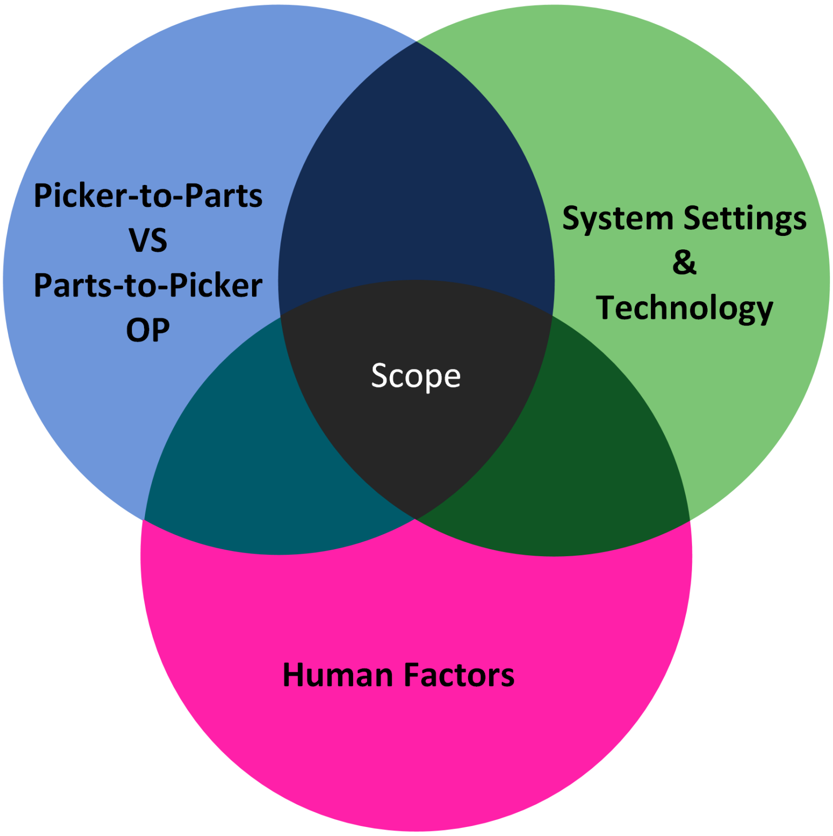


Figure 5: Thesis Intersection Scope

1.5 Thesis Structure

This section will present a systematic structure of the thesis. The structure flow is illustrated in figure 6.

Chapter 1 ***Introduction*** presents the background and motivation for addressing the topic, along with some of the likely contributions. The problem is described. The aim, research questions, and research objectives of the thesis are presented. Ending in a presentation of the thesis structure.

Chapter 2 ***Theory*** contains the necessary theoretical background literature used during the research process. It contains literature on the current state of OP and the system setting and technology configurations impacts on OP tasks in terms of HF aspects. Relevant literature for layout and storage assignment is identified and presented to contextualize system settings. The same is done for literature that addresses the technology that facilitates the incorporation of assistive technology orOP4.0 in manual picker-to-parts OP.

Chapter 3 ***Impact on HF*** focuses on isolating the impacts of system setting and technology on order pickers in HF aspect terms to provide the foundation to make the hypotheses and research questions.

Chapter 4 ***Hypotheses*** presents one of the outcomes of the literature review process, which are the hypotheses that are evaluated empirically in the research process.

Chapter 5 ***Methodology*** presents and justifies the methodology chosen to achieve the research aims and solve the research questions.

Chapter 6 ***Results*** presents the findings of the literature review, questionnaire, and interviews in a cohesive manner.

Chapter 7 ***Discussion*** evaluates the findings from the proposed methodology, and their significance for the research questions interpreted and discussed comprehensively.

Chapter 8 ***Conclusion*** is where the research findings are summarized and concluded by evaluating research objectives.

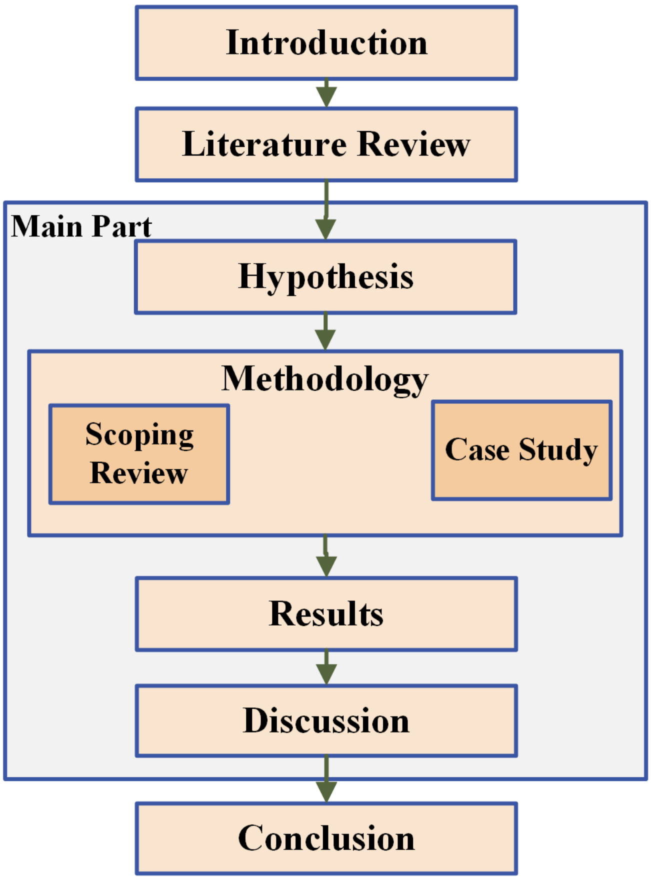


Figure 6: Thesis Structure

2 Theory

This chapter presents the theoretical background required to facilitate the research process. A literature review process is used to build this chapter. The primary purpose of the literature review is to provide an understanding of the whole body of available research on the topic and inform about the strengths and weaknesses of studies within the research field (Rhoades, 2011). The body of the literature review is structured thematically. Firstly, a holistic overview of the current literature on the OP process will be presented and synthesized to give a clear overview of the current state of this field. Secondly, the OP process as a sociotechnical system is explained and reveals some of the research gaps motivating the study. It contains a holistic overview of OP, system settings & technologies, and theHF framework relevant to evaluating the impact of HF concerns in manual picker-to-parts OP in the DL. The topics are concentrated on the intersection of these topics to keep the theory amount manageable.

2.1 Order Picking Overview

2.1.1 General Order Picking

This section presents OP's essential terms and concepts and some seminal literature on OP.

OP - *the process of collecting products from storage (or buffer areas) according to order lines in a picking order*(Koster et al., 2007). OP as a warehouse function arises because goods are received in large quantities while customers typically order different products in small amounts. OP is a labor-intensive exercise, and rough estimates reveal that total expenses in OP amount to 55% of operational costs in warehouse operations (Koster et al., 2007). The OP process involves clustering and scheduling the customer orders, delegating stock on locations to order lines, releasing orders to the floor, picking the items from the storage locations, and disposing of the selected items (Koster et al., 2007).

A typical manual picker-to-parts OP process requires the initiation of a *set up*. This task could entail receiving orders from customers, sorting and prioritizing them, preparing the pick list, and sequencing the pick with batching. After documenting and processing an order, the picker starts to pick the required items. The activities included are *travel*(get to storage shelf), *search*(screen for the correct item), *pick-up*(pick the right items and quantity), and document the picks. After completing the pick-list(usually paper-based), the picker returns the order to the depot. The process is completed by sorting(if necessary), packing, and documenting the completion of the order. By choosing time as the OP performance outcome, then an order picker can separate the op tasks accordingly (Tompkins et al., 2010):

- *Set up time:* the administrative time an order picker requires before starting the pick tour.
- *Travel Time:* the time necessary for an order picker to travel back and forth

between storage locations in the warehouse during a picking order.

- *Search time:* the time required to identify the items to pick at the pick location.
- *Pick Time:* the time required to collect the items from their storage location, including pick documentation, pick verification, interruptions(e.g., aisle congestion) and restocking.

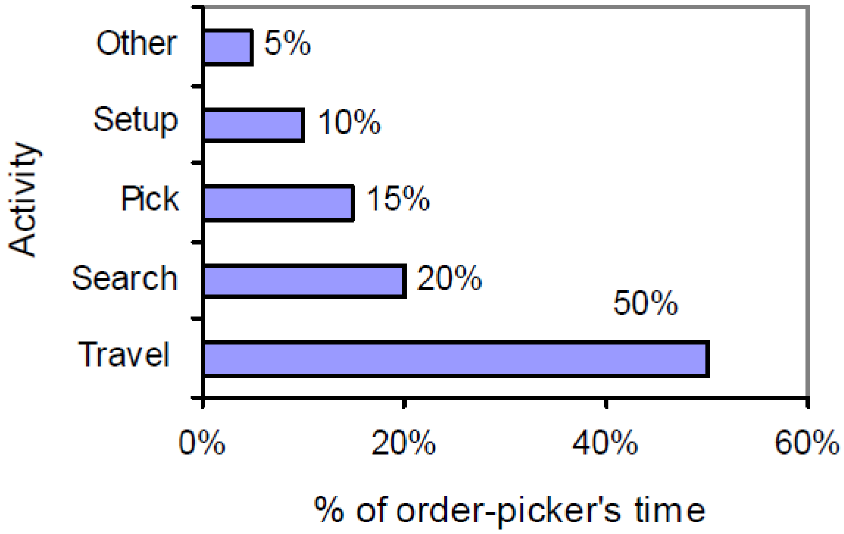
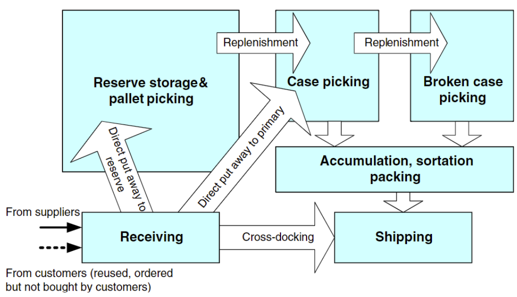


Figure 7: Time distribution for typical OP tasks

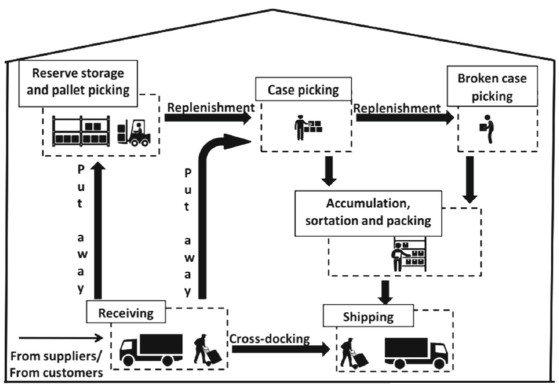
Source: Tompkins et al., 2010

The term OPS is used when referring to the compilation of these activities. A single warehouse may harbor several OPS and the most utilized one is the manual picker-to-parts OPS(Fig. 2)(Koster et al., 2007). The typical warehouse functions, flows, and activities of a warehouse are illustrated in figure 8a and 8b.



(a) Typical Warehouse Functions and Flows

Source: Tompkins et al., 2010



(b) Typical Order Picking Activities

Source: Tompkins et al., 2010

Warehouse managers have to contend with four OP planning problems to manage OP operations(Koster et al., 2007):

- Storage location assignment determines where to store the products entering storage physically.

- Order batching is about rules that decide which orders to combine on each pick tour.
- Zone picking is about dividing the picking area into smaller zones and having pickers operate separately.
- Routing is about determining the sequencing of the picks.

Many researchers have addressed the idea of improving the OP process. Over the last 30 years, OP has received exponential research attention, which emphasizes the importance that managers and researchers have placed on this topic (Winkelhaus, Eric H Grosse and Morana, 2021).

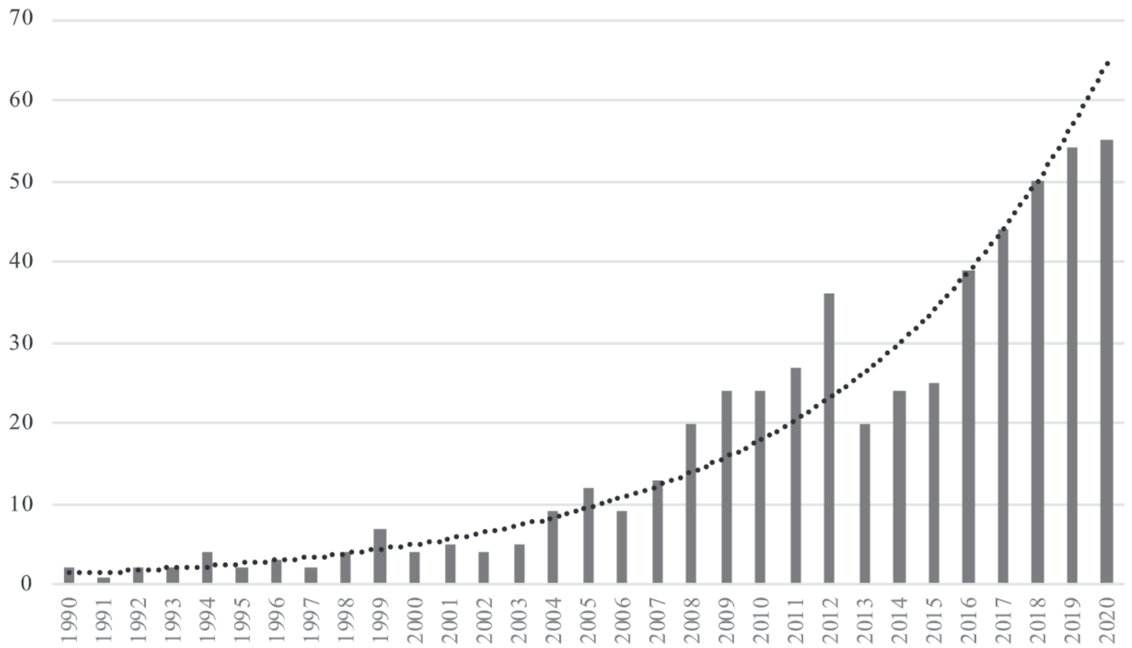


Figure 9: Number of articles with "Order Picking" in the title in the last 30 years

Source: Winkelhaus, Eric H Grosse and Morana, 2021

The majority of the studies have focused on improving the following planning problems separately for *layout design*(e.g.(Bartholdi and Hackman, 2011)), *storage*(e.g., (José et al., 2019)), *batching*(i.e., the accumulation of a smaller number of orders into batches (Gademann and Velde, 2005)), *zoning*(dividing the warehouse into multiple zones e.g. (Ho and Lin, 2017)) or routing(e.g. routing of the order picker through the warehouse during a pick tour (R. M. Elbert et al., 2017)). To view a extensive overview over single OP planning problem optimization the work of Koster et al., 2007 and Gu et al., 2007 is recommended.

More recent efforts have found that these OP planning problems are interdependent(Gils, Ramaekers, Caris et al., 2018), and considering several planning problems simultaneously holds potential for improving performance. Gils, Ramaekers, Braekers et al., 2018 were one of the first studies to explicitly and statistically analyze the relations between the OP planning problems by using a real-life case study for multiple generalized warehouse designs. The results showed that considering batching, routing, storage location assignment, and zoning simultaneously reduced OP time.

However, there is a lack of research on some planning problem combinations, i.e., Storage-Zoning, Batching-Zoning, and Routing-Zoning. The need for more holistic perspectives on OPS is revealing themselves.

2.1.2 Order Picking as a Sociotechnical System

This section aims to clarify the arguments for viewing OP as a Sociotechnical Systems. There seem to be potential benefits to considering a more holistic perspective of the OPS (Gils, Ramaekers, Caris et al., 2018).

Sociotechnical Systems are work systems in which social subsystems, i.e. (employees), and technical subsystems, i.e.(applied supportive and substitutive technology), and the physical warehouse interactions can affect one another (Dregger, Niehaus, Ittermann, Hirsch-Kreinsen and Ten Hompel, 2018). Sociotechnical Systems are related to the interrelatedness of social and technical aspects of an organization. Considering OPS as *a Sociotechnical Systems is meaningful because it yields a framework to view holistic interactions between humans and technology* (Dregger, Niehaus, Ittermann, Hirsch-Kreinsen and Hompel, 2016) and is illustrated by figure 10.

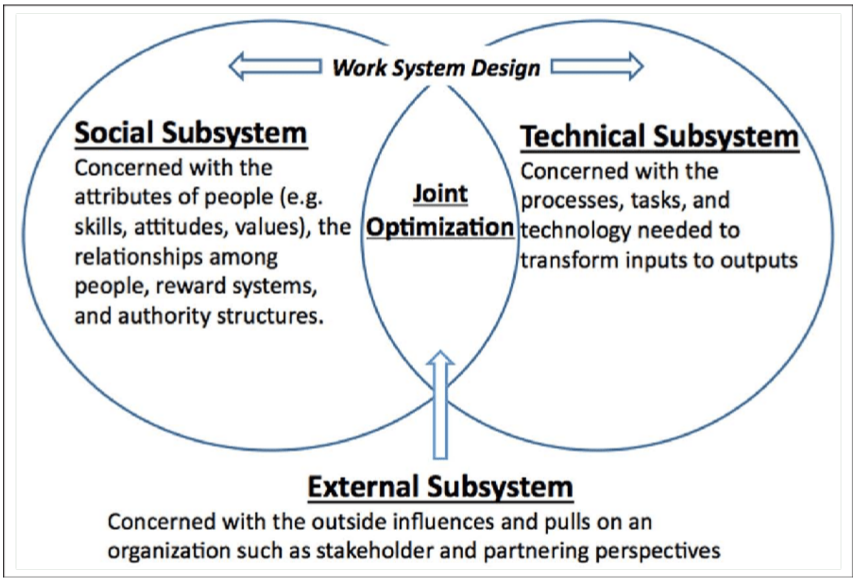


Figure 10: Sociotechnical Systems

Source: Militello et al., 2014

There is precedence fur using seminal literature to facilitate identifying and evaluating social and technological interactions. Bostrom and Heinen, 1977 proposed a framework to redesign existing work systems and separate the system into two jointly independent, but correlative interactive systems, as illustrated by figure 11.

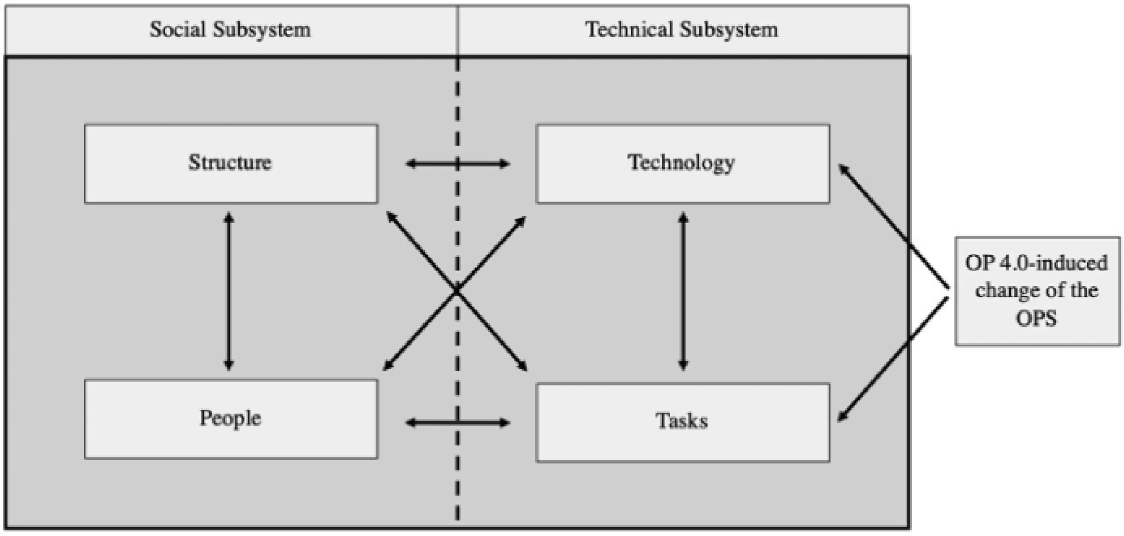


Figure 11: The Interacting Variable Classes In A Work System

Source: Bostrom and Heinen, 1977; Winkelhaus, Eric H Grosse and Morana, 2021

The human-technology interactions are possible to evaluate through the following literature. Eric H Grosse et al., 2014 has proposed a conceptual framework for incorporating HF aspects into planning models of OP activities to improve OP performance, well-being, and reducing OP cost. E H Grosse, C H Glock and W P Neumann, 2017 has systematically evaluated the literature on manual OPS and conducted a content analysis to gain insights into how HF aspects have been considered and discussed in the scientific literature thus far.

Winkelhaus and Eric H Grosse, 2020 introduced and defined the concept of Logistics 4.0. The resulting framework combines external triggers, main technological innovations, the impact of human interactions, and logistics tasks.Winkelhaus, Eric H Grosse and Morana, 2021 took the concept further, applied it to order pickers, and conceptualized OP4.0. He even developed a framework for OP4.0 and Sociotechnical Systems. These articles offer a way to evaluate interactions between social and technological subsystems in a meaningful way.

2.1.3 Defining Order Picking 4.0

The concept of OP4.0 ensures a harmonious union of its derived components. HF aspects and applicable supportive and substitutive technologies and their interactions so that they fit together, provide improved overall system performance, (W Patrick Neumann and Dul, n.d.; W. Patrick Neumann et al., 2021) and facilitate the goals of Logistics 4.0 (Winkelhaus and Eric H Grosse, 2020).

The focus concerning HF aspects is on limiting the load on human order pickers regarding physical, mental, perceptual, and psychosocial demands accumulated throughout the OP process. Automation and other digital technologies aid in supporting or substituting OP tasks and reduce the workload; hence the OP4.0 can be defined as (Winkelhaus, Eric H Grosse and Morana, 2021):

> ”Order Picking 4.0 is a sociotechnical OPS where individual or heterogeneous customer orders are compiled efficiently and sustainably into small batch sizes from a large variety of goods in a warehouse. Additionally, OP4.0 considers automation of supportive and substitutive technologies to a large degree along with HF objectives simultaneously.”

Summary

This section presents the development of OP research in improving OP tasks and planning problems. Additionally, some core concepts and literature used later to address the research objectives are presented:

- The OP research development is presented chronologically. Single planning problems → Combined planning problems → OPS as a Sociotechnical Systems → Holistic view of OP.
- OP is presented in the context of OP tasks and planning problems.
- Bostrom and Heinen, 1977's sociotechnical evaluation of work systems offers a more holistic perspective on OP, and some seminal literature is mentioned here.
- The separation of OP into social and technological subsystems can be used to categorize and sort OP task-related literature.
- Considering OPS as a sociotechnical system reveals a gap in research. Shows that digitization will transform human work in OP and justify further study.
- Recognizing the concept of Order Picking 4.0 as a vessel to drive OP towards increased performance, quality, well-being, sustainability, and incorporate HF aspects simultaneously.

2.2 Different System Settings

This section aims to define the core concepts within system settings in OP so that their significance to HF aspects are identified and allocated correctly later in the research process.

System settings are related to how OP tasks are arranged, designed, and managed to achieve an optimized system (Vijayakumar et al., 2021). System settings is a DL decision. DL signifies decisions that implicate long to medium-long term goals when the system is designed. The variables that involve decision-making in warehouse logistics are processes, *technology* and *system settings.*

Boysen et al., 2019 maintained that the decision problems that had the most significant influence on systems settings evaluated for DL concerns and e-commerce adaptability were (i) layout design planning and (ii) storage location assignment. The idea is to follow the same logic here and primarily focus on these areas when HF aspects are being evaluated to simplify the assessment regarding the research questions in section 1.3.

Humans are the primary actors in picker-to-part OPS(Koster et al., 2007), and several crucial OP design characteristics need to be included to explain their environment. The most important characteristics are the warehouse layout, storage assignment, routing and batching, and zoning (Eric H Grosse et al., 2014). These characteristics can either help or hinder the execution of OP tasks and should be scrutinized.

2.2.1 Picker-to-(?)

To make recommendations regarding technologies on the OPS, it makes sense to present some of the standard system settings most likely relevant for the warehouses evaluated during the research within logistics. The system settings presented are intrinsically linked with batching policy as well.

There are three types of settings that are likely to appear (Bartholdi and Hackman, 2011):

Table 2: Order Picker Settings

Picker-to-Piece	Order picker traverses the pick tour and picks one or few items at the time.
Picker-to-Carton	Order picker traverses the pick tour but picks items by the carton.
Picker-to-Pallet	Order picker traverses the pick tour but collects pallets of items(e.g., by trolley or truck)

The different system settings will pose the order picker with different challenges in the warehouse. The benefit of utilizing the various technologies could change regarding HF aspects. By presenting these three, the discussion of technology and human interactions becomes more nuanced and can be used to simplify the system setting differentiation later.

2.2.2 Layout Design

The concept of layout often involves placing the products conveniently so that it is easy to retrieve when a customer order is received. "Convenience" is a term that depends on labor and space requirements models. These models go from simple to relatively complex depending on the characteristics of the products stored. Pallets are simple since they have uniform dimensions and are usually handled one by one. The concept of "convenience" becomes much harder to settle when discussing the storage and handling of smaller product units, i.e., pieces, cartons, and pallets (Bartholdi and Hackman, 2011).

OP *layout design* consists of two separate issues: 1) The layout of the facility containing the OPS and 2) the layout within the OPS. The former is called the facility layout problem and is concerned with where to place departments, i.e., receiving, storage, packing, shipping, etc. The latter is the *internal layout* and concerns decisions regarding the number of aisles, cross aisles, length, and the width of the aisles. The typical internal decisions are illustrated by figure 12. Minimizing travel distance during an OP tour is often the deciding factor for these decisions (Koster et al., 2007), but factors like HF are receiving more attention (Eric H Grosse et al., 2014).

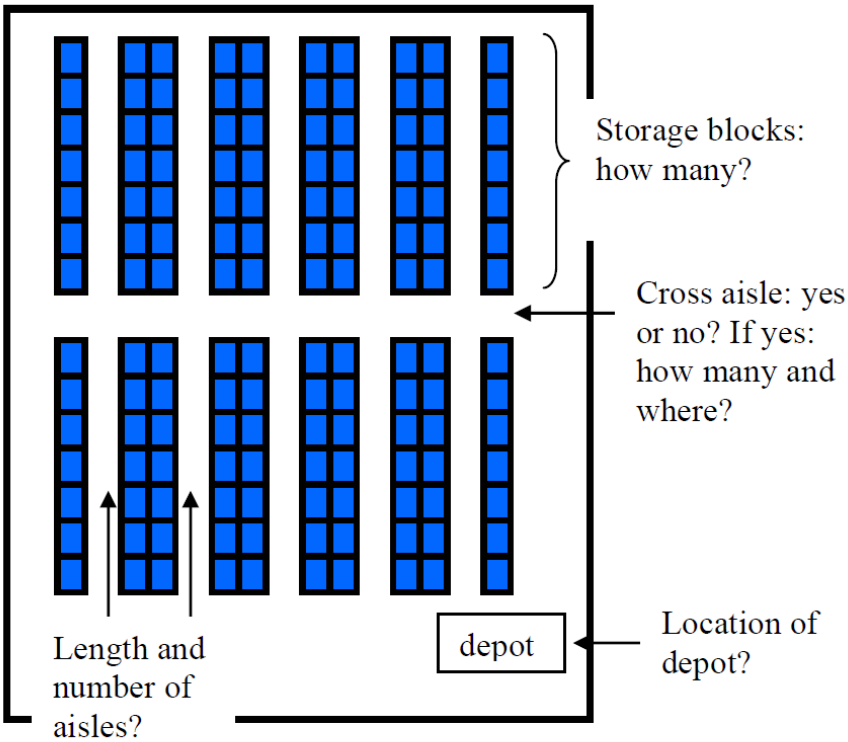


Figure 12: Typical Layout Decisions In a Warehouse

Source: Koster et al., 2007

Most *layout design* research concentrates on the *conventional* arrangement of the aisles with parallel picking aisles and perpendicular cross aisles.

The *warehouse layout* defines the number of depots, their locations, and the aisles' characteristics. Narrow-aisle warehouses can let the order picker pick from both sides of the aisle during a picking tour without needing to cross the aisle. However, wide-aisle warehouses would require increased travel distance to do the same (Masae et al., 2020).

Low-level storage racks allow for items to be picked by order pickers without needing vertical travel (Scholz and Wäscher, 2017). Still, high-level storage racks may require the order picker to travel vertically to complete OP tasks. These two cases are usually referred to as low-level and high-level OPS.

Several characteristics are related to the warehouse layout and are summarized by:

- **Type**
  - *Conventional warehouses* are rectangular-shaped warehouses with parallel

picking aisles and perpendicular cross-aisles(illustrated by figure 12). Warehouses with two cross aisles in the front and back end are often referred to as single-block warehouses, while warehouses with more than two cross aisles are called multi-block warehouses (Masae et al., 2020).
  - *Non-conventional warehouses* have aisles or cross aisles that are not necessarily arranged in parallel but select the layout that allows for easier access to specific regions or improves space utilization(e.g., flying V and fishbone (Çelk and Süral, 2014), and the U-shaped layouts (Christoph H. Glock and Eric H. Grosse, 2012)).
  - *General warehouses* make no assumptions regarding aisles but use general distance matrices instead.
- **Depot**
  - *Number of depots*
  - *Depot locations*
- **Aisle Characteristics**
  - *Narrow aisle*
  - *Wide aisle*
  - *Low-level storage racks*
  - *High-level storage racks*

2.2.3 Storage Location Assignment

A storage assignment method is defined as rules used to assign product locations(Koster et al., 2007). Assigning item locations in storage is a deceptively simple exercise. Still, factors like the volume of products, demand uncertainty, and the increasing requirements for service levels from the market make this complex instead (José et al., 2019).

The Storage Location Assignment Problem (SLAP) relates to allocating products into storage locations/zones that minimize material handling costs and improves space utilization. The chosen SLAP policy might vary depending on the warehouse Stock Keeping Unit (SKU) profiles and storage technology (Gu et al., 2007). The most popular storage policies are random, dedicated, and class-based storage (Gu et al., 2007; Koster et al., 2007).

When using random storage policy, the items are assigned to random empty storage locations without considering other qualities like pick frequency, weight, size, or other pick correlations with other items. Additionally, the location of a specific type of item will change over time when the item is replenished. The policy generally entails higher travel times and distances, but one significant advantage is the edge in space utilization compared with other policies (Koster et al., 2007). A closely associated policy to random storage assignment is called closest open location. The items are not placed at random, but at the nearest available location to the depot (Hausman et al., 1976).

Dedicated storage assignment policies will allocate items to a fixed location in the warehouse storage area, and item characteristics often rule the delegation. The standard policy is to let pick frequency determine the location. Items with higher pick frequency are placed closer to the depot to minimize the travel distance (Koster et al., 2007). Another alternative is the cube-per-index(CPI)(i.e., the items pick frequency divided by its space requirement) to determine the storage location (Malmborg and Bhaskaran, 1990). Additionally, some approaches consider an item's correlation to other items and focus on grouping picks often picked together near each other (Chuang et al., 2012; Eric H. Grosse et al., 2013).

A *class-based storage assignment* policy aims to exploit the combined strengths of random and dedicated storage assignment policies by grouping items into classes(e.g., by their sale frequency or item similarity) and by dedicating each group a dedicated zone in the warehouse. Each zone then has it's class items assigned in the zone randomly to available locations (José et al., 2019).

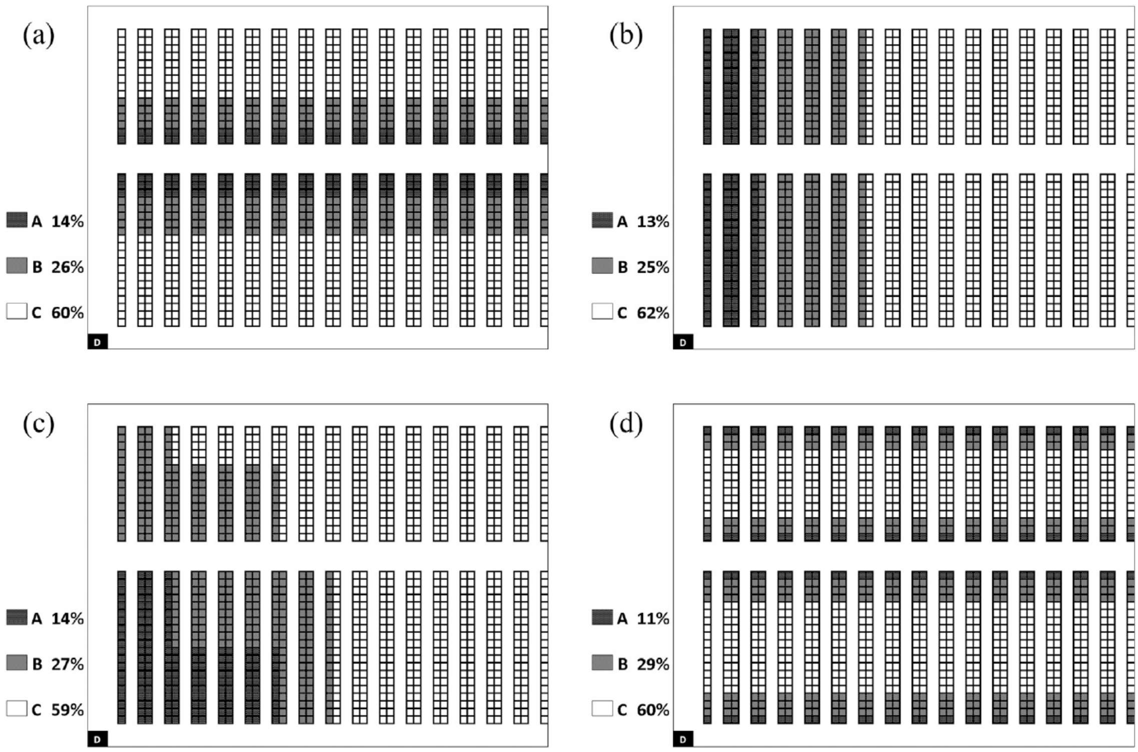


Figure 13: Examples of storage classes (a) Across-aisle, (b) Within-aisle, (c) Diagonal, (d) Perimeter

Source: Gils, Ramaekers, Braekers et al., 2018

Summary

- Random Storage - Storage location is selected randomly from all eligible empty locations.
- Dedicated Storage - The product type has one or more dedicated storage locations for the product.
- Full turnover storage - Products are distributed according to their turnover rates, e.g., the cube-per-order index(COI) rule.
- Class-based Storage - The products are sorted into classes, and the classes have dedicated storage zones.

2.3 Different Technologies

This section's purpose is to showcase the assistive technologies with the potential of influencing HF aspects of OP tasks.

Winkelhaus, Eric H Grosse and Morana, 2021 used a systematic literature review to sort the applied technologies into different OP4.0 OPSs and OP tasks. The relevant technologies for manual picker-to-part OP are isolated and extracted into this thesis.

For many of these technologies Romero et al., 2016 proposed an OP4.0 typology and explored a set of supportive technologies that aided the development of human-automation symbiotic work systems for OP4.0.

Among the OP literature, the technologies that have received the most research attention include Augmented Reality (AR) and smart glasses, followed by gamification, Virtual Reality (VR), and Radio Frequency Identification (RFID) applications (Winkelhaus, Eric H Grosse and Morana, 2021).

The following subsections that address each technology are structured, so the technologies are presented first, then some examples of relevant technology applications follow. The technologies are presented according to the HF aspects they are likely to impact: Phyical → Cognitive(mental & perceptual) → Psychosocial. Most articles are based on lab experiments, simulations, or case studies.

2.3.1 Exoskeletons

Exoskeletons are wearable, lightweight, flexible, and mobile biomechanical systems. They aim to increase the strength and endurance of human operators during manual labor (Romero et al., 2016). Exoskeletons are an assistive tool that has become the subject of increased studies for multiple settings (Nussbaum et al., 2020). However, studies that use exoskeleton in OP tasks are still quite limited.

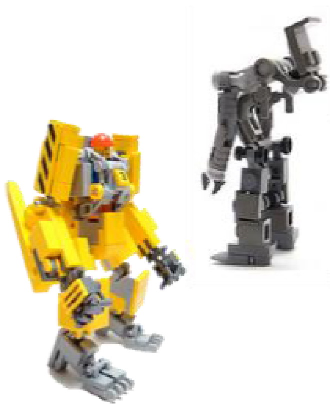


Figure 14: Exoskeleton

Source: Romero et al., 2016

Huysamen et al., 2018 evaluated an exoskeleton setting for two types of loads in lifting and lowering products compared to no support for the loads. The authors found a significant reduction in biomechanical load on the spine and a slight effect on the biceps. Still, only six out of ten workers deemed the device ready for use since it was uncomfortable. Motmans et al., 2018 witch made similar findings and studied a passive exoskeleton that supported the chest and the thighs/upper legs. However, a contradicting finding to the former was found through a usability study since they discovered that the operator accepted the exoskeleton, and only a few movements were assessed negatively by the order pickers.

Kinne et al., 2019 A questionnaire found that the wearing comfort and user handling of exoskeletons during OP tasks needed to be improved before being deployed on a large scale.

2.3.2 Wearables

Wearable devices have many applications. Managers or order pickers can use them to detect and measure stress, heart rate, exercise levels, or evaluate workers' posture during work (Romero et al., 2016). They can also facilitate other technology use(i.e., AR, etc.)

Lind et al., 2020 aimed to evaluate the short-term effect of real-time vibrotactile feedback on postural exposure by utilizing smart workwear to alert the order picker of bad posture in simulated industrial OP. Findings suggested the order pickers found the technology comfortable, usable, and conductive in learning how to maintain a good work posture.

Amiraslanov et al., 2017 recognized that detecting whether something has been taken from a specific shelf affordably and unobtrusively was an issue. The author, therefore, developed a WiCoSens - a wrist-worn color sensor array that could detect color-coded surfaces. The device could provide initial results of 100% accuracy.

Figure 15: Wearables

Source: Romero et al., 2016

Grzeszick et al., 2016 wanted to introduce a tool that could utilize the tactile perception of items to reduce the demands on the visual and auditive senses. By combining a smartwatch and a low-cost camera, the tool could improve the quality of the item recognition process, resulting in less mental strain and improved pick accuracy.

Diete et al., 2017 recognized the importance of reducing errors connected to missed or wrong items and introduced data glasses and a smartwatch. The added benefit of allowing hands-free OP is also a factor.

Kretschmer et al., 2021 subscribed to the idea that frequent cases of mental and physical workloads and prolonged work without breaks resulted in an OP-related health risk. The author introduced a sensor wristband, smartphone app, and Artificial Intelligence (AI) methods to collect and predict physiological data. To maintain the health, productivity, and safety of order pickers device used the individual readings to recommend break frequency for the order pickers.

2.3.3 AR - Augmented Reality

AR is a technology that enriches the operator's perception of the real-world workplace environment with additional digital information, i.e., sound, video, GPS, etc., overlapping with the real-time field of view by using, e.g., Head-Up Displays (HUD), tablets, AR-projectors (Wei Fang et al., 2019; Romero et al., 2016).

Figure 16: Augmented Reality(AR)

Source: Romero et al., 2016

(Mueck et al., 2005) was one of the pioneering actors to make an AR Pick-by-Vision (PbVi) system and submit it to performance testing. Findings suggested the potential for enhancing the performance in terms of workflow and efficiency in OP processes.

Fang and An, 2020 subscribed to using a scaleable and wearable AR system in manual picker-to-part OP to navigate warehouse floors. Findings suggested that pick-by-AR could alleviate the mental strain on order pickers.

Kim et al., 2019 recognized the need to evaluate the significance of choosing the right fit concerning HUD-type(i.e., binocular vs. monocular), User Interface (UI)(i.e., text vs. graphics-based), and information availability(i.e., always-on vs. on-demand). Findings suggested that job performance, workload, and usability depend more on the chosen UI. The graphic-based UI excelled in reducing job completion time and the number of errors.

PbVi systems are often AR glasses or HUD combined with a motion tracker. The system is an assistive technology that supports the order picker by guiding them to the correct pick location and highlighting the right pick. The Warehouse Management System (WMS) provides constant real-time information to the order picker through the glasses. Experiment results suggest that picking errors are reduced by 75% and picking time by 30% compared to paper-based picking systems (Haase and Beimborn, 2017). The best tool to combine with HUD or augmented glasses to confirm picks seem to be a scan-glove (Murauer and Pflanz, 2018)

An order picker can summarize the use of AR into the following segments: inform the picker about the next task, display imagery of products to pick next, display storage location and picking route, provide timely information to avoid congestion, give visual indicators on items to pick and their physical location. Finally, supervise the order picker's status and performance (W. Wang et al., 2020).

2.3.4 VR - Virtual Reality

VR is a immersive multimedia and computer-simulated reality that can digitally replicate anything from design, assembly, or manufacturing environments and let the operator interact with any presence within (e.g., workbench, ailes, production lines) with reduced risk and real-time feedback.

Friemert, Saala et al., 2018 found that researchers could use VR to perform workload and ergonomic analysis of OP tasks in a simulated reality. Potentially reducing costs substantially.

Figure 17: Virtual Reality(VR)

Source: Romero et al., 2016

Ralf Elbert et al., 2018 wanted to evaluate whether VR could be used to train order pickers by simulating 3D warehouses. The authors found that the learning effects were transferable to the real world. Yigitbas et al., 2020 developed a VR training program that integrated an existing WMS and trained order pickers in essential OP processes.

VR can also be used with other technologies to do cheap trail runs or experiments. Renner and Pfeiffer, 2017 used VR to evaluate decisions made regarding design choices for AR supported OP support systems. The findings suggested that PbVi could outperform PtL systems by reducing the required physical head movements.

2.3.5 IoT - Internet of Things

Internet of Things (IoT) describes the network of "things" embedded with sensors, software, etc., to connect and exchange data with other components and systems through the internet (Atzori et al., 2010).

Lee et al., 2018 wanted to address the challenge of increasing requirements of customized orders with high variability and small batch sizes. The author proposed IoT-based WMS with an advanced data analytical approach. The findings suggested improvements in picking accuracy, productivity, and efficiency.

Nagendra Guptha et al., 2018 proposed a IoT architecture for the OP process in a warehouse. The primary outcome of the author's work was the IoT design, but real-time tracking, item visibility, and cost reductions were other beneficial outcomes.

Nagda et al., 2019 combined IoT with AR into a tool called RASPICK. RASPICK could be used as a modular, robust, scalable, and cost-efficient OPS in warehouses of any size. The primary goal of the technology is to reduce the cognitive load of the order pickers.

2.3.6 Big Data

Big Data (BD) refers to the huge amount of data collected by the Internet of Things. Researchers can analyze BD to find hidden patterns that may influence processes.

R. M. Elbert et al., 2017 suggests big data could contribute to procuring real-time data in routing deviations and managing re-routing of the order picker through, e.g., AR technology. Another interesting avenue is analyzing the correlation between deviations and workload during the day.

Figure 18: Big Data

Source: Romero et al., 2016

2.3.7 Barcoding and RFID

The concept of RFID is to use electromagnetic fields to identify and trackable tags attached to objects. The technology has several advantages since it can simultaneously collect a large quantity of data without requiring counter-position, which removes the necessity of many daily mass repeating operations. RFID is a very versatile technology, but in the context of OP, it is usually associated with a WMS. The WMS supported by RFID can collect, transfer, check and update mass data on fast-moving products entry and delivery. Consequently, labor intensity is decreased, and errors related to scanning in repeated manual operations become avoidable, resulting in increased efficiency and accuracy (Yan et al., 2008).

Yeow and Goomas, 2014 compared a handheld *barcode scanner* and paper pick lists in a refrigerated storage facility. The barcode scanner provided an 8.4% in improved productivity and reduced picking errors.

Scheuermann et al., 2016 had the idea of using two types of smart gloves together with a smartwatch and compared them to a handheld barcode RFID scanner. The findings entailed 66% fewer picker errors by using the gloves and performed better in terms of technology rejection and reduced arm fatigue since there was no need to hold a device when using the gloves.

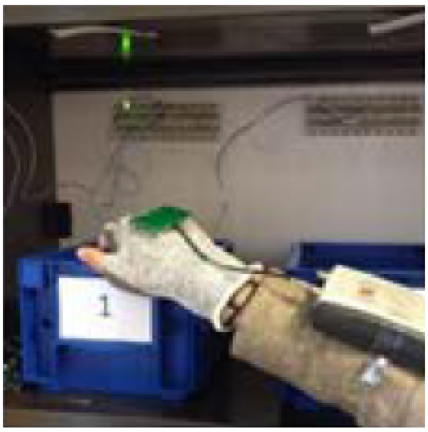


Figure 19: RFID PtL

Source: Scheuermann et al., 2016

Choy et al., 2017 proposed a RFID-based storage location assignment system that could provide decision support for a SLAP in a warehouse built on rule-based logic. One important distinction is that RFID tags are placed at item level instead of pallet level. The results suggest that the system can enhance OP efficiency.

Ma et al., 2018 proposed a way to use RFID to track the location of forklifts, minimize travel distance, optimize the pick-up sequence, and improve OP efficiency.

Nair et al., 2018 describes a new "line of sight" RFID scanner that enhances the user's efficiency by reducing or eliminating non-value-added wrist motions. One obvious additional benefit is the reduced ergonomic strain on order picker's wrists.

X. Wang et al., 2013 recognized that synchronized zone OPS are one of the more effective policies to improve productivity. However, the workload for order pickers often becomes unbalanced in such a system. To remedy this, the author proposed using RFID to get item location timely delivered to the right order picker.

Thomas et al., 2018 identified human-induced errors in order fulfillment as a significant issue. The author investigated the use of a wearable RFID scanner that scan passive RFID tags along with the help of a HUD to guide the user to the correct location. The author compared this OPS to a PtL, pick-to-paper solution. The findings suggested that the pick-to-HUD with RFID enabled *the fastest picking, least pick errors, and the lowest task workload.*

2.3.8 Gamification

Gamification entails using game-design elements in a non-game system context, i.e., OP, to achieve one or more of the following goals: increasing intrinsic and extrinsic user motivation, facilitating information processing, improving goal achievement, and facilitating behavioral changes (Treiblmaier et al., n.d.). There are three signs of intrinsically motivated behavior: immersion, contentment, and satisfaction, and all of the above are experienced by people playing video games or other games (Ryan et al., 2006). However, gamification is considered 75% psychology and 25% technology(Zichermann and Cunningham, 2011), but it's still considered a technology here.

Bright and S T Ponis, 2021 proposed a framework for how to support AR-enhanced OP processes by incorporating a fair and functional reward system through gamification.

There are a few examples of integrating gamification with a WMS to improve the order picker's engagement and performance (Small, 2017). One of them is Passalacqua et al., 2020 work, which provides evidence that a gamified interface can result in higher emotional and cognitive engagement, at least in the short term, and improved performance compared with non-gamified interfaces.

S. T. Ponis et al., 2020 wanted to get an empirical understanding, through a questionnaire-based survey, of the individual acceptance of introducing AR and gamification tools into the OP process to increase motivation and job satisfaction.

Some examples of how management could introduce gamification through feedback and badges are illustrated in figure 20.

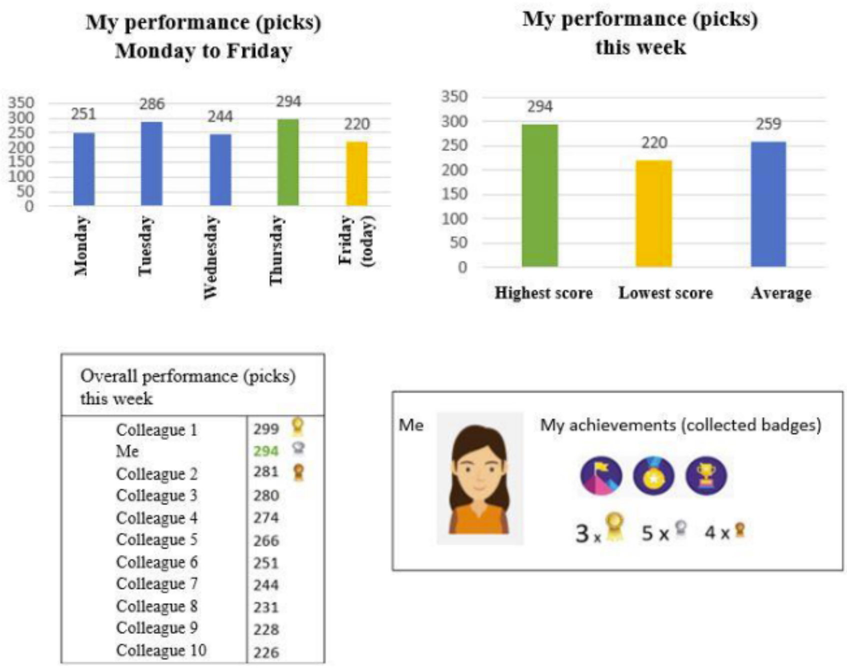


Figure 20: Gamified feedback feature for individual performance

Source: Bräuer and Mazarakis, 2019

2.3.9 Paperless Picking Systems

The technologies previously mentioned can be utilized to support OP in numerous ways, and one of them is to provide methods of paperless order picking.

There are several different types of OP support systems, and here are some of the more common ones (Battini, Martina Calzavara et al., 2015; Christoph H. Glock, Eric H. Grosse et al., 2020):

- Barcode handheld
- RFID handheld
- Pick-by-Voice (PbVo)
- Traditional PtL
- RFID PtL
- PbVi

Battini, Martina Calzavara et al., 2015 compared the picking systems mentioned above by developing hourly cost functions for each system. The findings suggested that the handheld solutions were preferable for low-level OP with low frequency picks per hour. However, with high-frequency pick per hour and multilevel OP, the RFID pick-to-light system performed best.

Alessandro et al., 2013 presented a new PtL design solution capable of supporting many order pickers during the OP, and preventing human errors with new real-time control and alert systems. The system could provide value in three ways: increased accuracy, productivity, and reduced need for training order pickers. Additionally, the system would be easy to use, cheap, modular, and have a low energy footprint.

Pick-to-light

PtL is a method to reduce local search time by having a computer turn lights on to indicate the next pick. One way of using PtL is to install a module that consists of an isle of flow racks, with a passive roller conveyor which pushes products in totes without needing to be lifted, as illustrated in figure 21(Bartholdi and Hackman, 2011).

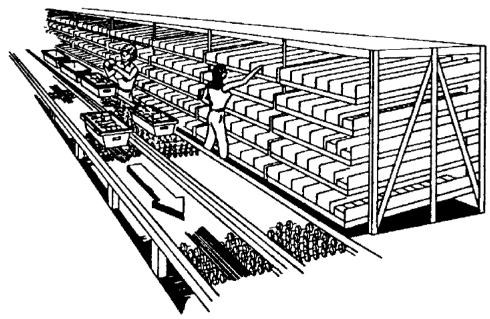


Figure 21: Gravity flow rack for cartons

Source: Bartholdi and Hackman, 2011

Füchtenhans et al., 2021 maintains that Smart Lighting Systems (SLS) has been discussed frequently in the literature but that exploring their potential in industrial environments, i.e., production and logistics, remains a rare occurrence. The literature is systematically reviewed to provide a number of propositions on how SLS can improve the efficiency of warehouse OP.

The three OP outcome factors and the proposed versatile opportunities that SLS offers OP design and management are energy savings, increased operational performance and worker well-being (Füchtenhans et al., 2021):

- Energy Savings
  - SLS may lead to substantial energy savings in warehouses.
  - SLS may influence warehouse processes
- Operational Performance
  - SLS may reduce OP errors.
  - SLS could reduce search times.
  - SLS could facilitate optimal OP routing policies.
  - SLS improves warehouse data transmission and gathering.
- Worker well-being
  - SLS improves worker well-being(i.e., reduced mental strain, less health issues)

Pick-by-Voice

Order pickers receive instructions about pick locations, items, and quantities through a voice delivered via headset. The order picker can verify the correctness of the pick, e.g., by reading the corresponding check string at the pick location. After verification, the pick tour continues. Compared to paper-based picking, the number of errors is reduced significantly. However, the autonomy of the order pickers is reduced, which also hurts motivation and job satisfaction. (Christoph H. Glock, Eric H. Grosse et al., 2020)

Pick-by-Vision

The PbVi system use AR technology to support the OP process. Order pickers use special devices(i.e.,HUD, glasses) for the super position of the real world with virtual object(Ong et al., 2008). The reader is referred back to section 2.3.3 to review the advantages of AR.

Order pickers with PbVi could boast of a 4% work speed increase, and the number of errors reduced to one-seventh compared to paper-based picking.

Summary

Table 3 is a summary of the advantages and disadvantages of different OP support systems, and a general overview of the technologies is found in table 4.

Table 3: Advantages and Disadvantages of Order Picking Systems

	Advantages	**Disadvantages**
Paper-based Picking	Simple and low cost to implement	Time consuming because of longer search times
	Low training time requirements, due to intuitive usage	Real time data exchange is not supported. Pick tour needs to be completed first before the WMS can be updated.
Pick by Light	Supports "hand and eyes free" OP operations and low training time requirements	High capital investment and installation and usually only one picker can work the zone at a time
Pick by Voice	Less errors	Hard to utilize in noisy industrial environments and reduces co-worker interaction, less autonomy
Pick by Vision	Less errors, faster picking	Reduced co-worker interaction, lower autonomy

Source: Haase and Beimborn, 2017

Table 4 provides a summary of the technologies, a choice reference, and descriptions of assistive technologies that emphasize enhancing manual picker-to-parts OP in HF terms.

Table 4: Overview of OP4.0 Technology

Technology	References	Description
Exoskeletonsr	Romero et al., 2016	Exoskeletons are wearable, lightweight, flexible, and biomechanic systems where the human-robotic exoskeleton is powered by a system of motors, pneumatics, levers, or hydraulics that work as a cohesive unit with the operator's body to enhance strength and endurance.
Wearables	Romero et al., 2016	Wearable trackers are devices that detect and measure stress, heart rate, and exercise levels.
Augmented Reality	Wei Fang et al., 2019; Romero et al., 2016	AR is an innovative human-computer interaction technology that overlaps the visual inputs for operators in a context-sensitive way, typically through a graphic interface(e.g., glasses).
Virtual Reality	Romero et al., 2016	VR is immersive multimedia and computer-simulated reality that can digitally replicate anything from design, assembly, or manufacturing environments and let the operator interact with any presence within (e.g., workbench, ailes, production lines) with reduced risk and real-time feedback.
Internet of Things	(Atzori et al., 2010)	IoT describes the network of "things" embedded with sensors, software, etc., to connect and exchange data with other components and systems through the internet.
Big Data Analytics	Romero et al., 2016	Big data analytics is about collecting, organizing, and analyzing large amounts of data to discover useful information and make valid predictions.
Gamification	Small, 2017	Gamification entails using game-design elements in a non-game system context, i.e., OP, to achieve outcomes within increased job satisfaction, motivation, and learning.
Pick-to-Light	Füchtenhans et al., 2021	Pick-to-Light is the utilization of SLS to support the OP process. LED lights to mark the OP item locations along an OP route.
Pick-to-Voice	Christoph H. Glock, Eric H. Grosse et al., 2020	Order pickers receive instructions about pick locations, items, and quantities through a voice delivered via headset.
Pick-to-Vision	Battini, Martina Calzavara et al., 2015	In PbVi order, pickers use AR(i.e., augmented glasses, HUD) to assist the OP process by providing visual cues on details like items locations, quantities, pathing, etc.

2.4 HF aspects and OP Tasks

This section aims to present the HF aspects and explain the framework used to discuss HF and technology interactions.

HF is defined as *"the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design to optimize the well-being of humans and the overall system performance"* (IEA, 2020).

Eric H Grosse et al., 2014 found that even though humans were essential actors in OP operations (i.e., 80% of all orders are picked manually(Koster et al., 2007)), human-system interactions had inexplicably been ignored or considered constant and independent of the essential planning problems in the OP process. To remedy this, the author proposed a conceptual framework to incorporate HF into OP planning to mitigate the previously lacking coverage of order picker characteristics to improve the models and achieve more realistic results. This framework categorizes and describes the impact of technologies and system settings on OP tasks in HF terms. The framework is illustrated in 22

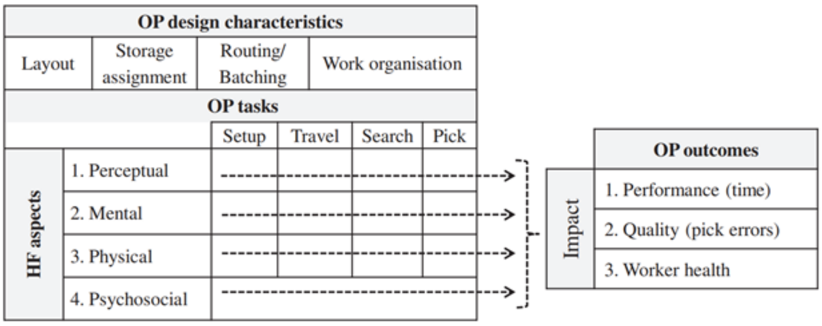


Figure 22: Conceptual framework for incorporating HF into OP

Source: Eric H Grosse et al., 2014

E H Grosse, C H Glock and W P Neumann, 2017 investigated how to best incorporate HF aspects into OP planning problems and further reviewed considerations of HF aspects. Findings suggested that cost efficiency had been prioritized unilaterally and that researchers had paid too little attention to HF in designing the system. This neglect could affect the order pickers' performance and long-term safety and well-being. The author provided the recording units used to identify human-technology interaction impacts of interest concerning the *physical, mental, perceptual, and psychosocial* aspects.

2.4.1 Perceptual

The perceptual aspects are related to the visual, auditory, and tactile stimuli and, consequently, the information processing demands required during the OP process(E H Grosse, C H Glock and W P Neumann, 2017). In short, the ability to perceive new information and the work environment. In OP, the perception of task information from reading a pick list is essential (Eric H Grosse et al., 2014).

2.4.2 Mental

The mental aspects are related to operators' cognitive, learning/forgetting, and behavioral and training condition during the OP process(E H Grosse, C H Glock and W P Neumann, 2017). Technologies and system settings are significant for the performance of warehouse functions.

2.4.3 Physical

The physical aspects involve the physical ergonomics, risk, workload, manual material handling, fatigue, and posture condition of the order picker in the execution of OP tasks(E H Grosse, C H Glock and W P Neumann, 2017).

2.4.4 Psychosocial

The psychosocial aspects relate to the motivational, feedback, incentives, stress, boredom, time pressure, job satisfaction, and personality trait condition of the order picker during the OP process (E H Grosse, C H Glock and W P Neumann, 2017).

When evaluating the OP tasks, the task components are sorted according to the relevant HF aspects by utilizing the framework(figure 22), and the result is illustrated in figure 23

	OP tasks			
HF aspects	Set up	Travel	Search	Pick
Perceptual	• perceive set-up operations	• perceive warehouse layout	• Read pick lists	• perceive pick operations and technical support
Mental	• receive and sort pick lists • Process documents	• Understand and remember pick route	• Search and identify items • Remember item locations	• Decide how to grasp and transfer a given item correctly
Physical	• Set up workstation	• Travel between depot and pick locations • Carry items • Pull/Push trolleys	• Neck flexion extension	• Stretch, bend, reach for items • Extract, grab, pick, put down items
Psychosocial	Motivation, stress, workload, boredom, work organisation, co-worker and supervisory support			

Figure 23: Critical HF aspects connected to OP Tasks

Source: E H Grosse, C H Glock, Jaber et al., 2015

Summary

Some of the key takeaways of this section are:

- Eric H Grosse et al., 2014 provides the framework to evaluate HF aspects in OP planning problems and tasks.
- How to incorporate HF into OP planning and the OP process in general is suggested.
- Defining the core terms and concepts used to discuss HF aspects for order pickers performing OP tasks.

3 Impact on HF aspects

This chapter aims to provide an overview of how the DL factors of system settings & technology can implicate the order pickers' HF aspects. Firstly is an evaluation of how system settings(i.e., layout and storage location assignment) can impact HF aspects—followed by an assessment of the influence of human-technology interactions on the different OP tasks. This section will help motivate and shape the hypotheses presented in the subsequent chapter 4.

3.1 Impact of system settings on HF aspects

This section aims to isolate the system setting impact on the order pickers' HF aspects. The two primary areas of interest in the DL are layout and storage location assignment, addressed in order.

The framework suggested by Eric H Grosse et al., 2014 and elaborated in section 2.4 is used to reason around what HF aspects they affect. The classification of most articles reviewed in this research is case studies, simulations, or lab experiments.

3.1.1 Layout

With a few exceptions, most of the literature focuses on the physical HF aspects because of the costs associated with order pickers developing health issues, i.e., Musculoskeletal Disorderss (MSDs). Some of the more cited and relevant examples include.

Calzavara, C H Glock et al., 2016 evaluated different rack layouts and found that replacing traditional pallet storage with half-pallets with a pull-out system could improve ergonomic and economic performance. Calzavara, Hanson et al., 2017 studied how picking time and ergonomic effort was affected by different storing configurations(i.e., stored in pallets or boxes, tilted towards order picker or not).

Diefenbach and Christoph H. Glock, 2019 wanted to determine an optimal configuration of a U-zone's layout and an optimized storage location assignment policy. Both a minimization of travel distance and ergonomic strain were considered objectives. Findings suggested these objectives were only marginally in conflict and an optimal solution for one of them implied a close-to-optimal one for the other.

Examples of articles addressing other HF aspects than the physical aspects are in the minority, making conclusions based on the literature less reliable. Eric H. Grosse et al., 2013 explored the importance of considering mental HF like human learning in OP by comparing learning curves in a lab experiment. In practical implication, the findings implied that considering human learning in designing the layout and setting up work schedules is essential.

Drury and Dawson, 1974 wanted to evaluate what spatial restrictions could do to the speed and performance of truck drivers. This paper is one of the few articles that deal with perception and is only relevant for the layout as long as system settings cause an excessive spatial restriction for OP.

3.1.2 Storage Location Assignment

The reviewed literature seems to overwhelmingly address the physical HF aspects here as well, which makes sense since developing MSDs is the primary risk factor for order pickers during OP tasks (Larsson et al., 2007). Lower back pain has one of the highest MSD occurrence rates and relates to OP tasks in 50-75% of known cases (BIGOS et al., 1986). These factors explain why the research is primarily around the physical domain.

Traditionally the research focus has been on minimizing travel distance and time in a planar warehouse environment. Still, more recent works have considered different height levels on the storage racks as a decision variable. Petersen et al., 2005 operated with the idea that OP would be less physically demanding and more efficient by having the order pickers do the OP tasks in the "golden zone"(i.e., from the hip and up to shoulder level). Studies like this that include ergonomic concerns are few.

Storage policies like random storage or closest open location have a disadvantage in HF terms by introducing confusion or uncertainty about where order pickers should place items since the item locations change when replenished. These challenges hamper the worker's ability to learn item locations and deploy heuristic policies efficiently (Eric H. Grosse et al., 2013).

3.1.3 Routing, Batching, and Zoning

Here are some examples of the other three planning policies' ability to influence HF aspects on OP tasks in relation to HF aspects.

R. M. Elbert et al., 2017 evaluated OP routing policies' relative efficiency when order pickers deviated from pre-specified routes. Findings made through simulations indicated that the optimal routing policies were quite robust towards deviations(caused by, e.g., confusion) and would mean they outperformed the heuristic methods despite the increased chance for deviations.

Zoning policies reduce the area in which order pickers need to operate in their picking tour. The requirements for remembering storage locations and performing efficient heuristic OP routs are lower by expanding the number of zones. OP is perceived as monotonous and repetitive by order pickers (Azadeh et al., 2019), but unlearned order pickers can still improve their performance by gaining a learning effect over time (Eric H. Grosse et al., 2013).

3.1.4 HF related potential

The overwhelming majority of the literature focuses on the physical HF aspects when seeking to improve performance in OP since the price of neglecting to do so is the highest here. Order pickers that carry most items manually have a higher chance of developing MSDs than forklift and cart users. The most common is lower back pain - only 6% of order pickers never experienced it(Gajsek, 2019). However, this means there is a significant gap in considering the perceptual, mental, and psychosocial HF aspects when making decisions about layout and storage location assignment.

Summary

- Mainly physical HF aspects have received attention from researchers.
- The other three HF aspects have received peripheral attention.
- Using reduced travel distance and ergonomic strain as objectives suggested that the optimization of layout and storage location assignment were only marginally in conflict, and an optimal solution for one of them implied a close-to-optimal solution for the other.

3.2 Impact of Technologies on HF Aspects

This section aims to find and isolate the significance of OP4.0 and assistive technologies in terms of HF aspects in OP tasks. The approach chosen is to identify the relevant human-technology interactions and put them in context with the corresponding OP tasks: *Set up* → *Travel* → *Search* → *Pick*.

Here OP4.0 is a term that references manual picker-to-part OPS in addition to warehouses that use traditional automation technologies (e.g., simple AS/RS)(Winkelhaus, Eric H Grosse and Morana, 2021). These human-technology interactions are considered when quantifying the impact on the ordere pickers' HF aspects.

W. Patrick Neumann et al., 2021 recognized the under-representation of HF aspects related to automation and assistive technologies. The authors proposed a framework to address this gap that integrated critical concepts from human factors engineering important in an I4.0 context. These sentiments are in line with the aim of this thesis.

Bzhwen A. Kadir et al., 2019 wanted to investigate how academic literature integrated the cross-section between I4.0 and Human Factors and Ergonomics into their research.

IEA, 2020 sorted HF and I4.0 related findings into three domains: physical, cognitive, and organizational. The physical ergonomics emphasized physical elements and interactions. Cognitive ergonomics combine the mental and perceptual HF aspects. The organizational domain focused on improving the surrounding organizational aspects of the systems the operators worked. Most of the identified literature addresses manufacturing processes at the lower operational level while neglecting upper levels like decision making, control, and scheduling. However, the qualitative findings that can apply to manual picker-to-part OP and logistics are extracted and illustrated in table 5. Organizational findings are excluded.

Table 5: Emerging Themes in HF/E

Aspects	Reference	Description
Physical	B. A. Kadir et al., 2018	- Manual repetitive tasks are subjected to automation
	Romero et al., 2016	- Wearable and handheld technologies are improving ergonomic feedback.
	Hummel et al., 2015	- New digital technologies are improving the internal logistics and transport
Cognitive	Mazali, 2017	- Virtual models aids in perception and enables better and more timely interaction between departments.
	Baechler et al., 2016	- The need for problem solving abilities and IT skills will increase.
	Romero et al., 2016	- AR will contribute to reducing the mental workload on order pickers during the OP process.
	(Peruzzini and Pelicciari, 2017)	- Changing(i.e aging, immigration, disability) demographics create a demand for logistics of the future.
	(Hummel et al., 2015)	- Data sharing across all the departments reduce the cognitive ergonomic requirements in the order pickers by providing real time individual stress status of a worker.
	Pacaux-Lemoine et al., 2017	- Technology forecasting can spot gaps in skill foundation at an early stage.

Source: Bzhwen A. Kadir et al., 2019

3.2.1 OP Tasks

The following sections will systematically go through the essential OP tasks and record the relevant human-technology interactions that could affect them concerning the framework presented in section 2.4.

Set Up

Before initiating the picking task, the order picker must determine the sequence of picks and prepare the pick tour. The planning and adaptation of the pick tours are essential activities. Two types of technology that can be of particular aid here are IoT and Big Data since they can obtain and process location and process data which eases the workload and improves efficiency (Trab et al., 2017; X. Wang et al., 2013).

Additional interactions of interest are the sensor-based data collected by wearables that can record and eventually predict order picker emotions and improve task management based on the data (Kajiwara et al., 2019). Combining smartphone apps, AI, and wearables allow managers to collect psychological data, predict stress levels, recommend individual breaks to order pickers, and maintain their health, productivity, and safety (Kretschmer et al., 2021; Mättig et al., 2018).

Travel

Several assistive devices can aid in the travel task of a manual picker-to-parts OP, but the author does not address these technologies in this study(e.g., adjustable height carts). The reader is referred to Christoph H. Glock, Eric H. Grosse et al., 2020 for more on these manual material handling assistive devices.

Search

A condition to picking an item is to locate it first, and in a warehouse with extensive product portfolios, this can present a considerable challenge. AR supported OPS have received significant research attention where information is visualized to the order picker(e.g., HUD or wearable glasses)(Wei Fang et al., 2019; Terhoeven et al., 2018).

Promising functionalities include the highlighting of storage locations (Wei Fang et al., 2019) or the ability to adapt the information according to the order picker's desired requirements (Kreutzfeldt et al., 2019). The outcome of such functions is reduced search time and possibly reduced cognitive workload.

The potential in AR is also for simplified routing by showing one pick location after another in the ideal order. This tool, therefore, facilitates applications of more data demanding routing policies(e.i, metaheuristic, exact algorithm)(Gils, Ramaekers, Braekers et al., 2018)).

There is also an argument for showing multiple storage locations simultaneously so that the order picker has more autonomy with what picks to choose(Renner and Pfeiffer, 2020). Autonomy promotes job satisfaction and motivation (Dickinson, 1995).

VR is a tool with a significant potential for training order pickers before exposing them to the warehouse. Additionally, management can use VR to analyze the ergonomics of an order picker's movements (Friemert, Saala et al., 2018). Use of VR can reduce order picker mental load(Elbert et al., 2019) since the learning effects are transferable to real-world scenarios and can be used to support research on HF in logistics (Ralf Elbert et al., 2018).

Pick

After finding the right pick location, the actual pick task commences. Two methods worth mentioning for direct physical support to support this task are *exoskeletons* and *wearables*. *Exoskeletons* can directly support the order picker in picking the items (Romero et al., 2016). In contrast, *Wearables* can support indirectly by providing corrections for bad posture (Lind et al., 2020).

Both methods provide a reduced physical workload for order pickers, but the former allows for more frequent loads at lower injury risk. In contrast, the latter reduces workload by correcting bad posture(e.g., feedback warnings through a wearable clock).

Confirming the pick is another essential aspect in OP since pick errors can impact quality and, by extension, increase costs substantially(E H Grosse, C H Glock and W P Neumann, 2017). There are two main motes of technology that can help here.

Firstly, provide the order picker with the support that automates this activity by delivering timely hints to the order picker if errors occur like IoT and RFID application(Alessandro et al., 2013).

Secondly, incentivize the order pickers to improve quality control. *Gamification* is one of the more promising avenues here, with the added benefits of increased productivity and job satisfaction (S. T. Ponis et al., 2020). These benefits are achieved by engaging in game-driven competition and incentives by incorporating achievement badges and leaderboards, as illustrated in figure 20. The gamification combined with AR would also have a synergistic effect and extract the previously described search-related benefits provided technology rejection does not become an issue(Haase and Beimborn, 2017).

Since quality control is simplified, order pickers can reduce mental strain by utilizing a RFID glove(figure 19). *Gamification* can contribute to a general improvement in HF aspects(Putz et al., 2019), but the potential within the psychosocial aspect is particularly promising.

3.2.2 HF Related Potential

Most supportive technologies are digital, while physical ones like exoskeletons have received less attention because of the limited potential displayed in the literature sample (Winkelhaus, Eric H Grosse and Morana, 2021).

There is a neglect of psychosocial aspects like motivation, job satisfaction, and job autonomy for most reviewed OPS (Winkelhaus, Eric H Grosse and Morana, 2021). It is essential to let the order pickers have a certain degree of autonomy when choosing their pathing throughout the warehouse(Renner and Pfeiffer, 2020).

3.2.3 Technology Adaption Barriers

There are challenges tied to introducing new technologies, and this section lays them out thoroughly.

Haase and Beimborn, 2017 found that when implementing OP support systems(i.e., paperless picking), they could deliver significant value in terms of performance increases. Still, managers can not ignore the importance of considering social influences among workers and other facilitating conditions.

There are barriers to incorporating new technologies and OP support systems(i.e., pick-to-light, pick-to-voice, etc.). According to Haase and Beimborn, 2017 there are seven of these barriers:

- An overwhelming subjective task load
- Perceived reduction of autonomy
- Less social interactions
- Negative influence from co-workers
- High complexity with handling the technology
- Lack of training
- Lack of technology maturity

There are two significant managerial implications to extract from these barriers.

The implemented paperless picking system technology needs to be intuitive and mature. When incorporating new technology, it is necessary to overcome the old habits and routines of the order pickers. The expectations regarding performance and required effort play a key role in adopting new technology. If the technology doesn't work properly, the expected performance boost does not occur. Such malfunctions are a severe threat to technology adaptation.

Managers must impress upon the order pickers that the technologies are supportive and not substitutive when possible. If the workers perceive the new technology as a nuisance or a threat to their job security, the adoption process is dead at birth.

Summary

- The OP tasks of set up, search and pick have the most promising technology interactions.
- Themes affecting physical HF aspects:
  - Manual repetitive tasks are automated
  - Wearable and handheld technologies improve ergonomic feedback
- Themes affecting mental HF aspects
  - Virtual models allow a better perception of warehouses and timely interactions.
  - AR has the potential to reduce the mental workload for order pickers.
  - Aging workforce poses new technology assistive technology considerations.
  - Technology allows real-time assessment of the mental workload.
  - VR allow for a safe learning environment that reduces the mental load of newly introduced order pickers while ensuring performance quality.
- Theme affecting psychosocial aspects:
  - Gamification can increase extrinsic and intrinsic motivation and promote job satisfaction and engagement.
- Technology resistance is a genuine concern when implementing new technology, and proper planning is essential.

4 Hypotheses

This section aims to argue for the hypotheses building and the resulting hypotheses that also contribute to shaping the research questions in section 1.3 that this thesis will address.

4.1 Defining the Hypotheses

A limited sample of literature considers HF in management-oriented OP research (E H Grosse, C H Glock and W P Neumann, 2017). This gap and existing literature contribute to the motivation of the hypothesis building. Some examples of the literature that help inspire the evaluation of system settings & technology configurations impact on HF aspects are listed below and include:

- Evaluating the role of human learning in the OP process (Eric H Grosse et al., 2014, 2013)
- Evaluating the effect that paperless information technologies have on OP errors (Battini, Martina Calzavara et al., 2015)
- Evaluating the physical workload in manual OP in different storage assignment settings and OP tasks (Battini, Persona et al., 2014).
- Evaluation of how behavioral issues, i.e., picker personality, can influence paperless information technology caused by factors like technology rejection (De Vries et al., 2015).

Boysen et al., 2019 found that conventional warehouses were ill-equipped to face E-commerce era requirements. Small orders, large assortments, tight delivery schedules, and varying workloads gave the author reason to survey different warehouse system settings from an operational angle and discover any promising future research areas. The authors' approach of separating OPS according to factors like layout and storage assignment inspired the idea of having system settings be independent variables in the hypotheses building.

System settings, ergonomics, and holistic research were among the areas with a less solid academic literature foundation. Satisfying the demand for practical holistic models presents a significant future challenge. Gils, Ramaekers, Caris et al., 2018 has echoed the same need in his survey on combining multiple planning problems.

The literature identified in section 3 shows that system settings and technology could have significant ramifications to order pickers performing OP tasks in terms of HF aspects. Some hypotheses are needed to check these assumptions empirically and make a deterministic assessment of the literature findings.

The cross-section between what was lacking in terms of an empirical foundation regarding DL decision making in OP and the available analytical tools like NASA Task Load Index (NASA TLX) became the primary motivator for choosing the hypotheses.

Defining Variables

This section provides the variables of interest when assessing the hypotheses in the end. They consist of two types of variables: independent and dependent.

Independent variables are manipulated, controlled, or changed. Independent variables are isolated from other factors of the study. The independent variables include:

- System Settings
- Technologies
- 4 OP Tasks: Setup - Travel - Search - Pick.

As the name suggests, dependent variables depend on other study factors. The changes in the independent variables influence them. They are the categories of the NASA TLX and consist of:

- Physical Demand
- Mental Demand
- Temporal Demand
- Performance
- Effort
- Frustration

4.2 Hypotheses

Considering independent and dependent variables is crucial for achieving satisfactory results and finding definitive empirical findings when building hypotheses. The process used to identify hypotheses is elaborated further in Appendix D. The process resulted in the following hypotheses:

Null Hypothesis 1. *"Variation in the system settings of an OP system has no significant impact on the HF aspects of the order pickers performing OP tasks"*

Hypothesis 1. *"Variation in the system settings of an OP system has a significant impact on the HF aspects of the order pickers performing the OP tasks"*

$\mu_m(SS1)$ = Mean NASA Task Load for picker-to-parts OP.

$\mu_t(SS2)$ = Mean NASA Task Load for parts-to-picker OP.

$$H_0 : \mu_m = \mu_t,$$
$$H_1 : \mu_m \neq \mu_t$$

Hypothesis 2. *"Different system settings & technology configurations(SS1, SS2) can benefit from different assistive technology recommendations to improve HF aspects"*

5 Methodology

This thesis is written with a deductive outlook regarding the research philosophy. The choice of research type is a mixed model, but with an emphasis on the qualitative research methods since the qualitative methods' ability to help understand people's perceptions and experiences are essential to addressing the HF aspects. The research is also empirical since several authors have pointed out the lack of holistic and empirical studies concerning HF and OP. (Eric H Grosse et al., 2014; Bzhwen A. Kadir et al., 2019).

5.1 Research strategy

The research strategy is built to align the steps so that the research questions are addressed and the research objectives are achieved using the appropriate methods. The end goal of this section is to describe the choices of research strategy to provide a solution to the problem in section 1.2. The right research strategy depends mainly on the research aim and questions in section 1.3, which is why the research questions are referenced while explaining the research strategy.

The research is exploratory and empirical. The study was designed to first explore the field to find the hypotheses then empirically evaluate the hypotheses and finally answer the research questions.

The *first research question* depended on the findings made during the literature review to solve the first objective and find the hypotheses. Solving the two remaining objectives required a case study. The data collected consisted of two rounds of semi-structured interviews(T1(Appendix B) and T2(Appendix C)) and a questionnaire. Each interview and the questionnaire has different targeted participants and purposes illustrated in figure 29. The literature review and the first T1-interview findings are required to answer the second objective. The thematic analysis extracted from the interviews and the literature findings on layout and storage assignment should provide insight into system settings & technology configurations. The third objective utilizes the quantitative findings of the questionnaire, the qualitative findings of the interview(T2), and the literature review to analyze how variations in system setting configurations affect HF aspects.

The *second research question* is answered by solving two research objectives. The first objective is achieved by using the literature review to identify promising human-technology interactions and their HF impacts and cataloging them. The second objective is achieved by combining the findings from the literature review in section 6.3 along with those made by the thematic analysis in table 9 and 10.

The literature review helped consolidate the topic's understanding and do so from multiple sources. The selected tool for this task was a scoping review. This step should help address the "who", "why", and "how" of the thesis. The reason for doing a scoping review was to develop a foundation to make the hypotheses regarding OP4.0 technologies and document the human-technology interactions.

The case study was separated into two segments with diverging purposes. The first segment is a round of semi-structured interviews with managers & designers of warehouses to record and clarify the characteristics of the design level choices made for SS1 and SS2. This step facilitates the context and environment for which the research questions are applicable and frames the context of chapter 7 **Discussion**.

The second segment was a combination of a quantitative questionnaire on workload sub-categories within NASA TLX and a qualitative semi-structured interview of the order pickers in the warehouses(Appendix C). The primary purpose of this segment was to get a baseline of the OP tasks in terms of HF aspects from the order pickers with a subjective assessment of their experience with OP4.0 technology applications.

The case study provided an empirical foundation for discussing the research questions and literature review findings. The primary benefit of choosing a case study method is the synergy with the research questions. Case studies excel in solving "how" and "why" questions(Yin, 2014). Lind et al., 2020 used the same case study strategy of semi-structured interviews and questionnaires, so there is precedence for the strategy. The choice is further supported by the fact that most of the literature identified and deemed relevant during the literature review used case studies, lab experiments, simulations, or mathematical modeling.

The research methodology structure is illustrated in figure 24 which connects the research questions to the corresponding research objectives and methods used to solve the research objectives.

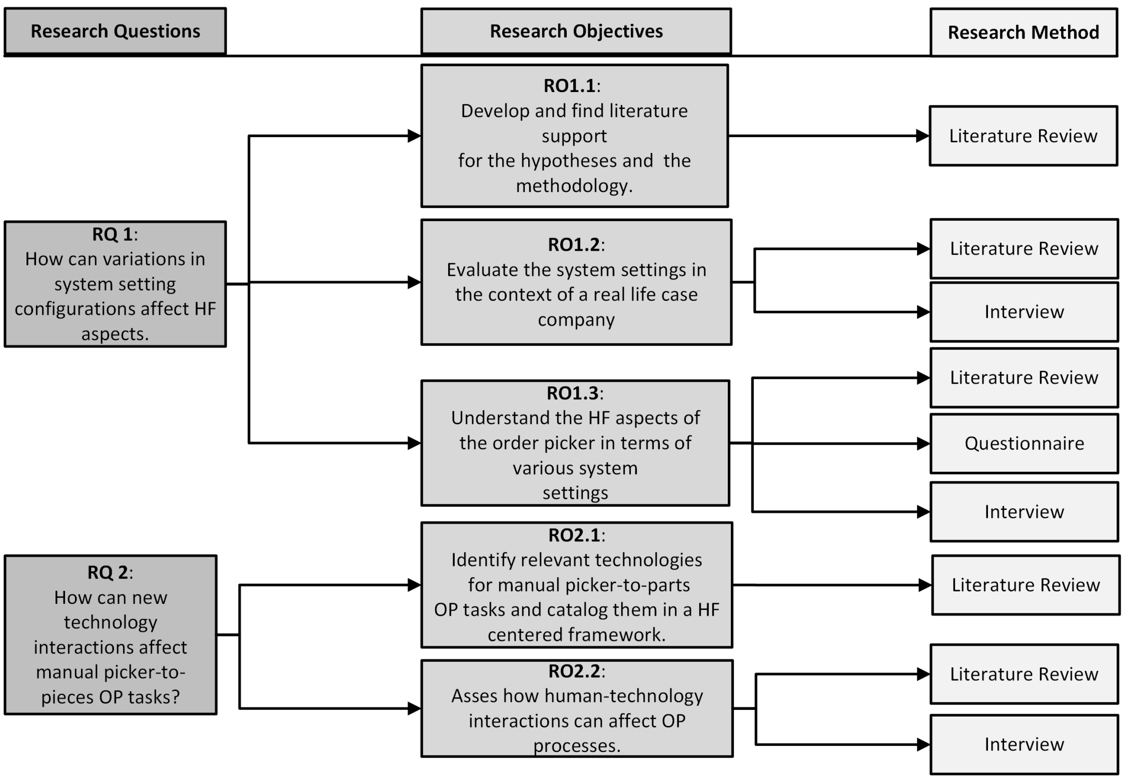


Figure 24: Proposed structure of the research design and the link between the research questions, their associated research objectives, and methods used to achieve the research objectives.

5.2 Theory and Literature Review

5.2.1 Introduction to the Literature Review

The literature review serves several purposes. Firstly, it clarifies what research has been done on the topic. Secondly is the revelation of disputed areas and gaps in the research foundation. These gaps and inconsistencies justify the topic choices. Thirdly, producing the literature review ensures that the research questions are continually improved to reach the research aim. Fourthly, the literature review reveals the most promising methodology used by fellow researchers when addressing the research objectives and questions. Finally, in the context of the case study, the literature review should support two functions: (1) introduce the concepts needed for the reader to understand the paper, and (2) persuade the reader that the research question or POV is credible (Schafer, 2020).

The literature review method is called a *Scoping Review*. In general terms, a *scoping review* aims to rapidly map the key concepts underpinning a research topic, the primary sources, and types of evidence available. The degree of depth of the scoping review is dependent on the purpose. In this case, a thorough summarizing of the field of technology and HF interactions is required so that policymakers, managers, and researchers alike who lack time to do the work can use the findings. The gap in the existing literature becomes clear. Another advantage is that researchers can easily change a scoping review into a systematic review should the need arise (Arksey and O'Malley, 2007).

5.2.2 Search and Selection Strategy

Articles used to orient preliminary knowledge were systematic reviews that synthesized the current research foundation regarding OP, social and technological subsystems well:

- Design of warehouse was supported by the work of Koster et al., 2007 and Gu et al., 2007.
- The reviews of Eric H Grosse et al., 2014 and E H Grosse, C H Glock and W P Neumann, 2017 were used to build a framework to analyze the implications in terms of HF interactions.
- The reviews of Winkelhaus and Eric H Grosse, 2020 and Winkelhaus, Eric H Grosse and Morana, 2021 were used to grasp the concepts of Logistics 4.0 and Operator 4.0 along with the essential technologies that are incorporated here.

Firstly, the scholarly databases of Scopus, Web of Science, and Google Scholar were screened for relevant literature for this study. The author used the scoping review framework and developed three keyword sets for the block search (Arksey and O'Malley, 2007). The author used these keywords to limit the literature to the relevant categories. One set was built around OP, the second was built on I4.0 assistive technologies, and the third built on HF interactions.

The search syntax consists of block searches used across the databases using Boolean operators like 'OR' between words within the sets and 'AND' between the three sets. The papers mainly consist of peer-reviewed scientific journals and are exclusively in the English language(See Appendix E)

Secondly, all duplicated articles(n = 38) are removed. The author screens the titles and abstracts of the remaining papers according to the exclusion and inclusion criteria illustrated in table 6 and those deemed unfit are removed(n = 173). A certain number of articles could not be retrieved in a full-text format and were also removed(n = 51).

In the second round of screening, the remaining articles (n = 32) were read more thoroughly and included if they could provide insight into technology and HF interactions within the scope of OP tasks. The author added the rest of the articles used in the literature review through the process of a *'snowball search'*(n = 27).

Even though the author used a scoping review to keep the review as systematic as possible, the Preferred Reporting Items for Systematic Reviews and Meta-Analyse (PRISMA) was modified and followed the checklist format(See Appendix F). The scoping review methodology follows the PRISMA framework and the steps are illustrated in figure 25

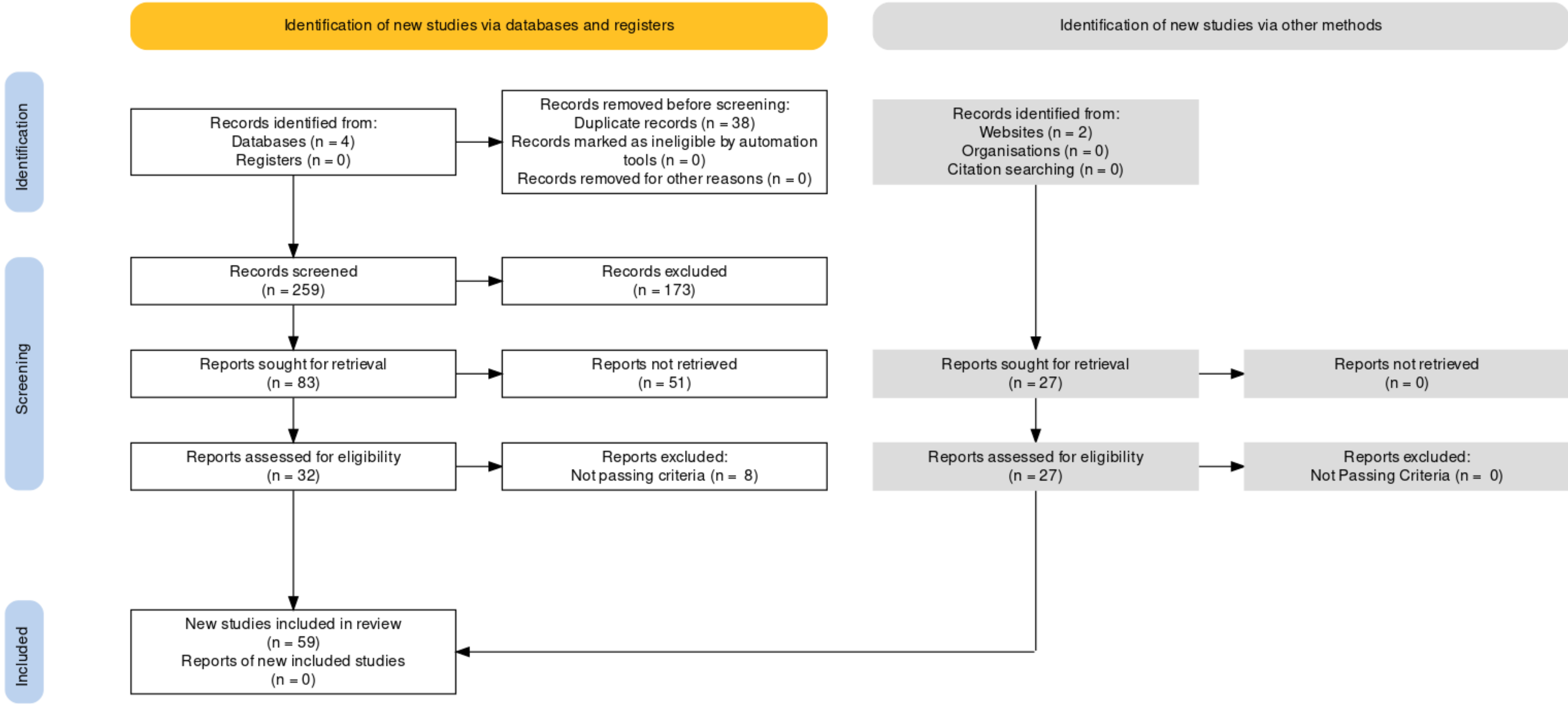


Figure 25: PRISMA Flow Diagram

5.2.3 Review Protocol

The review protocol presented here subscribes to the methodological framework presented in Arksey and O'Malley, 2007 on Scoping studies. The framework consists of five key steps:

- Identify the research question
- Identify relevant studies
- Select studies by inclusion and exclusion criteria found in table 6.
- Data extraction
  - The data relevant for the RQs was recorded in three literature catalogs. One for layout, one for storage location assignment, and one for technology. Key information for layout and storage assignment was what HF aspect they affected and how. The focus of the last catalog was the technology type and the relation they had to the HF aspects. These files are added to the zip file in the final delivery.
- Collating, summarizing and reporting.
  - The results are presented in the form of chapter Theory 2 as a theoretic foundation produced through a literature review process and the literature findings relating to human-technology interaction appear in section 6.3.

The protocol has been inspired by the systematic review written by Winkelhaus, Eric H Grosse and Morana, 2021 when forming exclusion and inclusion criteria. No article older than 2013 has been included in the literature review concerning the technologies since the origin of the term "Industry 4.0" is associated with Kagermann et al., n.d. and almost no other peer-revived journal article or conference paper existed before 2013 (Bzhwen A. Kadir et al., 2019).

Table 6: Exclusion and Inclusion Criteria

Inclusion/ Exclusion	Criteria	Criteria Explanation
Exclusion	Search Engine Reason	The article has the title, abstract, and keywords in English, but the text is in a different language.
	Non-related	The article is not an academic article, i.e., conference paper. Keywords related to another topic because of double meaning, e.g., data warehouses
	Loosely related	The article uses keywords of at least two topics in passing in a quotation, example, or in the research outlook/future studies.
Inclusion	Partially related	The article deals with keywords of at least two categories and mentions the third, e.g., keywords of order picking and manual picker-to-parts OP technologies, and at least a mention in the research outlook. The article directly deals with the intersection of the categories. The article addresses the topic without using the keywords but uses similar/equivalent meanings.
	Closely related	The article handles keywords of all three categories. Deals with two categories, in-depth and cursory, include the third.

5.3 Case Study

The research process requires a case study to facilitate the collection of qualitative and quantitative data. The section contains a brief case study presentation, then a framework and the critical analytical tools are addressed and explained.

5.3.1 Bring AS

Bring AS was established in 2008 and is a Norwegian mail and logistic company operating in the Nordic countries. In Norway, Bring primarily offer its services in a Business-to-Business (B2B) capacity, which physically manifests into the green color of their logo instead of the red Posten logo, which operates in a Business-to-Customer (B2C) capacity. Its strategy is to heavily cater to the Nordic company market and serve its logistical needs(Bring, 2019).

5.3.2 Case Study Framework

The methodology used to extract information from the relevant parties is presented here. A case study is an empirical study that comprehensively evaluates modern phenomena from reality, particularly if the correlation between the phenomenon and the context isn't apparent (Yin, 2014). Yin, 2014 provides the framework used in the case study that supports the data collection. Case studies are an iterative and linear process, as illustrated by figure 26. The different steps are given and explained through this very same framework and expanded upon to represent the case studies.

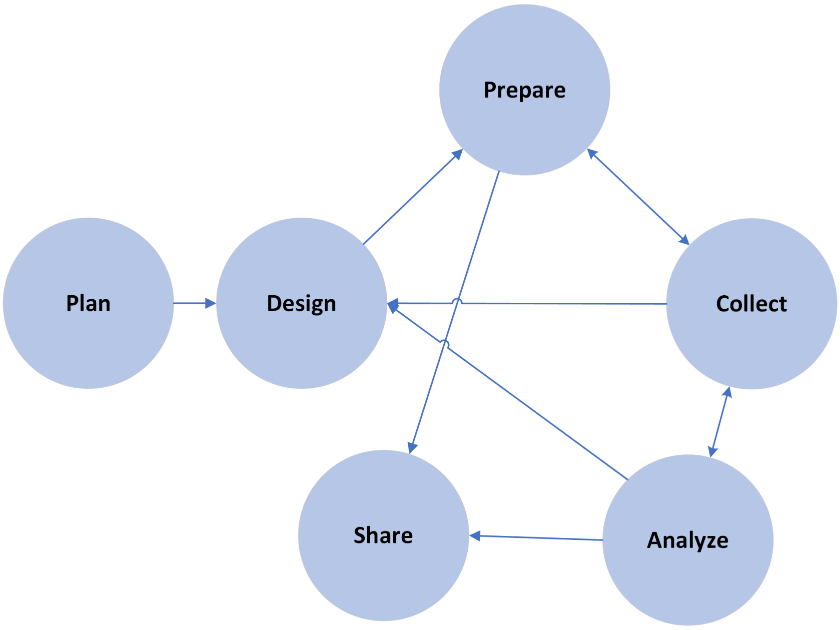


Figure 26: Doing Case Study Research

Source: Yin, 2014, p.50

Plan - To ensure a thorough understanding and overview of the problem and aid in evaluating and solving the hypotheses, a thorough planning phase is essential. Failing to plan is planning to fail. First, a theoretical foundation for the research topic was needed so that the information gathering would be efficient and targeted. The literature collected was beneficial in limiting the scope of what information to gather and how.

Design - The case study design needs to correlate with the aim of the thesis. This step aims to clarify how data collected can be attributed to the research questions and objectives.

Prepare - The preparation stage for a case study requires time. Resolving several vital questions is next on the agenda. "Who should be included and answer which questions?", "What are the access requirements?". The development of two interview guides and a questionnaire needed to be on point before starting the information-gathering process.

Collect - There are two primary sources for the data collection in these case studies at the Bring AS warehouse. Two rounds of semi-structured interviews, T1 and T2(Appendix B and C), and an online questionnaire(Q1).

The first interview provides information on the characteristics of the system settings & technology configurations from the perspective of managers & designers at the warehouses. The second round of interviews addresses the order pickers in the different system settings and technology configurations. It focuses on extracting the physical, mental, perceptual, and psychosocial interactions experienced by the order picker along the OP process. Human-technology interactions are separated into their corresponding tasks, as illustrated in figure 23.

Analyze - The main form of analysis of the interviews(T1, T2) is the thematic analysis, combined with a content analysis of the literature findings used to identify the human-technology interactions, allowing for the results to connect.

Cronbach's Alpha ensures the consistency of the NASA TLX findings. Then the means of the NASA TLX workload sub-categories for each OP task are found. Additionally, the means of each OP task are subjected to a weighting process. The order pickers make pairwise comparisons on the sub-categories, which allows a two-sided Analysis of Variance (ANOVA) analysis of the means.

Share - The findings need to be documented by a rapport to end the case study. An important step in this process is to identify the stakeholders for the study, make a rapport structure and perform quality management.

5.4 Data Collection Techniques

This section aims to provide an overview of the data collection techniques used in the research process. The techniques utilized here include semi-structured interviews and a questionnaire. Included information consists of several aspects: the use purpose and how they are employed, and the stakeholders involved during the data collection.

5.4.1 Semi-Structured Interview

The semi-structured interviews provide the qualitative foundation necessary to shape the hypotheses and provide the required context to address the research objectives. There are two semi-structured interviews arranged for the case studies. T1 and T2.

Interview - T1(Appendix B)

Participants: This interview prioritized management level since DL decisions are generally made here. The manager at the Bring AS warehouses were responsible for finding the participants.

Duration: 1 hour

Purpose: To collect data regarding the design of OPS(e.g., layout decisions, storage location assignment, technology, etc.

Interview - T2(Appendix C)

Participants: Bring AS management suggests order pickers at their warehouses that could participate. These are the stakeholders most affected in terms of HF aspect, making them the most interesting source material.

Duration: 1 hour

Purpose: To evaluate the HF aspects(i.e., physical, mental, perceptual, and psychosocial) of order pickers that perform the OP tasks.

5.4.2 Thematic Analysis

The interviews include much information not directly relevant to the research questions, so an extraction process of what is relevant is required. Thematic analysis can provide a compact overview of the relevant content for the research questions. The technique looks for patterns or meaning in a data set(e.g., interview transcripts) by evaluating bodies of data, often quite large, and groups them according to similarities, aka themes. The method excels in identifying people's opinions and perspectives on issues. When used in exploratory research, the analysis can result in research questions changes, which contributes to the time-consuming nature of the method since the data would have to be re-reviewed every time the research question is adjusted. Sample sizes then naturally become small because of time constraints (Crosley, 2021).

The thematic analysis is deterministic and will follow a predetermined series of steps to provide a qualitative perspective on the six dimensions of the NASA TLX workload through the lens of HF aspects. This analysis is particularly important for making nuanced assessments regarding workload contributors and impact on technology recommendations.

These steps consist of:

Step 1: Initial coding - Get an overview of all the collected data by transcribing audio and screen the resulting text with an initial coding to get familiarized with the content of the interview transcripts.

Step 2: Coding - Descriptive coding is used to create relevant short labels("codes") for describe the content. In the case of interview T1(Appendix B) labels, i.e., process, technology, layout, operational policy, productivity, quality, and well-being) for Interview T2, the assumptions that influence the construction of the thematic framework are illustrated in figure 27.

Step 3: Review the validity of the themes - The thematic analysis is deterministic since the themes are the NASA TLX sub-categories.

Step 4: Sort the codes into the six NASA TLX dimensions to get the qualitative foundation to judge the HF aspects.

Step 5: Report - Write the findings into chapter 6.

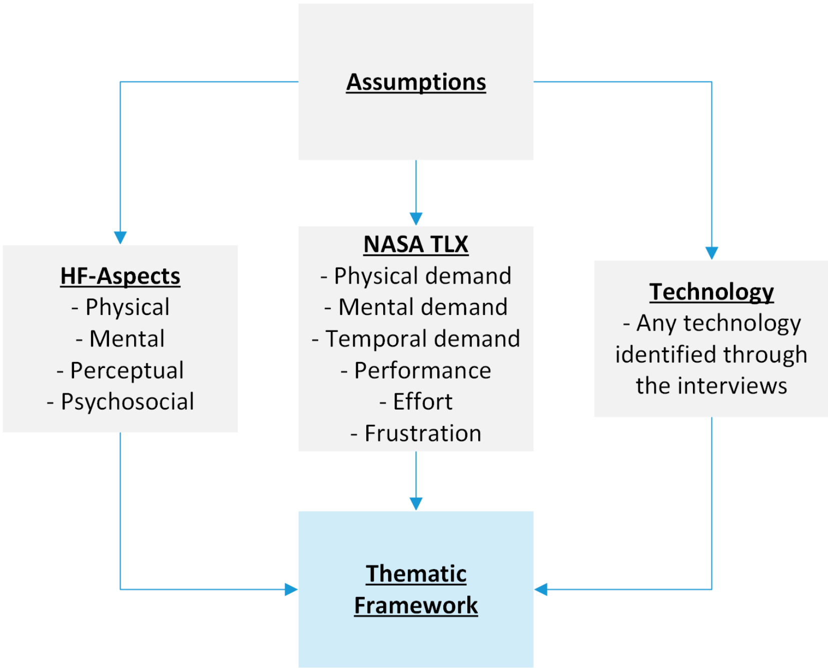


Figure 27: Assumptions Model

The software, NVIVO, made the line-by-line coding and sorting of the findings into themes a more systematic process.

5.4.3 Survey

The survey is a data collection and analysis method used here to describe the phenomena under research. Researchers can use it to collect both quantitative and qualitative data from individuals. This method's important concerns are ensuring a representative sample and response rate. Advantages to using this tool are low cost, convenient data collection, decent statistical significance, and resistance to observer subjectivity and bias.(Forza, 2002) The survey is one of the preferred methods in this situation since it allows for testing whether the hypothesized relationships or differences hold in different contexts.(Karlsson, 2010, p.85)

The most important tool in this survey is a questionnaire. The questionnaire provides the quantitative data foundation required to provide the necessary descriptive statistics to judge the well-being of order pickers during OP tasks. For this foundation, a HF related performance metric was needed. The subjective workload was chosen as the primary criteria since the NASA TLX offered a tried and tested method to evaluate it.

Questionnaire(Q1)

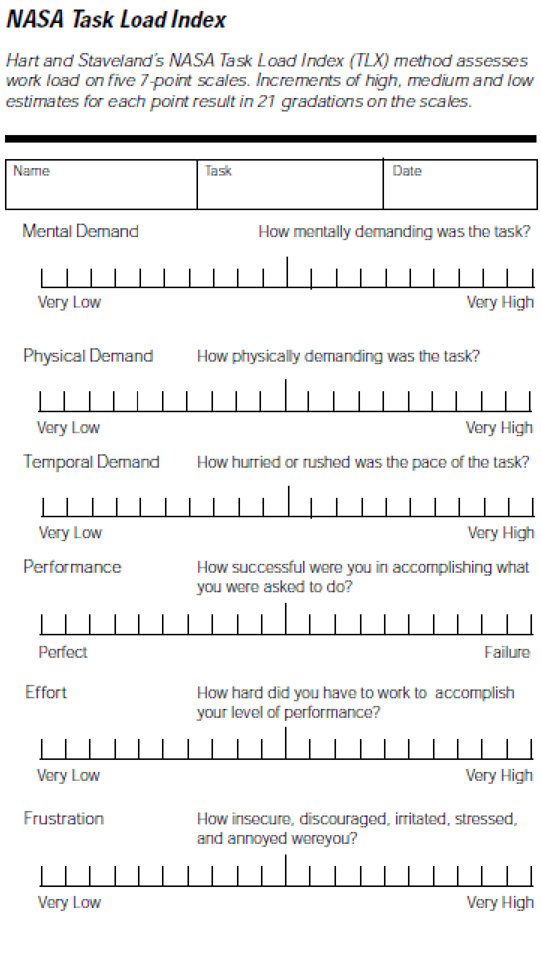
Participants: Order pickers at the Bring AS warehouses. Preferably all of them.
Duration: 10-12 min

Purpose: Provide a quantitative foundation to the descriptive statistics that can evaluate the physical, mental, perceptual, and psychosocial aspects of the order pickers.

- Some additional information on the questionnaire(Q1) is found in Appendix A.

5.4.4 NASA Task Load Index

NASA TLX is a subjective workload assessment tool that allows the users to subjectively assess the workload of order pickers when working with different human-technology interface systems. NASA TLX is used consistently as a questionnaire, and the increasing demand for this tool has resulted in the TLX Mobile App (So, 2020). The tool can provide an overall workload score based on the weighted average of ratings on the six sub-categories. The NASA TLX consists of two parts. The first part is the questionnaire illustrated in figure 28.


NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?
Very Low — Very High

Physical Demand — How physically demanding was the task?
Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?
Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?
Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?
Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?
Very Low — Very High

Figure 28: NASA TLX

Source: So, 2020

The NASA TLX consists of six different sub-categories:

- **Mental Demand**
  - How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
- **Physical Demand**
  - How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
- **Temporal Demand**
  - How much does the order picker feel time pressure due to the pace of tasks or task elements? Was the pace slow and leisurely or rapid and frantic?
- **Performance**
  - How successful was the order picker in accomplishing the task's goals? Degree of satisfaction achieved by accomplishing these goals?
- **Effort**

- How hard did the order picker have to work (mentally and physically) to achieve the desired level of performance?

- **Frustration**
  - How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

The second part of the questionnaire individually weighs the six NASA TLX sub-categories by letting the order pickers engage in pairwise comparisons. The order picker chooses between two sub-categories that they feel contribute most to the total workload. The frequency of each sub-category chosen then becomes the weighted score. This score is multiplied by the sub-category score for each dimension and then divided by 15 to provide a total workload score between 1-100 becoming the overall load index, TLX. Repeating the process for all four OP tasks: *Set Up, Travel, Search and Pick*.

Ralf Elbert et al., 2018 legitimized the choice of NASA TLX in the methodology in a study about transferability of order picking performance and training effect achieved in a VR using HUD.

5.4.5 ANOVA

The ANOVA aims to provide an analytical assessment of the means of the NASA TLX sub-categories extracted from the questionnaire. These means will provide insight into the workload at a specific system settings & technology configuration and support suggestions to HF related aspects in OP. Additionally, the result of the analysis provides a way of weighting the NASA TLX sub-categories the order pickers consider to be the most important contributors to the total workload.

ANOVA has been a popular tool in OP research, e.g., when analyzing the OP planning problems and their influence on each other (Gils, Ramaekers, Braekers et al., 2018).

The progression of the ANOVA follows the corresponding steps:

Step 1: Calculate the mean and establish the null and alternate hypotheses.
  - Null hypothesis make the assumption that there is no significant variance between the overall workload.

$$\mu_1 = \mu_2 = \mu_3$$

  - Alternate hypothesis make the assumption that the means are significantly different

$$\mu_1 \neq \mu_2 \neq \mu_3$$

Step 2: Calculate the sum of the squares, SS.
Step 3: Calculate the degree of freedom, df.
Step 4: Calculate the mean square, MS_w and MS_b.
Step 5: Create a summary table and present the F statistics.
Step 6: Find F ratios through table 7.
  - Compare the F-value on the table to the one in the F-ratio summary.

- If absolute value > critical value $\longrightarrow$ Reject null hypothesis 1 and accept Hypothesis 1 .
- If the absolute value < critical value $\longrightarrow$ Accept null hypothesis 1.

Table 7: ANOVA - Key Metrics

Source of Variance	Degree of freedom	Sum Squares(SS)	Mean Square	F-ratio
Within	$\sum_{j=1}^{SS_{within}} \sum_{j=1}^{I} (x - \bar{x}_j)^2$	$df = k - 1$	$MS_w = \frac{SS_w}{df_w}$	$F = \frac{MS_b}{MS_w}$
Between	$\sum_{j=1}^{SS_{between}} (\bar{x}_j - \bar{x})^2$	$df = n - k$	$MS_b = \frac{SS_b}{df_b}$	
Total	$\sum_{j=1}^{SS_{total}} (\bar{x}_j - \bar{x})^2$	$df = n - 1$		

5.4.6 Cronbach's Alpha

The results from the questionnaire are subjective and made by independent order pickers from the warehouse floor. The results become suspect to several issues. One of which is; reliability. The Chronbach's Alpha(ρ_T) is the most common test score reliability coefficient for single administration(i.e., survey or questionnaire) and excels at providing a simple data consistency check(Cho, 2016).

The most frequent used version of the formula is:

$$\rho_T = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k} \sigma}{\sigma_X^2}\right)$$

Calculating Cronbach's alpha can be done according to several approaches, but excel is the preferred tool here. The step-by-step procedure used:

Step 1: Enter the data
Step 2: Perform a Two-Factor ANOVA without Replication.
Step 3: Calculate Cronbach's Alpha(ρ_T)

Nunnally and Bernstein, 2010 is an authority on how high the reliability coefficients should be, and he suggests that the purpose of the study has significance. In exploratory research, values exceeding 0.7 would suffice, but most empirical studies should strive for a criterion value of **0.8-1.0**. Hence, if the value, ρ_T, found in the results extracted from the questionnaire, is between these values, the reliability is deemed high enough.

5.5 Analysis

This section provides a logical connection between the data collection techniques and the resulting analysis. The findings provide the foundation for solving the research objectives and answering the research questions.

5.5.1 Content Extraction from T1 Interview

The first interview's purpose, T1(Appendix B), is to collect the warehouse management's necessary information on the system setting and technology configurations. Then the key characteristics are placed into table 8.

5.5.2 Thematic Analysis of T2 Interviews

Thematic analysis is the study of patterns of meaning. In other words, it's about analyzing the themes within the semi-structured interviews to identify meaning. The analysis is deterministic, and NASA TLX sub-categories become themes.

The results will yield the factors that reduce or increases the order picker's workload while they perform OP tasks and, by extension, the impact on the HF aspects.

5.5.3 NASA TLX and ANOVA

The questionnaire provides a quantitative set of descriptive statistics in the form of means for the NASA TLX sub-categories for four OP tasks in a particular system setting & technology configurations. These means are then subjected to a weighting process based on the order pickers' choices on the pairwise comparison(ANOVA) of theNASA TLX sub-categories. Managers can combine these weighted means with the qualitative findings from the thematic analysis to make judgments through sub-category comparisons. Finally, the consistency of the data is ensured through the Chronbach Alpha test.

5.5.4 Literature Findings

The combinations of the qualitative and quantitative findings can now utilize the literature findings regarding assistive technologies to suggest improvements to reduce workload. Order pickers doing OP tasks in different system settings & technology configurations might benefit from different strategies when deciding between assistive technology type and order of prioritization.

5.6 Limitations

This section addresses the research limitations associated with the methodology choices made during the research process. No research design or methodology is perfect, and there will always be trade-offs between the "ideal" design and the practical and viable design, given the constraints. The necessary trade-offs will be discussed and justified according to the research context.

There are several points to address when discussing the strengths and shortcomings of the methodology. Some of the more essential limitation categories that the author will address in this section are as follows:

- Access to information
- Time and cost constraints
- Sample size and representativeness
- Methodological and design issues
- Researcher experience and bias

5.6.1 Information Access

Literature Access - The NTNU Oria databases, along with other academic literature research sources(i.e., Scopus, Google Scholar, Web of Science), provide solid access to relevant literature. Still, these sources had fewer articles addressing specific technology applications in OP. Fortunately, ACM(https://dl.acm.org/) could reinforce this aspect, but getting access to full version articles here was difficult.

Case Study - Bring AS were very helpful in providing access to their order pickers and managers for interviews and questionnaires. However, the limited ability to induce participation with the order pickers was an issue in getting the number of order pickers required to claim statistical significance.

5.6.2 Time and cost constraints

The interview guide needed a good trial run. Hence, after scrutinizing the interview guide and questionnaire, the order pickers and managers were involved. Which meant the data collection started much closer to the deadline than initially planned and left less time for data analysis. The thematic analysis was particularly vulnerable to these challenges since the interviews had to be transcribed and put into a thematic framework before being analyzed.

There is no research budget since this is a student research work product with no grants. Hence, lack of funds limited the ability to incentivize the order pickers and managers to participate in our questionnaire.

5.6.3 Sample size and representativeness

Semi-structured interviews are time-consuming the sample size will be small. However, only one order picker per system setting was interviewed, which is not ideal. There are inherent issues with how representative the findings will be.

The questionnaire used to collect the quantitative data has a sample size of 10 order pickers. Half the population represents one system setting & technology configuration each. This sample size is not large enough to claim statistical significance, but maybe enough to study some trends. The author then checked the consistency of the data with Chrohnbach Alpha.

Representativeness of data faces two challenges. 1) The OP tasks are not universal, and the separation of setup, travel, search and pick is a bit arbitrary since the order pickers don't naturally compartmentalize the tasks like this. 2) Different technology and system settings affect the OP tasks and the qualitative data collected in the questionnaire.

5.6.4 Methodological and Design Limiations

The mixed model approach was chosen to allow for analysis with both qualitative and quantitative methods and allow them to compensate for their inherent weaknesses. These methods suffer from different limitations.

Qualitative research has limitations tied to subjectivity and built-in unavoidable bias. The findings are often harder to generalize and are labor-intensive and expensive.

Quantitative methods have difficulties capturing real-world complexity; little information is known about each respondent, and they have difficulty recognizing the "right" questions/hypotheses.

Scoping review

A scoping review is a qualitative tool subject to the same limitations. The block search was first limited to Scopus and Web of Science databases, which are strong on OP and illustrated in Appendix E. One potential issue for replicating the research would be the substantial number of articles found through citation referencing, and snowball searches were articles found in databases like ACM(https://dl.acm.org/) and PubsOnLine(https://pubsonline.informs.org/). Many articles were found through the 'snowball technique, making the review harder and more time-consuming to replicate.

System settings were incorporated into the research aim after the first scoping review because the author recognized the synergy between system settings & technology for HF aspects through the literature review process. Consequently, the theoretical foundation was weaker on human-system setting interactions than human-technology interactions. To remedy this issue, the author used the "snowball method" to overcome the disparity. In hindsight redefining the build search phrases would be a better solution.

Motion Capture System (MCS) applications relevancy to order pickers' HF aspects was discovered too late in the writing of the thesis so it was not included in the literature review which means the chapter 2 **Theory** lack a section on the technology.

Case Study

The case study examines phenomena within a specific context and is a qualitative method used to test the hypotheses.

The questionnaire bases its structure on the NASA TLX. There is a disconnect between the perspectives on the NASA TLX and the research questions. The NASA TLX is a subjective snapshot of the subjects' workload intensity on specific OP tasks, and the framing of the research questions is holistic and thus harder to compare. *Crohnbach's alpha* ensure the consistency of the data collected from the questionnaire.

The NASA TLX is a limited analysis method focusing on subjective workload. Hence, the hypotheses considered by the collected findings should be judged accordingly. The results need to be interpreted carefully and not necessarily regarded as definitive.

Preferably the author should have made a trial run with the interview guides and the questionnaire to scrutinize them before being implemented at full scale properly, but time constraints did not allow it.

The study is cross-sectional, but having a longitude sectional approach could improve the validity of the findings, but time requirements are an issue.

The areas of interest for the research question are the findings related to system settings and human-technology interactions. The HF aspects of the physical and mental domains are covered well by the NASA TLX, but the data collection could have better evaluated perceptual and psychosocial aspects. To remedy this shortcoming, the interview(T2, Appendix C) has included some questions on the topic.

5.6.5 Researcher experience and bias

The author is a student in a Master program in Production Management at the Department of Mechanical and Industrial Engineering(MTP) at NTNU with exclusively theoretic academic experience with OP processes. Work experience is limited by being a wheelchair user as well. Some holes in the practical foundation are bound to be there. Still, the qualitative findings from interviews with managers and order pickers should mitigate the bias from lack of experience. However, keep in mind that the very nature of qualitative methods means the authors' bias and experience will affect the results.

5.7 Summary

The following steps can summarize the methodology. Firstly, the literature review provided the foundation for the hypotheses evaluated during the research process and identified the relevant human-technology interactions that impact HF aspects through a scoping review. Secondly, the case study design is two-fold. First a questionnaire(Q1 Appendix A) built on NASA TLX provides the quantitative empirical data and two semi-structured interviews(T1 & T2 - Appendix B & C) provide the qualitative empirical data. Thirdly, the interviews are analyzed through thematic analysis while the questionnaire is subjected to ANOVA to make workload impact on different OP tasks easier to analyze. Finally, figure 29 shows a step-by-step illustration of the methodology.

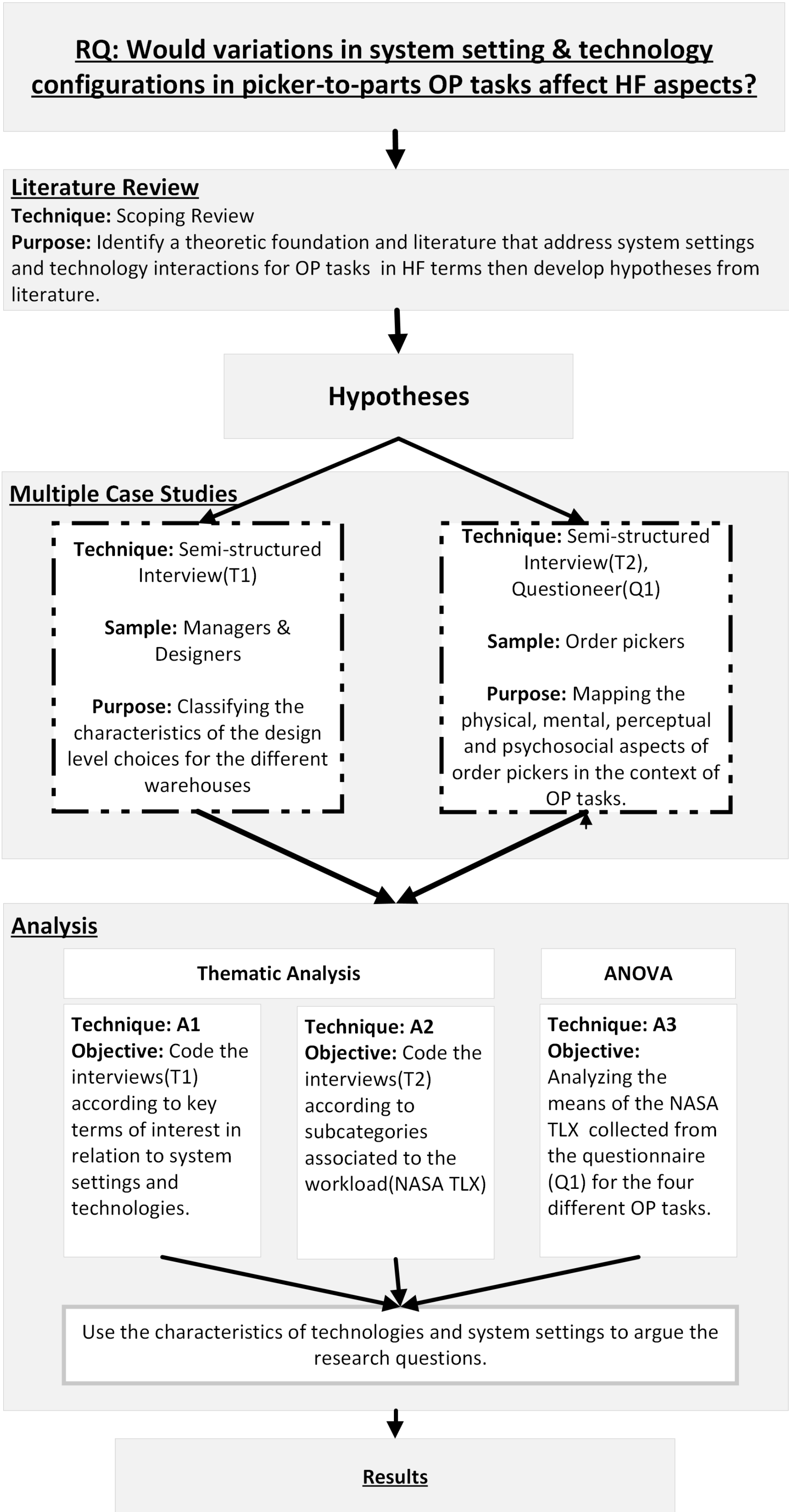


Figure 29: Methodology - Summary

6 Results

This chapter contains the findings made while solving the research objectives. The overarching aim is to empirically explore how OP tasks are affected by the DL choices. The avenues explored include system setting & technology configurations along with the human-technology interactions directly affecting HF aspects. Based on the findings, the hypotheses in section 4 are hopefully either validated or invalidated. First. is a description of the experience of the participating order pickers. Secondly, is a presentation of the characteristical traits of the two system settings & technology configurations. Thirdly, is a presentation of the qualitative findings from the thematic analysis. Fourthly, is a presentation of the results from the NASA TLX and ANOVA application. Finally, is the presentation of the relevant literature findings for human-technology interactions.

6.1 Qualitative Case Study Findings

The study questionnaire was conducted with ten participants. Five order pickers operating in picker-to-parts(SS1) OP and five order pickers in parts-to-picker(SS2) OP. Figure 30 shows the picking experience of the order pickers participating. Six participants had 2-3 years of experience while only one exceeded ten years of experience.

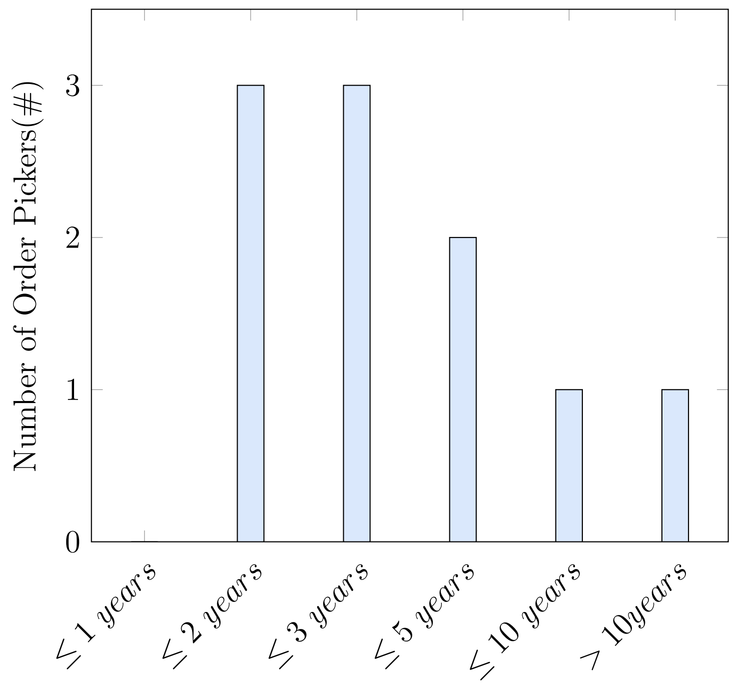


Figure 30: Participants' Order Picking Experience

6.1.1 System Settings(SS1 and SS2)

The author interviewed only one order picker in two rounds from management at Bring AS. One round focused on the picker-to-parts OP(SS1), and the other focused on parts-to-picker OP(SS2) in the new planned warehouse. The managerial perspective on OP is investigated through the semi-structured interview(Appendix B) explained in section 5.3 Case Study. The findings include the characteristical traits of the system settings & technology configurations that are illustrated in table 8.

Table 8: System Settings(SS1 and SS2)

	SS1	**SS2**
Process	The process consists of packing heavy goods and white goods (i.e., washing machines, refrigerators, furniture, etc.). Product type are built pallets.	Sorting and packing smaller packets into pallets with high frequency
Technology	Forklifts, barcode scanners, WMS(PtL(GLOW)).	Interface, forklift, barcode scanner.
Layout	Approximately 15 aisles. Length = 30-40 meter. Height = 15 meter. Racks split into four levels of 2 m each. Conventional warehouse layout. Heavier items at floor level and serviceable by forklifts.	Similar layout is assumed in those areas in which conveyor belts or AS/RS does not automate.
Storage Location Assignment	A hybrid solution of class-based and random storage is used. Within classes the weight along with a WMS decides the final location of an item.	Same approach as in SS1.
Other Operational Policies	**Zoning** - Pick-and-Pass solution is used. **Routing** - Managed by a WMS PtL(GLOW) to optimize routing paths. **Batching** - Priority and schedule decides the pick lists. Big items first to make a solid pallet.	**Zoning** - Just as in SS1 the zones are related to the type of goods treated here as well. **Routing** - The ability to practice optimal routing will be stronger by implementing robots that can retrieve pallets automatically. **Batching** - Same as SS1.

Figure 31a show the storage rack environment that SS1 order pickers navigate in when picking pallets in the warehouse. Figure 31b show the pallets that SS2 order pickers use to build pallets with smaller packets.

(a) Storage Racks for SS1 Order Pickers

(b) Pallets For Smaller Pallets(SS2)

6.1.2 Thematic Analysis

The order picker perspective was collected by interviewing two order pickers representing their system setting & technology configuration, SS1 and SS2. Tabel 9 and 10 hold the qualitative findings identified through interview T2(Appendix C). The emphasis is on the factors that can affect the workload of order pickers either positively or negatively in SS1 and SS2.

Table 9: Qualitative Findings for SS1

	Physical Demand	Mental Demand	Temporal Demand	Performance	Effort	Frustration
Beneficial	Exoskeletons support lower back, shoulders and biceps. Heavy physical lifts is rotated often Job rotation and break management	Job rotations and break management Coworkers working around you requires good perception of environment. Teamwork dynamics reduce mental strain		Teamwork improves productivity and quality control.		Pallet building autonomy is good for motivation. Management is good at feedback and training. Productivity is it's own reward for some. Self-realization over financial incentives.
Challenges	Exoskeletons tire pickers faster and gets stuck. High volume of heavy items. Tired pickers cause accidents and sorting errors	Fatigue from whole process instead of any one task. Order intensity amplifies load. Mental load primary in setup. PDA issues = mental load Tired pickers leads to accidents and sorting errors	Feeding new production is a bottleneck. Too few pickers is an issue. Time pressure causes accidents during travel. Checking condition damage and sorting errors is time consuming.	Invalid barcodes and sorting is an issue. Congestion and physical blocks.		Boredom is an issue. Burnout in production is a problem.

Table 10: Qualitative Findings for SS2

	Physical Demand	Mental Demand	Temporal Demand	Performance	Effort	Frustration
Beneficial	Job rotation & break management. Forklifts relieve load	Job rotation & break management. Interface help make required information available. Handheld scanners and glove scanners help identify items.				Good support and feedback from management and coworkers.
Challenges	Picking is physically taxing. Lower back pain is a recurring issue. High order intensity means wrists and shoulder issues. Heavy packets are dragged and often damaged. Automating the heavy manual tasks.	Too few pickers. High mental fatigue, increasing with order intensity. New sorting technology wanted. Small packets complicate the pallet building. Visual recognition used to identify packages. Increased knowledge and training could help. Wrong barcodes and sorting errors	Too few pickers	High workload and carelessness lead to human errors		Order pickers are often stressed. Low motivation and lack of resources are consistent problems. Repetitive work leads to bored pickers.

6.2 Quantitative Case Study Findings

These are the quantitative findings made through analyzing the data extracted from the questionnaire explained in section 5.4.3.

6.2.1 Data Consistency

Table 11 show the Chronbach Alpha values of the data collected from the questionnaire(Q1) and indicate the consistency of the data for both system settings & technology configurations and the four OP tasks.

Table 11: Chronbach Alpha values(ρ_T) for OP tasks in Q1

Task	SS1	SS2
Setup	0.89	0.96
Travel	0.83	0.93
Search	0.94	0.98
Pick	0.96	0.93

6.2.2 NASA TLX Workload Distribution

Figure 32 and 33 show the distribution of workload over the NASA TLX sub-categories for SS1 and SS2.

SS1

	Setup		Travel	
	Weighted	Raw/Unweighted	Weighted	Raw/Unweighted
Overall	36.27	33.33	33.87	29.00
Diagnostic Subscores				
Mental	75.00	26.00	42.00	28.00
Physical	142.50	32.00	20.00	18.00
Temporal	124.00	23.00	256.00	58.00
Performan	34.00	14.00	54.00	14.00
Effort	192.00	64.00	124.00	34.00
Frustratio	50.00	32.00	28.00	22.00

SS2

	Setup		Travel	
	Weighted	Raw/Unweighted	Weighted	Raw/Unweighted
Overall	69.08	67.67	65.60	62.00
Diagnostic Subscores				
Mental	128.00	80.00	296.00	74.00
Physical	312.00	78.00	70.00	46.00
Temporal	266.00	54.00	220.00	84.00
Performan	56.00	24.00	64.00	20.00
Effort	224.00	80.00	308.00	80.00
Frustratio	90.00	60.00	68.00	68.00

Figure 32: Workload Distribution of Setup and Travel

SS1	Search		Pick	
	Weighted	Raw/Unweighted	Weighted	Raw/Unweighted
Overall	56.27	54.67	61.33	50.67
Diagnostic Subscores				
Mental	70.00	46.00	15.00	24.00
Physical	165.00	60.00	358.00	78.00
Temporal	192.00	60.00	144.00	64.00
Performar	48.00	16.00	52.00	18.00
Effort	318.00	76.00	324.00	76.00
Frustratio	140.00	70.00	60.00	44.00
SS2				
	Weighted	Raw/Unweighted	Weighted	Raw/Unweighted
Overall	65.81	64.33	72.00	72.33
Diagnostic Subscores				
Mental	306.00	76.00	274.00	80.00
Physical	46.67	52.00	85.00	62.00
Temporal	200.00	86.00	286.00	94.00
Performar	124.00	32.00	104.00	36.00
Effort	234.00	80.00	206.00	84.00
Frustratio	200.00	60.00	293.33	78.00

Figure 33: Workload Distribution of Search and Pick

Figure 34 show the workload distribution for the order picker's four OP tasks in SS1 and SS2. These diagrams use the workload values weighted in the questionnaire through two-sided ANOVA.

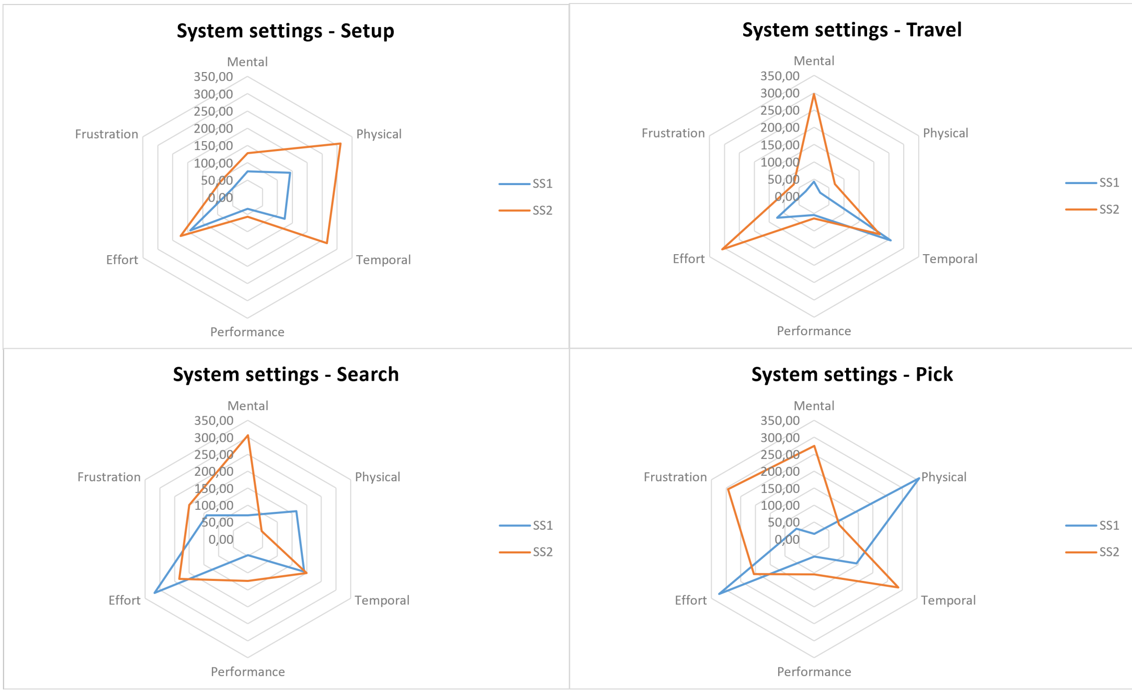


Figure 34: Weighted NASA TLX Workload Distribution for Order Picking Tasks

6.3 Literature Findings

The literature review process identified the literature findings which apply to the research questions.

6.3.1 Human-Technology Interactions

Here are the findings from the literature review process related to human-technology interactions in picker-to-parts OP. The index used to make the overview of interactions are found in table 12.

Table 12: Technology Abbreviation Index

Technology	Tech ID
Exoskeleton	EX
Wearables	W
Augmented Reality	AR
Virtual Reality	VR
Internet of Things	IoT
Big Data	BD
Paperless Picking	PP
Radio Frequency Identification	RFID
Gamification	GM
Apps	APP
Artificial Intelligence	AI
Motion Capture Systems	MCS

The human-technology interactions experienced by the order pickers are sorted into three different OP task and HF aspects. The *setup*, *search* and *pick tasks* are found in table 13, 14 and 15.

Table 13: OP Task - Setup

Set Up			
HF aspects	**Reference**	**Tech**	**Interaction**
Physical	X. Wang et al., 2013	IoT, BD	Manage and balance workload, reduce fatigue
	Calzavara, C H Glock et al., 2016	MCS	Identify the fatigue level of different pick heights and settings
Mental	X. Wang et al., 2013	IoT, BD	Manage and balance workload and reduce fatigue
Perceptual			
Psychosocial	Kretschmer et al., 2021; Mättig et al., 2018	APP, AI, W	Predict stress levels and recommend individual break schedules for order pickers.
	Kajiwara et al., 2019	W	Predict human emotion and improve task management. Influence stress, motivation and job satisfaction
	X. Wang et al., 2013	IoT, BD	Manage and balance workload, reduce fatigue

Summary - Improved physical health, reduced mental load, and improved psychosocial well-being.

Table 14: OP Task - Search

Search			
HF aspects	**Reference**	**Tech**	**Interaction**
Physical	Friemert, Kaufmann et al., 2019	VR	Positive implications for physical workload by correcting bad posture
	Friemert, Saala et al., 2018	VR	VR moch-up warehouses can support general ergonomic analysis in OP
Mental	Fang and An, 2020	AR	Guide the order pickers through the warehouse
	Wei Fang et al., 2019	AR	Aid by highlighting the picking locations
	Kreutzfeldt et al., 2019	AR	Adapt the level of complexity of information to the individual order picker
	Elbert et al., 2019; Friemert, Saala et al., 2018 **elb**	VR	Train order pickers outside the warehouse environment and improve ergometrics (e.g. posture)
Perceptual	Renner and Pfeiffer, 2020	AR	Show multiple item locations simultaneously to simplify routing. Can reduce errors and time needed for visual search
	Kreutzfeldt et al., 2019	AR	Adapt how information is provided to the individual order pickers
	Friemert, Kaufmann et al., 2019	AR	PbVi adequatly supports order pickers, particularly in shorter intervals, but the design of the AR is essential.
	Amiraslanov et al., 2017	W	Aid in tracing items back to their specific shelves through color coding detection.
Psychosocial			

Summary- Mental and perceptual aspects are the primarily affected aspects in the search process.

Table 15: OP Task - Pick

Pick			
HF aspects	**Reference**	**Tech**	**Interaction**
Physical	Huysamen et al., 2018	EX	Reduced physical workload on back and biceps
	Lind et al., 2020	W	Improving posture and reducing physical workload. Comfortable smartwear
Mental	Alessandro et al., 2013	IoT, RFID	Alerting pick errors and improving quality control
Perceptual	Grzeszick et al., 2016	W	Improving item recognition by allowing the tactile senses to be used in increasing item pick accuracy.
Psychosocial	S. T. Ponis et al., 2020	GM	Increased productivity and job satisfaction along with improved quality control.

6.4 Summary of findings

The purpose of this section is to summarise the key findings that will lay the foundation for chapter 7 Discussion. The research questions are directly influenced by these findings and are the result of solving the research objectives.

Thematic Analysis

Key findings from the semi-structured interviews, when combined with some literature findings in section 6.3.1:

- The findings for both system settings & technology configurations focused on the physical demand, mental demand, temporal demand, and frustration. Hence, these are promising targets for workload reduction.
- New technology deployed in SS1 must avoid affecting beneficial teamwork dynamics.
- Order pickers at SS2 are more vulnerable to boredom, lower back pain, reduced motivation, and stress-related issues.
- Both system systems have high temporal demands caused by a minimal number of order pickers in rotation.
- The induction of pick-to-HUD seems like the most promising improvement for both system settings, but with different concerns.
  - SS1 need to replace their PDA while maintaining the benefits of teamwork cooperation.
  - SS2 would benefit more from introducing gamification since motivation & boredom are larger issues, and socializing has less room. Reduced fatigue is another.
- Both SS1 and SS2 could benefit from the wearable technology and app that monitor individual stress levels to manage the break schedule since job rotation

and break management are important tools to avoid burnout.

NASA TLX

- All the Cronbach Alpha values(ρ_T) illustrated in table 11 are all within acceptable range, $\rightarrow .8 \leq \rho_T \leq 1.0$.
- The order pickers's workload distribution at SS1 and SS2 is segmented into the NASA TLX sub-categories for all four OP tasks and found in figure 32 and 33.
- The overall workload profiles for setup, travel, search and pick tasks are illustrated in figure 34.

Literature Findings

The human-technology interactions identified through the literature review process are described in section 6.3.1. An illustration of The human-technology interactions sorted according to the OP tasks and HF aspects they have the potential to influence is in table 16. These are the human-technology interactions evaluated in section 7.

Table 16: Operator 4.0 technologies sorted by HF aspects and Tasks They Influence

HF Related Tasks	Operator 4.0 OPS
Physical OP tasks(setting up, walking, grasping, transporting)	Exoskeletons, Wearables
Mental OP tasks(planning, checking)	AR, VR, IoT, Big Data
Perceptual OP tasks(identifying)	AR, Paperless picking(PtL), RFID
Psychosocial OP tasks	Gamification, apps

7 Discussion

This chapter aims to answer the research questions/hypotheses chosen. This will be achieved by presenting the primary results from the literature review and case study process. Interpret and explain their significance in relation to how variations in system settings & technology configurations impact order pickers and how managers can apply new assistive technology to improve OP in terms of HF aspects.

7.1 Research Question 1

"How would variations in system setting & technology configurations in OP tasks hold significance in relation to order picker's HF aspects?"

From chapter 4 Hypothesis, it is important to recognize and reiterate that the variables that are under scrutiny are:

- System Settings - Layout & Storage Location Assignment
- Technologies (See table 4)
- The four OP tasks: Setup → Travel → Search → Pick

The metric used to evaluate the affected variables is workload, which is further divided into the NASA TLX sub-categories.

Consistency

Firstly, it is important to acknowledge that table 11 identify how consistent the order pickers opinion on workload intensity is in SS1 and SS2. Observations made regarding OP tasks that satisfy the predetermined consistency level, $.8 \leq \rho_T \leq 1.0$, will have more credibility. All the tasks are within range, but the data for SS2 seem particularly consistent.

Variations between SS1 and SS2 in HF aspects

The total workload composition identified through NASA TLX indicates how the system setting & technology configurations influence the order picker's HF aspects.

First, it is essential to describe the workload development for order pickers in the four OP tasks separately before judging the trends as a whole. The following observations are based on findings illustrated in figure 34.

In the *setup task* both SS1 and SS2 have similar *effort* loads. They both have significant loads in mental demand, temporal demand, and physical demand. However, SS2 have a much higher amplitude on physical and temporal demands. Consequently, order pickers at SS2 will experience more stress and fatigue and increase the risk of burnout and injury compared to their colleagues in SS1.

In the *travel task* order pickers in both SS1 and SS2 experience similar temporal demand. However, SS2 has considerable higher workloads tied to mental demand and the efforts required to maintain performance levels. The reported high levels of mental demand in this task could be attributed to the time pressure the order pickers experienced while trying to maintain the desired service level. This development also coincides with the order pickers' reported lack of resources, i.e., an insufficient number of workers.

The *search task* represent two very different workload profiles for SS1 and SS2. Experienced temporal demand is similar, but the other sub-categories diverge heavily. SS1 has a high workload tied to effort requirements, and frustration is at its highest in this task for SS1. SS2 have visibly high loads in the required effort, frustration, and mental demand. The mental demand may have a high correlation to temporal demand since the qualitative findings suggest that the high order intensity translates to high mental demand.

The *pick task* has a workload profile in SS1 dominated by effort and physical demand, which correlates with all the heavy lifting. For SS2, the bulk of the workload is concentrated around effort, mental demand, temporal demand, and frustration. Lower physical demand could be explained by the items picked being smaller. The high order intensity and repetitive work leading to stressed and bored order pickers could explain the amplitudes of mental and temporal demand and high frustration levels. The order pickers' autonomy could also be lower here and would explain the high frustration.

By assessing the quantitative findings, the first observation is that there are substantial differences in the amplitude of the workload intensity for order pickers in SS1 and SS2, especially for *setup* and *travel*. Additionally, the NASA TLX sub-categories attributed the most weight by the order pickers in a OP task vary significantly in many tasks.

Table 17: Overall NASA TLX Index for OP Tasks

Overall NASA TLX Index Comparison		
	SS1	**SS2**
Setup	36.27	69.08
Travel	33.87	65.60
Search	56.27	65.81
Pick	61.33	72.00

The comparisons made in table 17 show that the order picker's overall workload of the two system settings & technology configurations is significantly different. Especially for the *setup* and *travel* task.

The overall assessment of the SS1 workload profile is that consistent high workloads are tied to the effort required to maintain performance. The physical demand at the pick task and the spike in frustration at the search task stand out. The accumulated workload is much lower here than for SS2, which indicates that the order pickers are not pushed to their limits here.

The overall assessment of SS2 is that several workload categories are not sustainable. In setup, physical demands and temporal demands are substantial. In travel, the issue is mental demand, temporal demand, and effort. The mental demand and frustration are way higher in the search and pick tasks here compared to SS1.

Impact of System Settings & technology

The literature findings explored in section 3.1 show that the layout and storage location assignment policies have mainly received attention concerning the physical HF aspects. By looking at the empirical findings in this thesis and how different the workload profiles are for the four OP tasks, it is evident that this is not sufficient to describe the full consequences of variations in system settings to HF aspects. However, since physical demand has received more attention here, it makes sense to evaluate system settings effects based on the physical aspects first. Then consider the other HF aspects afterward. Diefenbach and Christoph H. Glock, 2019 suggest that when reducing travel distance or ergonomic strain are the objectives, achieving an optimal solution to either layout or storage location assignment is barely in conflict with each other, and to optimize one is equivalent to nearly optimizing the other.

Choices concerning technology seem to have a much more versatile toolkit when management wants to improve mental, perceptual, and psychosocial HF aspects. The many different human-technology interactions identified through literature and illustrated in section 6.3 support this assumption. System settings alone cannot efficiently address all four HF aspects. However, supported by a good combination of the technologies explored in section 2.3, management at a warehouse will be able to achieve a more targeted strategy for addressing HF aspects in system setting & technology configurations in logistics.

Hypothesis Validation

The findings discussed in this thesis suggest that variations in system settings & technology configurations can significantly impact the HF aspects of order pickers performing OP tasks. There is a significant difference in the overall workload intensity for the OP tasks observed in figure 33 and 32. Hypothesis 1 can be validated and null hypotheses 1 rejected based on these findings.

Summary

Summarize the factors that imply that variations in system setting & technology configurations impact HF aspects:

- The findings are based on sufficiently consistent data.
- There are significant differences in both workload profile and amplitude((intensity) observable through the weighted NASA TLX sub-categories.

- *Setup task* has similar workload profiles, but SS2 has way higher amplitudes in physical and temporal demand.
- *Travel task* has low physical requirements because of forklifts, but effort, temporal demand, and mental demand are exceptionally high for SS2.
- *Search task* has high workloads in frustration for both SS1 and SS2. The workload profile in SS2 revolves around temporal, mental demand, frustration, and the effort required to maintain performance levels.
- The *Pick task* workload is dominated by the physical demand and required effort in SS1. Frustration is relevant as well. SS2 has high mental and temporal workloads caused by high order intensity. Order pickers are stressed and tired. Burnout is a real threat.
- SS1 has issues with frustration in the search task.
- Mental demand and frustration levels are exceptionally high for SS2 in the search and pick task.
- Hypothesis 1 is deemed validated.

7.2 Research Question 2

"How does different system settings & technology configurations(SS1, SS2) impact assistive technology recommendations seeking to improve HF aspects?"

Assessing Human-Technology Interaction Literature

The research identified the human-technology interactions for assistive technologies that can improve productivity, quality, and worker well-being. The Eric H Grosse et al., 2014 framework presented in section 2.4 allows researchers to evaluate OP tasks and record the benefits from considering the four different HF aspects when making recommendations to assistive technology priorities.

Physical HF Aspects

Order pickers that carry most items manually have a higher chance of developing MSDs than forklift and cart users. The most common is lower back pain - only 6% of order pickers never experienced it(Gajsek, 2019). This problem alone justifies evaluating physical HF aspects. The *physical tasks(i.e., setting up, walking, grasping, transporting)* has two primary technologies of interest: exoskeletons and wearables.

The primary health benefit of utilizing these two efficiently is reduced health issues(i.e., MSDs), which can cause businesses substantial extra costs. The exoskeleton can reduce the load on the spine and even alleviate the strain on the biceps. However, exoskeletons are uncomfortable to wear, and alternative solutions could be cheaper and easier to implement. Wearable smart suites that alert the user when the posture of the order picker is not ideal is one such alternative.

Other technologies with implications for physical HF aspects are RFID-gloves which can reduce arm fatigue and wrist issues caused by handheld scanners (Nair et al., 2018; Scheuermann et al., 2016).

Additionally, the use of VR can aid the training of ideal movement patterns during OP that reduce the overall physical load and even improve efficiency(Friemert, Saala et al., 2018). MCS can be used to identify the physical workload of different pick heights and system settings.

Mental HF Aspects

According to the literature, the *mental OP tasks(i.e., planning, checking)* have more potential for benefiting from assistive technologies than the physical aspects. The potential technologies of interest here are AR, VR, IoT, big data, wearables, and apps.

AR can support PbVi, which is considered the most promising OP support system OP and potentially improve performance by reducing picking time by 30% and picking errors by 75%(Haase and Beimborn, 2017). New developments have also reduced the necessary investment capital for such systems and lowered the barrier for smaller warehouses to commit to the technology, i.e., RASPICK (Nagda et al., 2019).

The most obvious benefit of utilizing VR technology today is in reducing the cost connected to training order pickers and preventing halts in production by simulating the warehouse and making costly adjustments to the layout, storage location assignment, and technology in a simulated environment and enabling a weighing of the pros and cons.

IoT provides the ability to deliver real-time data to order pickers promptly. Reduce the physical and mental strain and improve item visibility and real-time tracking.(X. Wang et al., 2013) Consequently, reducing costs. Big data could provide a foundation for identifying and analyzing issues(e.g., human-caused routing deviations (R. M. Elbert et al., 2017)).

Another interesting application of technology lies within combining wearables and apps to manage the individual break frequency in a way that increases safety and reduces the mental and physical workload (Kretschmer et al., 2021).

Perceptual HF Aspects

The *perceptual OP tasks(i.e., identifying, translating, understanding)* can benefit from technologies such as AR, paperless picking(e.g., PtL), RFID, and wearables. Many advantages synergize mental HF aspects since technologies(i.e., AR, RFID, IoT) support both. AR seem to be particularly promising for supporting the *search task* based on the literature findings identified in table 14.

RFID is a very versatile technology. One of its HF-related benefits is the possibility of balancing skewed workloads by delivering pick orders appropriately promptly to order pickers with spare capacity. The RFID-gloves mentioned previously also help identify and reduce pick errors. Thomas et al., 2018 investigated the support of AR technology that enables pick-to-HUD, suggested to be the fastest, least error-prone, and cause the lowest task workload during the OP.

Psychosocial HF Aspects

The *psychosocial influence on OP tasks* is a bit more abstract and harder to gauge, but still essential. They entail stress, motivation, job satisfaction, autonomy, co-worker interaction, and supervisory support. Promising technologies that can influence these aspects include gamification and apps/AI.

Gamification can provide a fair and engaging reward system for order pickers through badges and achievements, resulting in higher emotional and cognitive engagement. Increased motivation and job satisfaction are additional benefits. However, care is required to navigate technology resistance (Haase and Beimborn, 2017).

Empirically Assessing Human-Technology Interactions

To make any judgments and advice concerning how assistive technology can improve operations in SS1 or SS2, they need to not significantly hinder the beneficial tools and attack the challenges mentioned in table 9 and 10.

The thematic analysis identified the most beneficial factors and challenges to workload concerning physical demand, mental demand, temporal demand, and frustration. Therefore any introduction of new assistive technologies should target these workload categories effectively.

Beneficial Factors & Challenges

A summary of the beneficial factors and the challenges registered by the order pickers and used to facilitate this discussion is found in table 9 and 10.

The most reoccurring beneficial factors found in SS1 and SS2 are job rotation and break management. These factors contribute to reducing the perceived workload in several NASA TLX categories. Hence, conserving or even boosting these benefits is a priority. Kretschmer et al., 2021 found that smart workwear and app-application could individualize the break management according to personal requirements and help maximize these benefits.

SS1, in particular, has to consider the benefits of working in groups of 3-4 on mental and temporal demands. Introducing PbVo could be problematic since it hinders communication, and limiting perception for workers could lead to an increased risk of accidents. However, improving the current PDA system for managing pick lists should be a priority since order pickers experience error here. Nagda et al., 2019 work on cheap PbVi systems looks particularly promising since resource access seems to be a consistent issue at Bring AS.

Within physical demand, using the exoskeleton in SS1 protects the lower back and reduces biceps and shoulder load. However, the energy required to use it is high and problematic in intervals exceeding 2 hours. The issue of lower back pain and muscle inflammation is higher for SS2 caused by more repetitive order picker movements. Still, the packets are often smaller, which reduces the benefit of using exoskeletons to reduce workload—especially considering that order pickers at Bring AS had issues with the energy required to operate exoskeletons and equipment glitches. Improve work posture with smart workwear and a better consideration of HF in system settings configurations, i.e., layout and storage location assignment, could be a better area to optimize when reducing the order pickers' physical demand.

Within mental aspects, both SS1 and SS2 seem to have problems with barcodes, sorting, and information technology, e.g., PDA and interface. Introducing pick-to-HUD/PbVi would improve OP speed and accuracy and reduce workload, (Thomas et al., 2018) and the price has become manageable(i.e., RASPICK(Nagda et al., 2019)). Order pickers in SS2 often experience high order intensity, leading to a near exponential development of mental demand. Burnout then becomes a legitimate issue.

SS1 has a bottleneck in its feed operation, so focusing on the more time-consuming OP tasks such as travel(50%) and search(20%)(see figure 7) should be prioritized along with HF aspects. Assistive technologies can help the search process by utilizing a PbVi OP support system.

Perceptual issues are very relevant in SS1 since order pickers work close to each other in teams while packing pallets and performing quality control. The potential for improving the order pickers' ability to perform the search task is considerable here. Implementing AR and PbVi could remove the pick list errors tied to the PDA and increase picking efficiency.

SS1 and SS2 both have issues with boredom and burnout, but these issues appear to be smaller for SS1 and might be mitigated by teamwork dynamics. However, psychosocial aspects like frustration contribute to a higher workload for SS2 since reduced motivation and stress are significant issues. Frustration in the *search task* is not well addressed in the literature, which is interesting since the case study found frustration levels high here, even for SS1. Gamification offers an artificial way of inducing intrinsic and extrinsic motivation, improving work engagement and relieving boredom. Bring AS's management should not ignore the added benefit of combining gamification with a PbVi support system in SS2.

Management has found that some steps in the OP tasks are hard to automate in SS2. One example is picking packets arriving through the AS/RS where order pickers must sort and pack the packets into pallets. Order pickers have a more repetitive and uniform load for those movements, causing an additional risk of tendinitis. Exoskeletons and smart workwear could help, but good ergonomic planning of workstations would likely be a more beneficial tool supported by the previous research question findings. These tasks are also monotonous, and order pickers don't get the same benefit of working in teams here, contributing to high frustration and stress levels in SS2.

Hypothesis Validation

The findings suggest that there is merit to adjusting the recommendations related to new assistive technologies for different system settings & technology configurations which go a long way in verifying Hypothesis 2.

Summary

- In the literature findings, it appears that new assistive technologies that improve physical aspects are limited to reducing the load on the spine and biceps with exoskeletons and improving posture with smartwear. VR and MCS aid in finding ideal order picker movement patterns and mapping load and fatigue levels for different system settings. In contrast, mental and perceptual HF interactions have numerous promising effects on improving productivity and quality for search in particular(e.g., pick-to-HUD, VR see table 14). The psychosocial benefits of deploying gamification should also not be underestimated, especially regarding worker well-being, e.g., motivation and engagement in *setup* and *pick tasks*(see table 13,15).
- Order pickers at SS1 contradict the literature a bit on exoskeletons since they don't have issues with the effect being limited but took issue with the user-friendliness and the operator energy required.
- Effective utilization of job rotation and break management is essential. Appropriate technology implementation can boost these tools.
- SS1 need to protect their autonomy and teamwork-related benefits.
- Based on the different system setting & technology configurations, Bring AS should consider different new assistive technologies.
- Lower back pain and muscle inflammation are an issue for SS2. Both would benefit from improving OP search of items through an PbVi support system.
- SS2 is incentivized to look at gamification to reduce the number of bored order pickers with low motivation and engagement.
- Gamification also has potential for SS1 in the *search task* since frustration is significant here.
- Gamification can also help reduce human errors and increase quality.
- Order pickers in the case study contradict literature and claim exoskeletons improve performance significantly but highlight energy requirements as a barrier.

8 Conclusion

This chapter aims to conclude the research. Firstly, summarize the key research findings and present them in a research objective context. Secondly, a presentation of the contributions to knowledge and management. Thirdly, a presentation of the study's limitations before finally ending in a observation on potential future work.

Summary of findings

This research has evaluated two system settings & technology configurations in warehouse logistics. The workload is used as a medium to compare variations in system setting and technology configurations and judge what technologies can better serve HF aspects in OP tasks.

The first research objective concerned the identification of two hypotheses that could be empirically evaluated by analyzing the makeup of the total workload in OP tasks through NASA TLX by using semi-structured interviews and a questionnaire.

The second research objective involved the identification and analysis of Bring AS's picker-to-parts(SS1) OP and parts-to-picker(SS2) system setting & technology configurations. First, by mapping the characteristical traits of SS1 and SS2. Finally, finding a thorough overview of beneficial factors and challenges SS1 and SS2 need to manage. One key finding was that SS1 needed to reduce workload and increase efficiency through pick-to-HUD and better break management to attack their feeding bottleneck while conserving their teamwork-related benefits. SS2 has more significant motivation and stress issues and should encourage the implementation of gamification.

The third research objective concerns the quantitative findings gained from the questionnaire. Findings provided a workload profile for the four OP tasks to identify the major workload contributors in SS1 and SS2. Hence, it helps managers focus their efforts on the most pressing subcategories for order pickers and identify what OP tasks could benefit from introducing any new assistive technology.

The fourth research objective was solved by going through OP4.0 related literature, then sorting and cataloging the human-technology interactions according to E H Grosse, C H Glock, Jaber et al., 2015's framework and allowing the use of the findings to solve the final research objective.

The fifth research objective concerns identifying the technologies that could improve SS1 and SS2 by focusing on the beneficial and challenging aspects they need to manage and their workload profiles. SS1 should reduce workload and increase efficiency through pick-to-HUD and better break management to attack their feeding bottleneck while conserving their teamwork-related benefits. SS2 has a very high overall workload and significant motivation and stress issues. Gamification combined with pick-to-HUD becomes a very promising option here.

The literature review process and the case study's empirical reach created the foundation for the hypothesis's development and solving of the first research objective.

The case study provided the means to solve the second research objective. However, the inability to access multiple manual picker-to-parts OP warehouses with similar system settings & technology configurations meant the objective was repurposed to compare a picker-to-parts and parts-to-picker OPS in the same warehouse. The literature review provided the human-technology interactions required to solve the fourth research objective. Finally, solving the last objective, which ends in the ability to provide individualized technology recommendations for SS1 and SS2 focusing on improving HF aspects of order pickers. In conclusion, the data suggest that the two hypotheses can be considered validated.

Contribution to Knowledge

A workload analysis empirically reveals the significance of system setting & technology configuration on the HF aspects of order pickers operating in logistics. Analyzing OP tasks and the assistive technologies with the potential to improve them by evaluating the human-technology interactions and collecting them allows researchers to use the research as a reference for more targeted efforts in future works. The findings can help managers decide where to focus their research efforts by targeting workload contribution while navigating the order picker's beneficial factors(i.e., job rotation, break management) and challenges(burnout, boredom, fatigue) in OP tasks.

Contribution to Management

Managers can use the findings to identify the assistive technologies they should prioritize first when HF aspects are the primary consideration. The dominant contributors to the workload in the two system settings & technology configurations have been identified for each OP task and allow for effective targeting of these with appropriate technology introduction and decision-making. One of the more promising contributions is the generalizability of the approach. All system settings & technology configurations can be compared and open for tailor-made solutions within warehouse logistics. Consequently, reducing the workload of order pickers, reducing work-related illness, absenteeism, and presenteeism, along with higher workplace quality and safety in the OP tasks, consequently reducing long-term costs.

Limitations

One limitation of the research is that workload is the only metric analyzed quantitatively. It is reasonable to assume that it is insufficient to base HF related decisions on workload alone. An important step forward would be to increase the analytic framework models and tools to improve the foundation for making generalizable contributions. Primarily this thesis will suffer from qualitative research-related limitations since the source of quantitative data is the NASA TLX which is a subjective assessment of workload components and the remaining data is qualitative. Hence, vulnerable to bias and diverging understanding of workload. Comparing system settings & technology configurations for several warehouses with a uniform OPS, i.e., manual picker-to-part OP would provide a more nuanced picture of more comparable environments and consequently isolate the impact on the order pickers HF aspects better. Finding additional ways to evaluate and compare different system settings & technology configurations would improve the foundation to form conclusions.

Future Work

One promising avenue of future work is to continue expanding the holistic understanding of OP as a Sociotechnical Systems and the importance of incorporating HF through empirical work. W. Patrick Neumann et al., 2021 presents a solid framework for initiating research and development to systematically consider HF in Industry 4.0 designs and implementations. Combining this framework with empirical testing to quantify the benefits of introducing new technology in different OPS by evaluating workload is a worthy subject. The literature review process identified that so far, the impact of physical HF aspects have received the bulk of the research attention concerning system settings & technology configurations in OP, which leaves room for further research in the other three aspects. Winkelhaus, Eric H Grosse and Morana, 2021 identified another interesting avenue on technology synergies effect on HF aspects and an economic perspective on how ROI is affected by introducing new technologies. AR is particularly interesting from a financial point of view. Exploring the economic benefit of considering variations in system settings & technology settings through the lens of HF aspect would be worthwhile to give conclusive evidence of why considering HF aspects early is essential.

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Appendix

A Questionnaire(Q1) Information

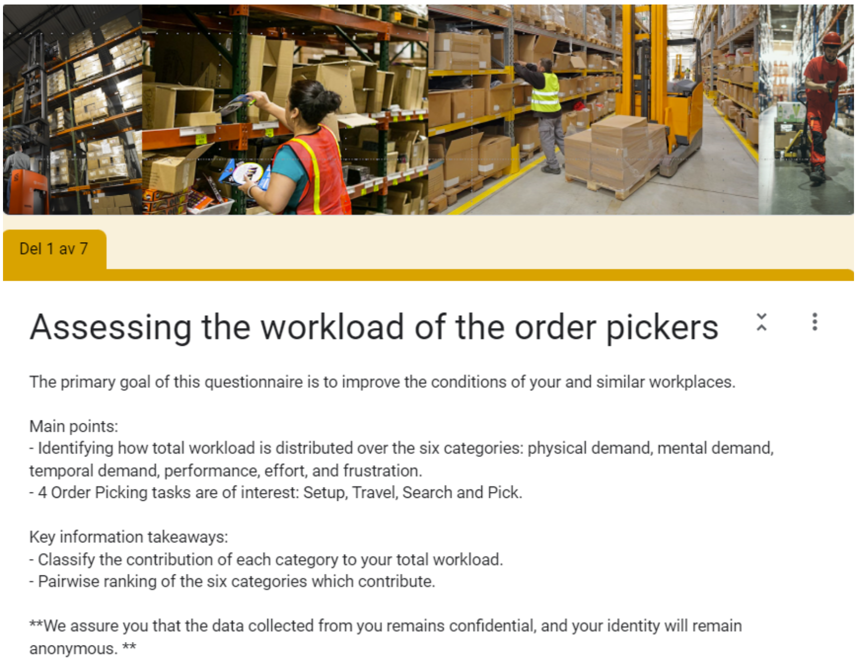


Figure 35: Questionnaire Q1 Front Page

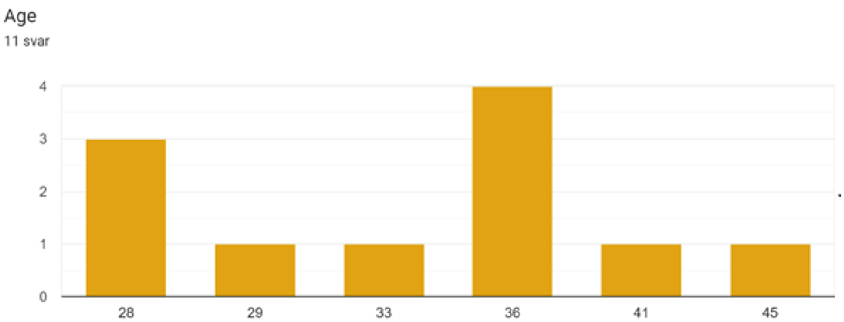


Figure 36: Participating Order Pickers' Age

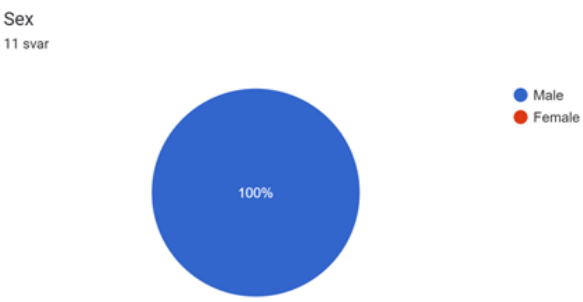


Figure 37: Participating Order Pickers' Gender

B T1 - Interview Questions to Managers & Designers

Introduction

-What is your job title?

____

- How long have you worked at this company?

____

- What are your roles?

Process

-Could you describe the type of products that are managed in this warehouse.
Example: Heavy, small, and white goods

System settings

-Please provide some information regarding your layout configuration.
Based on number of aisles, number of cross aisles, number of blocks

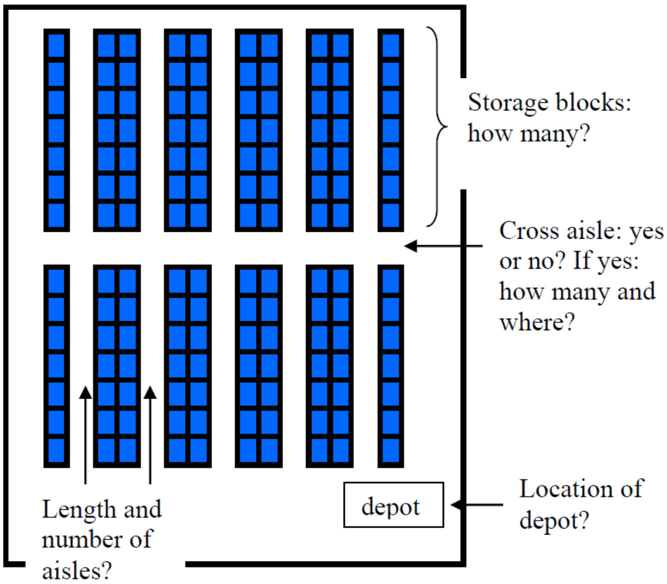


Figure 4 Typical layout decisions in order picking system design (top view of storage area)

How many storage blocks? ________________
How many cross aisle? ________________
Length of the aisles? ________________
Number of aisles? ________________

-What type of product unit do the order pickers usually handle in your warehouse?
For example: piece, case, pallet, etc.

-What height would you say the products are being picked at by the order pickers?
For example: floor level, shoulder level, waist level, above the level of the head, etc.

-Do the order pickers move towards and collect the products, or are the order pickers stationary while the products move towards the order picker?

Technology

-What kind of technologies are being used in the order picking process?
Probe: Technologies used for the setup, travel, search, and pick.
For example: AGV and forklift for travel, paperless picking such as pick to light, pick to voice head mount display for picking, AR, VR?.

OP Tasks	Technologies
Setup	
Travel	
Search	
Pick	

Operational policies

-What kind of **storage assignment policies** are used in the warehouse? And how often would you say that changes are made in the storage assignment polices?
*For example**, random storage**(Every incoming pallet (or number of similar products) is assigned a location in the warehouse that is selected randomly from all eligible empty locations with equal probability), **dedicated storage**,(Store each product at a fixed location), **Full-turnover storage** (This policy distributes products over the storage area according to their turnover), **class-based storage** (Classes are determined by some measure of demand frequency of the products) etc.*

- What kind of **zoning approaches** are used in the warehouse?
*For example: **Pick and pass** (Using this approach one order picker starts on the order. When he finishes his part, the picklist (or any other means that are used) are handed to the next picker, who continues the assembly of the order), **parallel picking** (A number of order pickers start on the same order, each order picker in his own zone. The partial orders are merged after picking. In practice, zoning is partially based on product properties, like size, weight, required temperature and safety requirements), Hybrid, etc.*

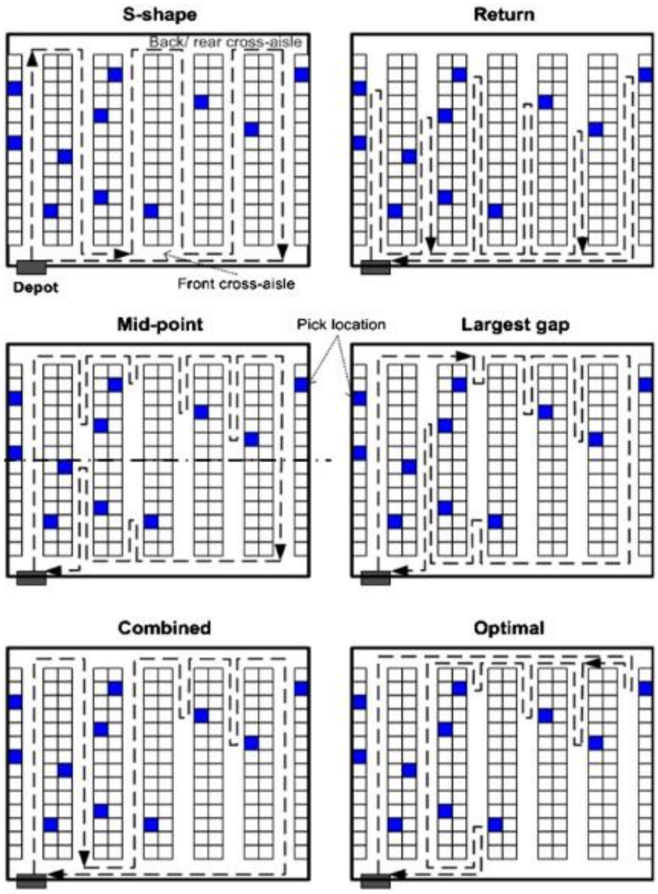
- Usually, how many zones is your warehouse segmented into?

-Also, how often do you make changes in the zoning approach?

- What kind of **batching approaches** do you use in the warehouse? And how often are changes made to the batching approaches?

*For example: **Proximity batching** (Assigns each order to a batch based on proximity of its storage location to those of other orders), **Time window batching** (The orders arriving during the same time interval i.e. fixed or variable length, called a time window, are grouped as a batch), savings based (Pick lists are composed based on the distance savings that can be obtained by combining two or more customer order into a single route), metaheuristic (A set of guidelines to develop heuristic optimization algorithms for batching of orders), hybrid, etc.*

- What kind of **routing methods** do the order pickers use in the warehouse? And how often



are changes made to these routing methods?

Routing policies	Check box
S-shape	☐

Return	☐
Mid-point	☐
Largest gap	☐
Combined	☐
Optimal	☐

-Do you have a **job rotation schedule** within the order pickers? Yes/No

____

- If yes, how are these job rotations done?

____

____

Productivity

-How many **items** are picked in total per day on average in an off season (*For example: normal days)*?

____

-How many **items** are picked in total per day on average in high seasons (*For example: easter, Christmas, black Friday, etc.)*?

____

-How many **orders** are picked in total per day on average?

____

-How many **order pickers** are assigned per day on average on off seasons (*For example: normal days)*?

-How many **order pickers** are assigned per day on an average on high seasons (*For example: easter, Christmas, black Friday, etc.)*?

____

-How do you measure the **productivity** of the warehouse? How often do you calculate the performance of the warehouse?

The productivity of the system determines the time and cost required to complete an activity.

____

____

Quality

- How do you measure the **quality** (error) of the warehouse? How often do you calculate the quality of the warehouse?

Quality is determined by the rate of error that occurred during the activity.

____

____

-Are there mispick of items? Yes/No

Picking the wrong item or picking an item in addition to the correct item

-If yes, could you provide the rate of mispick?

____

- Are the order pickers picking the wrong quantity of products? Yes/No

The quantities picked are too high or too low

-If yes, could you provide the rate of wrong quantities?

____

- Are there any condition errors on the products *(For example*: *damaged item, expired, improperly labeled, etc.*)? Yes/No

-If yes, could you provide the rate of condition error?

____

Wellbeing

-Do your order pickers face work-related musculoskeletal disorders, such as injuries or disorders with muscles, back or nerve pain, while doing OP tasks etc.?

____

-If yes, how often do order pickers take a leave of absence due to work-related musculoskeletal disorders?

____

-Have you experienced absenteeism in your warehouse? Yes/No

____

-If yes, how often do you experience absenteeism?

____

-Have you experienced accidents in your warehouse? Yes/No

____

-If yes, how often you experience accidents and what were the major accidents?

____

-Do you as a manager have conflicts with your order pickers at the warehouse? Yes/No

____

- If yes, how often you experience these conflicts and what are the major causes for these conflicts?

____

-Have you had any cases reported on conflicts in between your order pickers? Yes/No

____

- If yes, how often you experience these conflicts and what are the major causes for the conflicts?

____

- What aspects of the design and configuration of the system affect operators' wellbeing?

Closing

- Is there anything else you would like to add specifically in relation to your order pickers?

- Are there topics regarding your warehouse and order pickers that we did not cover in our interview that you feel should have been?

C T2 - Interview Questions To Order Pickers

Introduction

- What is your job title?

____

- How long have you worked at this company?

____

OP tasks

The next set of questions that I am going to ask you will be regarding the order picking tasks illustrated in the table below. These tasks are further segmented into the following 4 human factors aspects:

Perceptual aspects: The perceptual aspect reflects the visual, auditory, or tactility demands on operators.

Mental aspects: The mental aspect reflects the cognitive, learning/forgetting behavioral and training condition of the operator.

Physical aspect: The physical aspect reflects physical ergonomics, risk, manual work tasks, fatigue, and posture condition of the operator.

Psychosocial aspects: The psychosocial aspect reflects the motivation, feedback, incentives, stress, boredom, work satisfaction, time pressure, and personal condition of the operator.

Use the critical HF aspects for each task on the table below to answer the next questions.

	OP tasks			
HF aspects	Set up	Travel	Search	Pick
Perceptual	• perceive set-up operations	• perceive warehouse layout	• Read pick lists	• perceive pick operations and technical support
Mental	• receive and sort pick lists • Process documents	• Understand and remember pick route	• Search and identify items • Remember item locations	• Decide how to grasp and transfer a given item correctly
Physical	• Set up workstation	• Travel between depot and pick locations • Carry items • Pull/Push trolleys	• Neck flexion extension	• Stretch, bend, reach for items • Extract, grab, pick, put down items
Psychosocial	Motivation, stress, workload, boredom, work organisation, co-worker and supervisory support			

Figure 1: Examples of critical HF aspects for each OP task type

- Could you specify your job task by task in the correct order?

-Could you describe how you **setup** the search list before your pick tour?

- What can go wrong while **setting up** the search list?

Probes: Physical, mental, perceptual and psychosocial

- Could you describe by which means you **travel** (i.e. walk or drive forklift) between storage locations?

-What can go wrong while **traveling** between storage locations?
Probes : Physical, mental, perceptual and psychosocial

- Could you tell me about how you **search** items in the warehouse?

-What could go wrong while **searching** items in the warehouse?

Probes : Physical, mental, perceptual and psychosocial

-Could you tell me about how you **pick** items from your storage locations

-What could go wrong while **picking** items from the storage locations?

Probes : Physical, mental, perceptual and psychosocial

Technologies

- What technologies do you use for the different tasks?
Example (setup): readability of pick lists, usability of bar code scanner, pick-by-light

Order Picking Tasks	Technologies
Setup	
Travel	
Search	
Pick	

How does the technology help or hinder your task performance? What do you like/dislike about it?
Probes: Technologies mention by the order pickers in the above question

____

____

- Do you feel any resistance to using these technologies?(e.g. uncomfortable with changes etc.)
Probes: Technologies mention by the order pickers in the above question

____

____

- Does combining several technologies help or hinder your task performance or resistance to technology? If yes, how? *

____

____

*This question is asked if more than one technology is used to perform any OP tasks

Productivity

- What kinds of things slow you down at work?

____

____

- How do you think the order picking time could be improved(reduced)?

____

____

- How much time does each task takes to complete?

Setup ________________
Travel ________________
Search ________________
Pick ________________

Quality

- What kind of errors occur during your job?

Example: reading mistakes, picking wrong item, entering wrong aisle, forgetting information

- What do you think causes these errors?

Example: Information processing, storage assignment, routing strategy, work conditions

- Do you have any suggestions as to how these errors might be eliminated?

Wellbeing

- Can you tell me more about situations in which you felt physically strained performing your job tasks?

Example: carrying load, pulling trolleys, stretching, and reaching for items

- Can you tell me more about situations in which you felt mentally strained or fatigued at work?

Example: strenuous tasks, causes of fatigue, heavy workload, disappointment, work conditions

- How might mental and physical fatigue or discomfort be reduced?

- Can you tell me about the relations among fellow workers?

Example: support, feedback

- Can you tell me about the relations among your managers?

Example: support, feedback

- Is your daily routine causing boredom at work? If yes, why?

- Is your daily routine causing stress at work? If yes, why?

- What factors could have an impact on your motivation at work?
Example: financial incentives, job rotation, work-rest schedules

- How high would you rate the intensity of the demand leveled on you in each task?

Mental Demand

How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex?

Physical Demand

How much physical activity was required? Was the task easy or demanding, slack or strenuous?

Temporal Demand

How much time pressure did you feel due to the pace at which the tasks or task elements occurred? Was the pace slow or rapid?

Overall Performance

How successful were you in performing the task? How satisfied were you with your performance?

Effort

How hard did you have to work (mentally and physically) to accomplish your level of performance?

Frustration Level

How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?

Please elaborate in relation to the categories in your own words. Preferably with a sentence on each.
Example: workload, time pressure

- How much control would you say you have over your work tasks(autonomy)?
Example: work pace, work order, method choices

Closing

- Is there anything else you would like to add in relation to the order picking tasks?

D Hypotheses Building

To help you formulate a promising research hypothesis, you should ask yourself the following questions:

1. Is the language clear and focused?
2. What is the relationship between your hypothesis and your research topic?
3. Is your hypothesis testable? If yes, then how?
4. What are the possible explanations that you might want to explore?
5. Does your hypothesis include both an independent and dependent variable?
6. Can you manipulate your variables without hampering the ethical standards?

A testable hypothesis is not a simple statement. It is rather an intricate statement that needs to offer a clear introduction to a scientific experiment, its intentions, and the possible outcomes. However, there are some important things to consider when building a compelling hypothesis.

1. State the problem that you are trying to solve.
   - Make sure that the hypothesis clearly defines the topic and the focus of the experiment.
   - **How does variations in system settings impact manual picker-to-parts OP tasks by incorporating new technologies in terms of HF aspects?**
2. Try to write the hypothesis as an if-then statement.
   - Follow this template: If a specific action is taken, then a certain outcome is expected.
3. Define the variables
   - *Independent variables* are the ones which are manipulated, controlled, or changed. *Independent variables* are isolated from other factors of the study.
     1. *System settings, technologies and the 4 OP tasks*
   - *Dependent variables*, as name suggests are dependent on other factors of the study. They are influenced by the change in *independent variable.*
     1. *Physical Demand, Mental Demand, Temporal Demand, Performance, Effort, Frustration*

Hypotheses suggestions of the thesis:

1. μ_0: Variations in system settings has an impact on OP tasks in HF aspect terms.
2. μ_1: Higher assistive technology system settings, T_A, perform better in OP task operations in terms of HF aspects than lower assistive technology system settings, T_M. $T_A > T_M$.

E Work Document for the Literature Search

Research Question: How are the manual **picker-to-parts OP** tasks affected by incorporating the new **operator 4.0 technologies** in terms of **HF aspects**?

Search terms or phrases(in all relevant languages) – brainstorm all the relevant search terms you can think of.

Facet	Terms in English	
Order Picking	• Order picking • Order-picking • picker-to-part	
Human Factor(OP task related)	• Setting up, preparation • Workload, carrying, pushing, pulling • Searching, remembering • Manual handling, lifting, lowering, posture, occupational disease, low back pain • Human factor, ergonomics, learning, error, motivation, boredom, stress, fatigue	
Operator 4.0 technologies	• Pick-by-Vision • Pick-by-Watch • AR • Augmented Reality • VR • Virtual Reality • Exoskeleton • RFID • IoT	• Internet of Things • AI • Artificial Intelligence • Big Data • Gamification • Blockchain • Wearable

Log book:

Defining the literature and materials to be used in your paper

Criteria of selection: Partially related The article deals with keywords of at least two categories and has a mention of the third, e.g keywords of order picking and manual picker-to-parts OP technologies and at least a mention in the research outlook. The article directly deals with the intersection

of the categories. The article addresses the topic without using the keywords, but using similar/ equivalent meaning. Closely related The article handles keywords of all three categories. Deals with two categories in depth and cursory includes the third.

Criteria of rejection:
Search Engine Reason: The article has the title, abstract and keywords in English, but text in different language. Non-related The article is a not a academic article, i.e conference papers. Keywords related to another topic because of double meaning, e.g. data warehouses Loosely related: The article uses keywords of at least two topics in passing in a quotation, example or in he research outlook/future studies

Search history – overview of the databases and search terms that have been used and of the different search results.

Date	Database	Search Strategy	Search terms (combination of terms, keyword search)	Notes	Number of hits	Items selected
15.01.22	Scopus	Block Search	TITLE-ABS-KEY ("order picking" OR order?pick* AND review)	Used for holistic OP overview	53	28

09.02.22	Scopus		TITLE-ABS-KEY ("order picking" OR order?pick* OR picker-to-part*) AND TITLE-ABS-KEY (exosceleton* OR ar OR (augmented AND reality) OR vr OR (virtual AND reality) OR wearable* OR iot OR (big AND data) OR (pick AND to AND light) OR rfid OR gamification OR app) AND (LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013))	OP vs Tech	98	
10.02.22	Scopus	Block search	TITLE-ABS-KEY ("order picking" OR order?pick* OR picker-to-part* OR warehouse) AND TITLE-ABS-KEY (exosceleton* OR ar OR (augmented AND reality) OR vr OR (virtual AND reality) OR wearable* OR iot OR (big AND data) OR (pick AND to AND light) OR rfid OR gamification OR app) AND (LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013)) AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "DECI")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SUBJAREA , "SOCI"))	Op+WH vs tech	25	
16.02.22	Scopus	Block search	TITLE-ABS-KEY (("order picking" OR order?pick* OR picker-to-part*) AND warehouse) AND TITLE-ABS-KEY ((setting AND up) OR preparation OR workload OR carrying OR pushing OR pulling OR searching OR remembering OR (manual AND handling) OR lifting OR lowering OR posture OR (occupational AND disease) OR (low* AND back AND pain) OR (human AND factor) OR ergonomics OR learning OR error OR motivation OR boredom OR stress OR fatigue) AND (LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013))	OP+(hf+op tasks)	178	

16.02. 2022	Scopus	Block search	(TITLE-ABS-KEY (("order picking" OR order?pick* OR picker-to-part*) AND warehouse) AND TITLE-ABS-KEY (exoskeleton* OR ar OR (augmented AND reality) OR vr OR (virtual AND reality) OR wearable* OR iot OR (big AND data) OR (pick AND to AND light) OR rfid OR gamification OR app)) AND (TITLE-ABS-KEY (("order picking" OR order?pick* OR picker-to-part*) AND warehouse) AND TITLE-ABS-KEY ((setting AND up) OR preparation OR workload OR carrying OR pushing OR pulling OR searching OR remembering OR (manual AND handling) OR lifting OR lowering OR posture OR (occupational AND disease) OR (low* AND back AND pain) OR (human AND factor) OR ergonomics OR learning OR error OR motivation OR boredom OR stress OR fatigue)) AND (LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013))	combined	24	24
16.02. 2022	Web of Science	Block Search	((TS=(("order picking" or order-picking or picker-to-part) and warehouse)) AND TS=(exoskeleton* OR ar OR (augmented AND reality) OR vr OR (virtual AND reality) OR wearable* OR iot OR (big AND data) OR (pick AND to AND light) OR rfid OR		24	24

			gamification OR app)) AND TS=((setting AND up) OR preparation OR workload OR carrying OR pushing OR pulling OR searching OR remembering OR (manual AND handling) OR lifting OR lowering OR posture OR (occupational AND disease) OR (low* AND back AND pain) OR (human AND factor) OR ergonomics OR learning OR error OR motivation OR boredom OR stress OR fatigue)			

You can add this overview to your paper as an appendix.

Motivation for your choice of documents(your notes for the methods and materials section of your review) To support the literature review. The literature review serves a number of purposes. First, it clarifies what research has been done on the topic. Secondly, it reveals the areas under dispute and the gaps in the research foundation, which in turn is used as a justification for the research in this paper. Thirdly, the process of producing the literature review ensures that the research questions are continually improved upon in order of reaching the research aim. Fourthly, the literature review reveal the most promising methodology branches used by fellow researches when addressing the research objectives and questions. Finally, in the context of the case study the literature review should support two functions: (1) introduce the concepts needed for the reader to understand the paper; and (2) persuade the reader that the research question or POV is credible. (http : //users.clas.ufl.edu/msscha/landarch/caseiitreview.html)

F Checklist for PRISMA - Scoping Review

Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	
Limitations	20	Discuss the limitations of the scoping review process.	
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.
* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.
† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).
‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.
§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMAScR): Checklist and Explanation. Ann Intern Med. 2018;169:467–473. doi: 10.7326/M18-0850.

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Master Thesis

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