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Identification of possible use cases of smart glasses in intralogistics and conceptual design of a specific scenario

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Affidavit

I, **MELANIE ZAHN, BENG**, hereby declare

1. that I am the sole author of the present Master's Thesis, "IDENTIFICATION OF POSSIBLE USE CASES OF SMART GLASSES IN INTRALOGISTICS AND CONCEPTUAL DESIGN OF A SPECIFIC SCENARIO", 82 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

Vienna, 06.03.2022

Signature

English Abstract

Identification of possible deployment scenarios of smart glasses in intralogistics and conceptual design of a specific scenario

This master thesis examines the identification of case studies where smart glasses technology can be used in intralogistics. In addition, a conceptual design of a concrete scenario and its application in a plant of an automotive company illustrates the thesis. In intralogistics, much untapped potential could be realised using digitalisation. This thesis addresses smart glasses technology and its benefits for intralogistics in the automotive sector.

Many new technologies that have become known in the course of Industry 4.0 do not have a standard in conventional process planning for logistics processes. The following research problem was therefore developed: no standardised recommendation for smart glasses technology in intralogistics exists. This thesis describes the theoretical fundamentals and presents the current state of the art. Furthermore, it elaborates the technology of smart glasses and brings it into the context of intralogistics. The methodological approach includes literature research and a personal interview with the head of the logistics and supply chain management department of the Fraunhofer Institute. The core of this thesis is the identification of use cases in intralogistics, with a focus on the three significant processes in intralogistics:

1. storage and retrieval of materials
2. picking of material supply and
3. assembly line feeding.

The identification and evaluation of the use cases are assessed through the literature review and the expert interview. Finally, a concrete scenario from industry, which the author conducted as a pilot test, is presented. The use case is detailed, and a process-related evaluation is performed. The master's thesis ends with a critical discussion, a conclusion and an outlook.

Deutsche Kurzfassung

Identifikation von möglichen Einsatzszenarien der Datenbrillen Technologie in der Intralogistik und Konzeption eines konkreten Anwendungsfall

Diese Masterarbeit beschäftigt sich mit der Identifikation von Fallbeispielen, in denen die Datenbrillentechnologie in der Intralogistik eingesetzt wird. Darüber hinaus wird die Arbeit durch die Konzeption eines konkreten Anwendungsfalls veranschaulicht. Im Bereich der Intralogistik gibt es noch viele ungenutzte Potenziale, die durch die Digitalisierung realisiert werden können. Die Arbeit befasst sich mit der Datenbrillentechnologie und deren Nutzen für die Intralogistik in der Automobilbranche.

Viele neue Technologien, die im Zuge von Industrie 4.0 bekannt geworden sind, haben in der konventionellen Prozessplanung für Logistikprozesse noch keinen Standard. Dies führt zu folgendem Forschungsproblem: Es gibt noch keine einheitliche Empfehlung für die Datenbrillen Technologie in der Intralogistik. In der Arbeit werden die theoretischen Grundlagen erarbeitet und der aktuelle Stand der Technik dargestellt. Die Technologie der Datenbrille wird erläutert und in den Kontext der Intralogistik gebracht. Das methodische Vorgehen umfasst eine Literaturstudie sowie ein persönliches Experteninterview mit dem Leiter der Abteilung Logistik und Supply Chain Management des Fraunhofer Instituts. Den Kern der Masterarbeit bildet anschließend die Identifikation von Einsatzszenarien in der Intralogistik. Dabei wird ein Fokus auf die drei Hauptprozesse der Intralogistik gelegt:

1. Ein- und Auslagerung von Materialien
2. Kommissionierung
3. Produktionsversorgung

Die Identifikation und Bewertung der Anwendungsfälle wird durch die Literaturrecherche und das Experteninterview verifiziert. Anschließend wird ein konkretes Szenario aus der Industrie, dass der Autor als Pilotprojekt durchgeführt hat, vorgestellt. Der Anwendungsfall wird detailliert beschrieben und eine prozessbezogene Bewertung durchgeführt. Die Masterarbeit endet mit einer kritischen Diskussion, einem Fazit und einem Ausblick.

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1 Introduction

Smart glasses is a technology that has been gaining increasingly more relevance in recent years due to digitalisation. Intralogistics is a complex subarea of logistics that must now contend with new requirements. Furthermore, companies' increasingly complex logistics processes make fulfilling the logistics task more difficult. Digitalisation is therefore considered one of the sector's most significant challenges and opportunities (Winkler & Zinsmeister 2019: 538).

The logistics processes are characterised by strong price pressure, high quality demands and high employee turnover. Traditional logistics processes are reaching their limits and have much potential for improvement. Smart glasses offer enormous potential for supporting logistics processes as they display information directly in the user's field of vision and can ensure among other things a reliable process (Thomas 2020: 3)

This thesis aims to establish possible deployment scenarios for using smart glasses technology in intralogistics in the automotive industry. In addition, these scenarios are evaluated to determine the added value for companies. Based on a promising deployment scenario, a project pilot will be tested in a concrete use case at an automotive company for three months to demonstrate the beneficial use of smart glasses technology.

First, the theoretical basics important for understanding the topic are elaborated. Intralogistics is thus classified in the relevant context and clarified through the literature review. Smart glasses technology then becomes the focus. Theoretical knowledge on this technology and the current state of the art are presented. Once the basics have been addressed, deployment scenarios for smart glasses technology in intralogistics are identified. The basis for the evaluation of these scenarios is the literature review, the author's personal experiences and the expert interview with

Dr Martin Riester, Head of Business Unit Logistics and Supply Chain Management at the Fraunhofer Institute Austria. A pilot project for a deployment scenario, which demonstrates the use of a scenario and was tested at a plant in the automotive industry for three months, is then elaborated. Finally, the results of this work are summarised, and an outlook for the topic is provided.

2 Fundamentals of intralogistics in the automotive industry

Logistics is traditionally defined as the interface between companies or company units. While it was once considered mainly an isolated area, it is now an integral factor in the value chain. Indeed, companies have realised that they will lose their performance potential if they neglect logistics (Wehking 2020: 127). Supply chain management and logistics are thus among a company's core competencies. Moreover, logistics costs are a significant cost factor and account for more than 50% of the industrial value added (McCann 1996: 114). Neglecting logistics therefore drastically affects the company's competitiveness.

This chapter aims to introduce the topic of intralogistics, providing the relevant background. The term "intralogistics" is first defined and put into context before the various processes that are assigned to intralogistics are described. After the goals of intralogistics are established, the challenges and opportunities are identified. Finally, Industry 4.0's influence on intralogistics is analysed with a focus on digitalisation and automation.

2.1 Definition

Intralogistics is a sub-area of logistics that is initially classified in the context of logistics. The term "logistics" comes from the military and originally described the army's supply and troop movements (Arnold 2008: 3). The task then was to provide and use the necessary funds in time (Heiserich et al. 2011: 3). The terminology has since evolved to encompass the scientific study of the planning, design, management and control of material and information flows in systems (Martin 2016: 3). The task of logistics is now based on the assumption that the required goods or services are produced somewhere other than where they are ultimately needed (Heiserich et al. 2011: 8). E. Plowmann's seven rights definition is often used to define the goal of logistics: "Logistics means ensuring the availability of the right good, in the right quantity, in the right condition, at the right place, at the right time, for the right customer, at the right cost." The meaning of "right" in this statement depends on the elements of the logistics task and focuses on, for example, the corporate strategy or customer requirements (Gleißner & Femerling 2012: 4). The focus is on physical transfer activities, such as the transport, handling and storage of goods, and activities for the design and operational implementation of logistics processes. Logistics can be assigned to strategic and operational areas of responsibility. The strategic component consists of the design and review of logistical structures and processes, while the operational component is understood as the planning, control and optimisation of object flows and performed within the framework of the strategic component (Heiserich et al. 2011: 10).

Pfohl delimited logistics in 1990 by listing the systems and distinguishing between the qualitative and spatial-temporal transformation of goods. The triggering event for a spatial-temporal goods transformation is the emergence of a demand (Heiserich et al. 2011: 8). Figure 1 demonstrates the systems of goods transformation according to Pfohl.

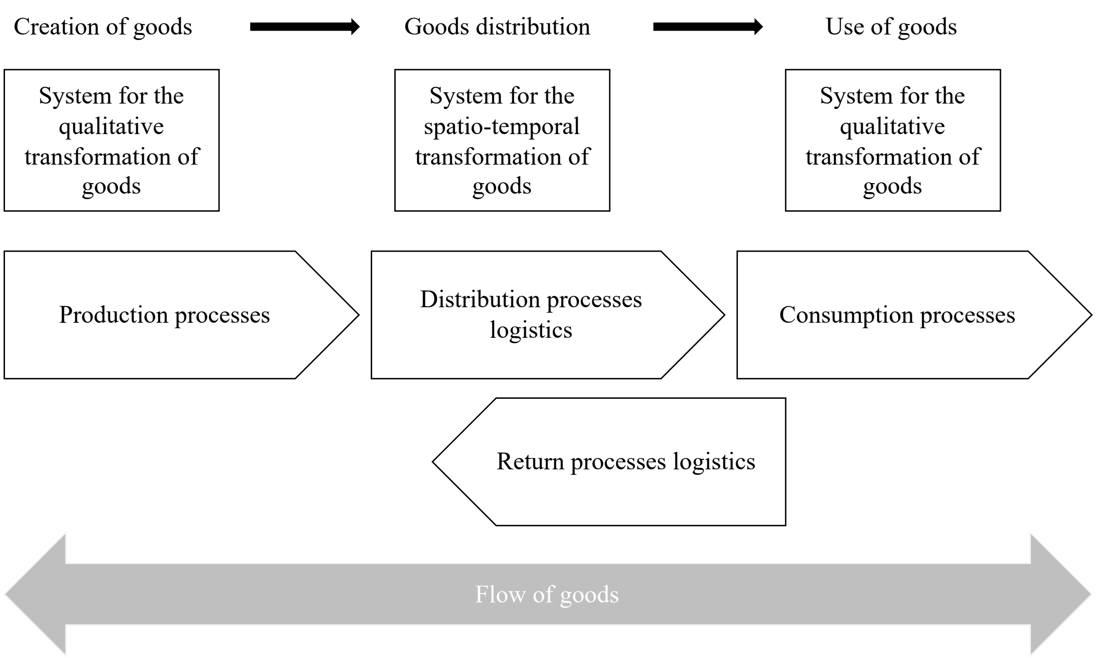

Figure 1: Systems of goods transformation

(Based on Pfohl 2010: 4)

The task of logistics in companies is therefore to economically plan, design, manage and control the flow of materials and the associated flow of information within the company and from the company to the customer or supplier. The sectors of logistics in companies can hence be divided into procurement, production, distribution and disposal logistics (Martin 2014: 2).

Procurement logistics includes all goods that a company needs as input for its operational purpose. It includes the management of suppliers up to the provision of goods for the production of a manufacturing company or sale at a trading company. In the case of an industrial company, the provisioning often occurs directly at the production site, usually with the interposition of a procurement warehouse. The activity thus involves the needs-based supply and procurement of capital goods, such as systems, machinery and equipment (Muchna et al. 2021: 31). In a manufacturing or processing company, production logistics directly follows procurement logistics. The task is to feed the incoming goods to the individual production points and logistically manage semi-finished and finished products within the production processes. Depending on the company's manufacturing processes, intermediate storage may also occur in the production logistics until the goods are further processed. This logistics phase ends with the transfer of the finished products and, if applicable, the semi-finished products to a distribution or sales warehouse. Production logistics therefore consists of only internal company processes, although networked manufacturing can mean that production is distributed across several locations, resulting in transports between individual factory sites (Muchna et al. 2021: 31). Distribution logistics includes the storage and delivery of the products to be sold. This sector thus connects production logistics with the sales market or the customer. Distribution logistics commonly includes one or more sales or regional delivery warehouses. The task is to supply the markets or end users on time (Muchna et al. 2021: 33). The final phase comprises disposal logistics, which inspects the backward flow of goods, including the returns of residues, waste for disposal, recyclables for recycling, returns, empties, load carriers (e.g., pallets and boxes) and packaging (Muchna et al. 2021: 34). Legal regulations often prompt disposal logistics, which ultimately necessitates the logistical task of disposing of residual materials. This task entails controlling and monitoring disposal processes while reducing disposal costs (Heiserich et al. 2011: 11).

Figure 2 arranges the individual phases in a diagram and puts them in context. Moreover, the diagram places intralogistics in the overall picture.

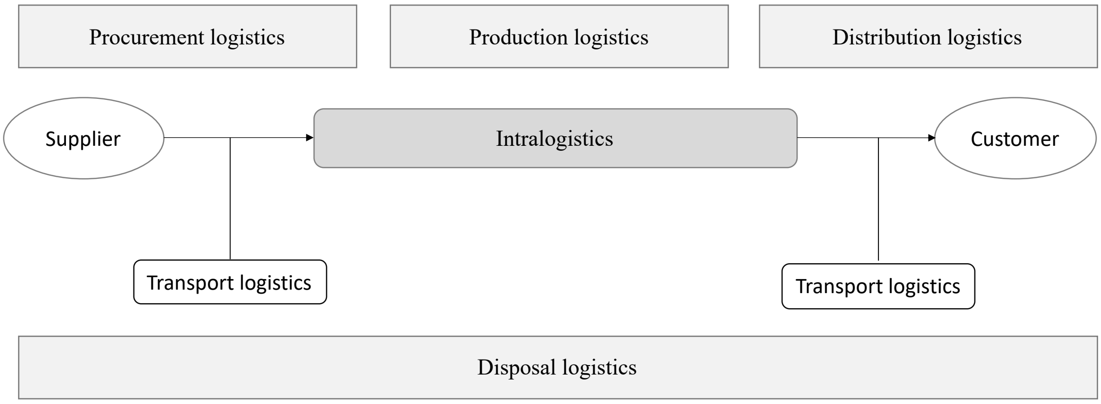

Figure 2: Phases of logistics with the classification of intralogistics

(Own representation based on Pfohl 2018: 19)

Intralogistics refers to the logistical flows of goods at a company's premises. The primary functions are conveying and transporting, distributing and merging and storing and handling goods (Martin 2014: 6). Intralogistics therefore tends to include production logistics and part of the procurement and distribution logistics. Depending on the disposal strategy, disposal logistics can also be part of intralogistics (Muchna et al. 2021: 33).

In addition to intralogistics is transport logistics, which distributes the goods between the different locations or to the end customers. Since transport logistics thus encompasses intralogistics and focuses on external transport and information flows (Tempelmeier 2018: 7). This thesis does not elaborate this concept further.

2.2 Introduction to intralogistics processes

The terms "transport", "handling" and "storage" summarise the core processes in intralogistics and are abbreviated as "TUL processes" from this point forwards (Muchna et al. 2021: 7). A process is a logical and temporal sequence of activities that manage a business object (Heiserich et al. 2011: 14). In procurement, production, distribution and disposal logistics, production companies execute TUL processes that supports the picking and packing process (Muchna et al. 2021: 86). Figure 3 creates an extension of Figure 2 to reveal the TUL processes.

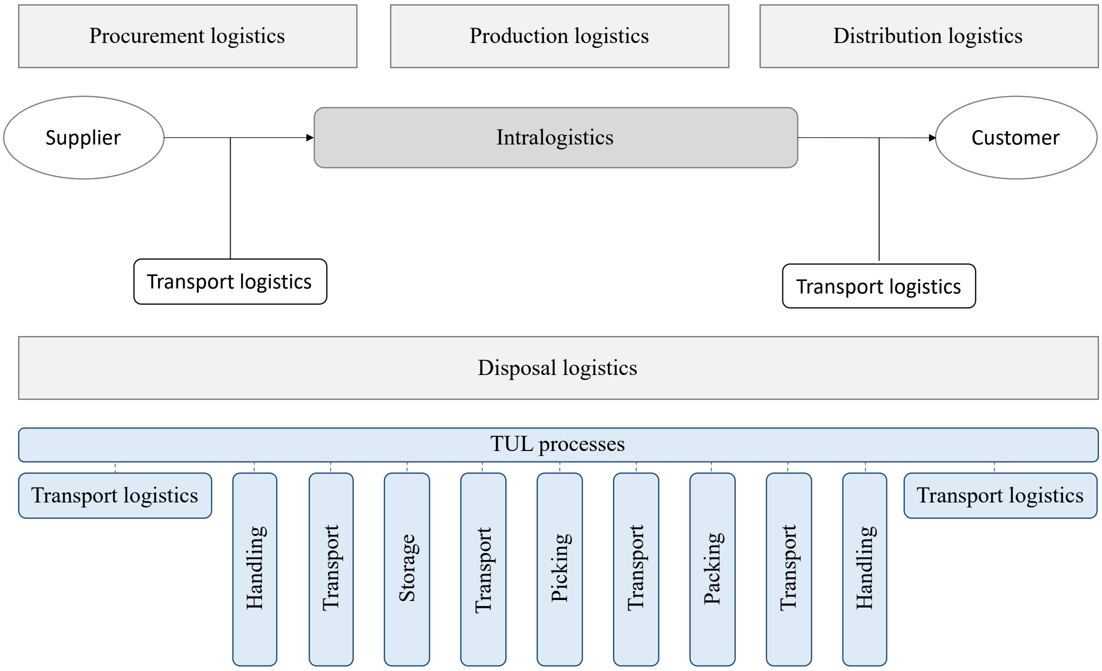

Figure 3: Phases of logistics with the classification of intralogistics ant the extension of TUL processes

(Own representation based on Pfohl 2018: 19, Muchna 2021: 87)

In view of the application scenarios, the processes are now explained in more detail.

2.2.1 Transport

In transport logistics, goods are brought from a staging point to a destination. The transport of goods can occur outside the company (e.g., be transported to a customer's point of demand or within the company (e.g., be transported from a storage location to a production location). Different transport equipment is used depending on the goods to be transported, the transport time and the distance. In warehouses and production halls, forklift or pallet trucks are often used. This process minimises the effort required for transport and optimally accelerates the material flow (Heiserich et al. 2011: 5, Pfohl 2018: 169).

2.2.2 Handling

Handling involves conveying and storing goods and transferring them from one transport to another. The handling function includes the interface between procurement and distribution logistics and production logistics. The objective is to plan, manage and control the flow of goods and information across the company (Muchna et al. 2021: 86).

2.2.3 Storage

Storage or warehousing is a planned period between the provision of the product and the time of need. Warehouses are generally located near production to buffer goods and maintain the highest possible flexibility (Muchna et al. 2021: 87). On the one hand, warehousing is a balancing function in the form of throughput quantity control to ensure that a time and quantity balance for the material flow is possible with different consumption speeds. In the event of a discrepancy between supply and demand (e.g., seasonal demand for consumer goods), assembling stock up to the point of need can ensure the ability to deliver. On the other hand, storage is a function that ensures the flow of materials in the event of uncertainties, such as the failure of or a defective delivery; the flow of materials can be guaranteed for the subsequent steps (Muchna et al. 2021: 89).

Furthermore, depending on the goods, storage also involves adaptation or refinement as the stored goods are intentionally changed during storage. Finally, storage can be a speculative function if the stock depends on a possible change in the price of the good, which can be a price increase or decrease in the sales or procurement market. Depending on the storage function, the stored goods and the storage period, goods are stored for short, medium or long periods. Warehouse logistics includes many strategies that this thesis does not address (Muchna et al. 2021: 89).

2.2.4 Picking

Order picking is a core element of intralogistics and significantly contributes to a company's economic success. Picking is the process of assembling stock items that are required for a particular order in a specific quantity. Two points illustrate the importance of picking: First, the picking area is labour intensive and therefore causes relatively high costs. Second, picking impacts subsequent processes if the picking is not error-free. Depending on how the processes run, the service level of the company's production or the customer can be negatively affected (ten Hompel et al. 2011: 3). The order is for a production delivery or a customer order and can be fulfilled with different picking techniques (Tempelmeier 2018: 7).

Picking entails two basic methods:

- Man to goods
- Goods to Man.

With the first method, the picker moves towards the required goods, which means that the picker must move to reach them. Depending on the goods, the picker can walk or drive through the picking shelves with a picking trolley. The worker removes the required items from the shelves at the respective picking locations and places them in the collection container. Once the picker has filled the container or picking trolley, it is taken to a transfer zone, where it is usually collected for production delivery (ten Hompel et al. 2011: 41). With the second method, the picker stands in a fixed place and does not move; the required goods are then automatically retrieved and made available to them. This method is often used in automated warehouses (ten Hompel et al. 2011: 41).

2.2.5 Packing

Packaging includes all activities needed to produce a package, consisting of the loose goods and the packaging. Depending on the use, different forms of packaging with different objectives, including protecting the goods, can be distinguished. Packaging material, such as cardboard or paperboard, and packaging aids, such as adhesive tapes and cushioning material, are used for this step (Muchna et al. 2021: 100). In addition, the packaging should be easy to manage during handling and order picking and have reasonable space utilisation for transport and storage, which suitable dimensions and stackability can facilitate (Tempelmeier 2018: 8).

2.3 Aims of intralogistics

The general goal of economics "efficiency" in intralogistics is to ensure that the costs of the logistical processes for the respective performance are minimal and that the performance at the respective costs is maximal (Tempelmeier 2018: 9). In this context, the goal of intralogistics is to ensure that the goods are made available for the next process step under the following aspects:

- the right materials and goods
- in the right quantity
- at the right time
- at the right place
- at minimum cost.

In summary, intralogistics aims to reduce the costs of the operational material flow and the associated information flow and increase the performance-associated information flow to increase overall performance (Martin 2016: 2). Logistics costs include the costs for the TUL processes of goods and the costs for systems and their control. In contrast, logistics performance is measured in terms of reliability, delivery time, accuracy, flexibility and precision (Martin 2016: 3).

The magic square of logistics, depicted in Figure 4, is often mentioned as a guideline.

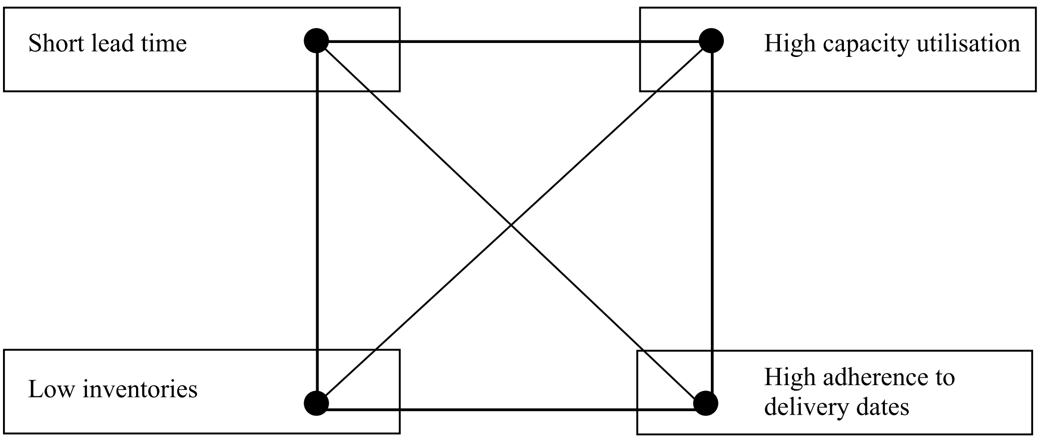

Figure 4: Magic square of logistics

(Own representation based on Heiserich et al. 2011: 19)

Capacity utilisation is the extent to which the existing capacities are utilised, and the capacities' fixed costs are thus used optimally. High capacity utilisation means that the fixed costs incurred are used well. The lead time is the sum of the processing, transition and buffer times of the company's orders and provides information on the company's readiness and flexibility to deliver (Heiserich et al. 2011: 20). Heiserich, Helbig and Ullmann distinguished the lead time in the broader sense, which extends from the acceptance of the order through production to the delivery of the order.

The flow of materials should generally be accelerated to gain time and make throughputs more efficient. High inventories mean capital commitment and storage costs for the company and should therefore be kept as low as possible. "Adherence to delivery dates" describes adhering to the delivery dates promised to the customer. Adherence to delivery dates also indicates the company's ability and flexibility to deliver (Heiserich et al. 2011: 19). The four goals of the magic square of logistics sometimes conflict. For example, if stocks are low, the risk of not meeting a delivery date arises if a replenishment delivery is delayed or the available goods are useless for production. Logistics objectives must thus be prioritised, depending on the company's goals (Heiserich et al. 2011: 22). Furthermore, logistics and intralogistics aim to increase the company's market performance, identify rationalisation potential and guarantee delivery service (Martin 2014: 3).

Tempelmeier even defined ecological goals for logistics. In the context of logistics processes, intralogistics generates negative impacts on the environment in the form of energy consumption, space requirements, noise, waste generation and pollutant emissions. Since companies' ecological goals contrast their economic goals, one must be prioritised over the other. Sustainability can therefore also be defined as a goal of intralogistics (Tempelmeier 2018: 10).

Another application is the definition of intralogistics objectives via logistics performance, which the following four criteria usually define: delivery time, reliability, quality and flexibility. Logistics performance is contrasted with logistics costs, which are divided into the various logistics processes (Tempelmeier 2018:

10). Table 1 summarises all the components that belong to logistics performance and logistics costs.

Table 1: Comparison of logistics performance and logistics costs

Logistics performance	Logistics costs
Delivery time	Transport costs
Delivery reliability	Handling costs
Delivery quality	Picking costs
Delivery flexibility	Packing costs
	Storage costs
	Costs of control

(Own representation based on Tempelmeier 2018: 10)

The delivery time includes the time between when the order is placed and when it is delivered to the customer's premises. Delivery reliability is a measure of meeting the delivery time, whereas the delivery quality describes whether the delivery is complete and whether the goods' overall condition corresponds to the order. The final component of logistics performance is delivery flexibility, which measures how flexibly the company can respond in all aspects (Tempelmeier 2018: 9). Finally, logistics costs include all costs incurred in the various sub-processes, such as transport, handling, picking, packing, storage and IT control costs (Tempelmeier 2018: 10).

2.4 Challenges and opportunities of intralogistics

Intralogistics must optimally coordinate highly complex intralogistics processes and react to changing market conditions. In the process, intralogistics is responsible for supplying the supply chain and determining which goods are brought in and in what composition (Miebach & Müller 2006: 22). Miebach and Müller described intralogistics as the "heart" and the "eye of the needle" of the supply chain as the rest of the supply chain and the industries supplied depend on the performance of in-house logistics (Miebach & Müller 2006: 28). According to the magic square of logistics, the pursuit of low inventory necessitates complex manufacturing processes. Just-in-time or just-in-sequence delivery minimises inventory by providing the exact quantity of goods needed for the next step at the appropriate time (Miebach & Müller 2006: 20), which places high demands on logistics to be able to ensure the supply of goods. The increasing demand for individualisation is also a significant challenge for intralogistics. The extreme case of lot size 1 means that each product is a single-item production, which thus means a more complex production supply and that an individual goods composition is required for each product (Günther & ten Hompel 2010: 4). This development places ever higher demands on the material flow in terms of flexibility, changeability and adaptability, for which the original methods are no longer sufficient (ten Hompel 2006: 266).

Miebach and Müller consider intralogistics in the supply chain as the area with the highest potential for rationalisation, as well as service and quality. With automation, inventory can be reduced or costs can be saved through improved capacity utilisation. In terms of quality, technical support for picking processes can lead to significant improvements (Miebach & Müller 2006: 26). Furthermore, a reduction in lead time can result in a more flexible delivery, producing a competitive advantage. As part of a continuous rationalisation of all processes, IT systems also automate and support intralogistics processes (Kilger & Hermann 2006: 212). Indeed, software systems automate numerous processes that were previously executed manually. Varying degrees of effort must be expended to utilise the abovementioned opportunities (Geutebrück 2020: 3).

According to Miebach and Müller, the implementation efforts to develop opportunities in intralogistics can be divided into the different areas presented in Figure 5. Miebach and Müller assign the area of personnel a medium potential with a low implementation effort. In contrast, the areas of infrastructure and technology each have a high potential with a high implementation effort. In intralogistics, the proper interaction of technology, IT and personnel is particularly important in terms of service and quality. The potential for improvement contribute to achieving logistics goals (Miebach & Müller 2006: 28).

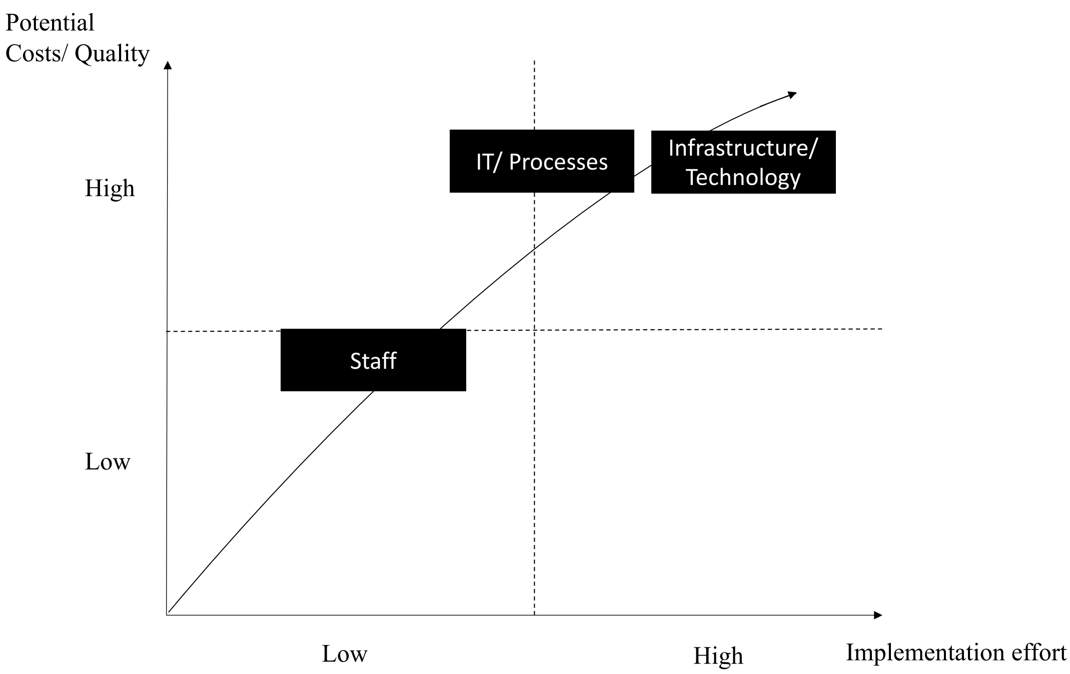

Figure 5: Development of potentials in various areas of intralogistics

(Based on Miebach & Müller 2006: 27)

2.5 Digitalisation and Industry 4.0 in intralogistics

The terms "digitalisation" and "Industry 4.0" have become indispensable in the current era. Both expressions indicate considerable potential for the entire supply chain in the logistics sector (Geutebrück 2020: 27).

"Industry 4.0" refers to the fourth industrialisation of the Industrial Revolution. The first revolution, which generated a fundamental change in the economy and society, began in England in the 18th century before spreading to the USA and Western Europe. The second revolution followed in the 19th century with mass production. The third revolution then followed in the 20th century with the invention and spread of electronic data processing (Voß 2020: 73).

Winkler and Zinsmeister consider digitalisation one of the greatest challenges and opportunities (Winkler & Zinsmeister 2019: 538). Industry 4.0 is understood as the complete networking of an autonomously acting value chain. Conversely, digital transformation describes the process that a company undergoes until it reaches this state. Digitalisation can thus be defined as a necessary tool for change (Geutebrück

2020: 21). Geutebrück expects the greatest transformation effects in production and logistics (Geutebrück 2020: 6). The most desired benefits of digital transformation include increases in quality assurance and time, cost savings and the reduction of manual work steps (Geutebrück 2020: 10). Industry 4.0's most important tools are networking and self-control, which encompass the areas from production to material flow control (Zsifkovits & Woschank 2019: 42).

Geutebrück developed a model with six progressive stages that demonstrates where a company or a division of a company is concerning the transformation towards the vision of Industry 4.0. The first two stages, computerisation and connectivity, form the foundation for the four maturity levels, visibility, transparency, predictability and adaptability (Geutebrück 2020: 22). Figure 6 illustrates the maturity levels of Industry 4.0.

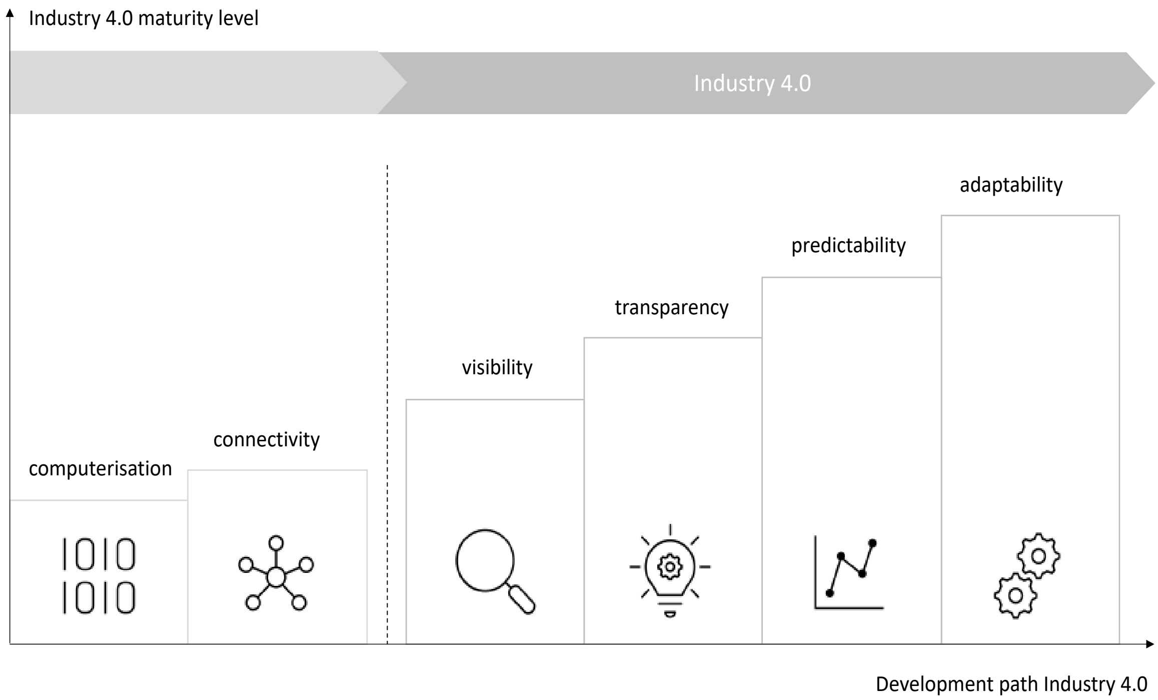

Figure 6: Maturity levels of Industry 4.0

(Based on Geutebrück 2020: 22).

The first maturity level, visibility, describes the automatic data collection for the digital mapping of activities. Visibility allows methods, concepts and algorithms to be used for data preparation and plausibility checks to understand why an event is occurring. Based on cause-and-effect relationships, the third maturity level, predictability, allows decisions on events that are likely to occur to be made early. The highest maturity level, adaptability, describes autonomous systems' self-optimising and proactive behaviour. The activities are defined independently and continuously improved based on the analysed data (Geutebrück 2020: 21).

Prerequisites for digital transformation include the networking of plants and products, autonomous systems of material flow and systems of control (Zsifkovits & Woschank 2019: 42). The main goal is creating a lean and intelligent supply chain based on the foundation of networking sensors, data networks and smart technologies (Zsifkovits & Woschank 2019: 45). Automated processes, such as intelligent logistics systems and autonomous means of transport, also offer opportunities for change and reducing manual and time-consuming work (Zsifkovits & Woschank 2019: 43).

Another important factor is that digitalisation requires technical prerequisites, such as a powerful IT infrastructure. The challenge is adapting the existing infrastructure to the state of the art of current IT (Voß 2020: 71). In the change of the digital transformation, the logistics sector is identified with the vision of Logistics 4.0 and facilitates further potentials to improve the industry and generate new opportunities regarding the goals of intralogistics.

2.6 Summary

This chapter describes the background of intralogistics and the main processes of transport, handling, storage, picking and packing. Moreover, the goals are described with the magic square of logistics. Intralogistics must face various conflicting goals and challenges, including individualisation, whereby it can counteract these with potentials, such as the application of new technologies, among other things. Following, the trend of the digital transformation, the logistics sector is identified with the vision of Logistics 4.0 and facilitates further potentials to improve the industry and create new opportunities regarding the goals of intralogistics and ultimately for the success of the company.

3 Introduction of smart glasses in intralogistics

Using digital innovation technologies for the transmission of information and support in routine work is being discussed in many industries. The aim is to accelerate work processes, reduce errors and increase efficiency. The high number of repetitive processes in intralogistics ensures a high potentiality of deployment scenarios. Moreover, implementing smart glasses promises new possibilities for digitalising work processes (Berkemeier et al. 2019: 308). Smart glasses technology demonstrates beneficial development potential for intralogistics. This chapter elaborates this technology and the current state of the art.

3.1 Smart glasses technology

Smart glasses are small computers supplemented with peripheral devices that are worn on the head and controlled with the eyes and hands (Bendel 2021). They can be used with augmented reality (AR) and virtual reality (VR) technology. AR involves adding a digital layer to the physical world, which facilitates enriching the real world with virtual details to enable easier managing of the environment. In contrast, VR replaces the real world with a digital world. A new interactive and digital environment where the user is integrated is created. Using VR facilitates creating different environments and situations that might be encountered in one’s personal or professional life. VR training is an effective method for learning work steps or preparing for specific situations within the work environment. For instance, a company can use the glasses for training, virtual tours or conferences and especially training exercises that are impossible, expensive or too dangerous in real life.

Smart glasses are regularly equipped with a touchpad integrated into the temple. Voice, eye and head movements are used to control the system. The glasses can be accessed through a smartphone or notebook. For the visualisation of AR and VR, a head-mounted display (HMD), such as the classic smart glasses, is required. HMDs are small displays worn directly in front of the eye and can be compared to traditional glasses that compensate for impaired vision (Theis et al. 2015: 7).

Depending on the provider, smart glasses have different components. The most frequently mentioned features are display, prism, microphone, camera, eye sensor, Bluetooth, WLAN and USB connection. Niemöller divided all functionalities into six clusters: tracking, glasses interaction, environment identification, picture and video, information provision and advanced communication (Niemöller et al. 2016: 757). Table 2 reveals the individual features of the six clusters.

Table 2: Overview of smart glasses features

No.	Cluster	Feature
[1]	Tracking	Temperature Gauge
		Health Tracking
		GPS Navigation
[2]	Glasses Interaction	Hands-free Content Navigation
		Voice Recognition
		Gesture Recognition
		Eye Tracking
		Head Tracking
[3]	Environment Identification	Identifications of Objects
		Identification of People
		Night/ Thermal Vision
[4]	Picture and Video	Pictures and Videos
[5]	Information Provision	Search Information
		Contextual Information
		Real-time Statistics
		Information Overlay/Application
[6]	Advanced Communication	Textual Communication
		Video Conferencing
		Real-time Translation
		Live Streaming

(Own representation based on Niemöller et al. 2016: 758)

Included in the first cluster, temperature gauge can measure the temperature of the environment, whereas health monitoring can be used to ensure the tracking of health activities by measuring, for example, the heart rate using sensor components. The last feature in the tracking cluster is GPS navigation, which is how the system provides location information (Niemöller et al. 2016: 758).

The glasses interaction cluster includes functions that are present in the device itself and work with sensors. Hands-free content navigation ensures that the user can navigate through the information and content they need without using their hands. In addition, hands are not required to execute commands. A variant for control is voice recognition, which executes spoken commands. Executing commands by recognising and interpreting gestures through mathematical algorithms is also possible. The last two features in this cluster are eye and head tracking. Here, either the viewpoint or the movement of an eye relative to the head is used for analysis or navigation. Conversely, head tracking allows the camera to move in the same orientation as the user's head (Niemöller et al. 2016: 758).

Features in the third cluster are associated with environment identification. Objects and persons are identified using the camera function. Night/thermal vision can also be ensured by detecting infrared radiation in objects. Furthermore, an integrated camera enables the data glasses to take pictures and videos (Niemöller et al. 2016: 758).

The penultimate cluster includes functions for information provision. Smart glasses can search for information using search terms and images and present relevant and usable information by analysing data on the device's environment. The glasses can even display compilations of real-time statistics on relevant information and selectively add additional information by overlaying virtual objects with the view of the real world (Niemöller et al. 2016: 758).

The final functions can be grouped in the advanced communication cluster. Smart glasses can send and receive text messages with input mechanisms such as speech recognition. In addition, communication with multiple users can occur in real time through bidirectional video and audio transmissions. In the case of language barriers, translations of foreign languages can also be performed spontaneously.

Finally, live streaming can occur through a compressed form via the Internet (Niemöller et al. 2016: 758).

3.1.1 Technical construction

HDMs use a see-through display method to allow the overlay of computer-generated images with the view of the real world (Kollenberg et al. 2010: 121). An HMD consists of a display unit, a module in front of it and various expansion modules. Examples of extension modules are loudspeakers, a headband for mounting and a tracking system (Theis et al. 2015: 10).

Humans need a stereoscopic representation to perceive information spatially in a virtual environment. In this representation, the stereoscopic parallax has shifted an image that is presented to the left and right eyes, which is considered the ability to gain a spatial visual impression using two functioning eyes (Alexander 2007: 989). Stereoscopic vision is the basis for HMDs, which enable the fusion of the real and virtual worlds. The illusion of 3D vision is created by displaying a slightly different image for both eyes on the HMD display. The difference is that the same content is presented from two minimally different perspectives, similar to in the real world. The stereoscopic difference that a computer programme simulates enables the brain to calculate a 3D impression of the virtual world (Dörner et al. 2019: 47). In contrast, 2D images without spatial impression are called monoscopic.

The HMD device still needs a lens so that a sharp image can be seen. The eye can recognise a sharp image only when the image is at a certain distance. Since the projected image in the HMD device is only 5–8 cm away from the eye, the eye cannot see it. The HMD device is therefore equipped with a lens that refracts the display so that a sharp image can be formed on the retina. This procedure is the same as with strong reading glasses (Mißfeldt 2012).

HMDs can be classified into two groups: see-through and lookaround (i.e., non-see-through). These groups are described in Table 3.

Table 3: HMD classification

No.	Group	Description
[1]	See-through	- Information can be superimposed on the real environment - Used through a semi-transparent mirror (i.e., prism) placed at an angle in front of the user's eye - The user sees the real environment behind the mirror - Images on the display have a high luminance in the real outdoor lighting conditions - The real environment can be displayed without loss of quality - Used for AR
[2]	Look-around (i.e., non-see-through)	- The real environment is faded out - Digital information is presented on a closed display - Used for VR applications (e.g., computer games and training simulations)

(Own representation based on Theis et al. 2016: 11)

3.1.2 Technology selection

To date, several suppliers have launched different models in the market. The decisive criteria for technology selection include battery life, display resolution, wearing comfort and interaction possibilities (Thomas et al. 2020: 12). The relevant decision criteria are explained in more detail in the following paragraph.

1. Industrial suitability
2. Ergonomics and wearability
3. Resolution and positioning of the display
4. Camera quality
5. Interaction possibilities

As smart glasses were initially developed exclusively for the consumer market and not the industrial market, testing the module for industrial suitability is necessary.

Ergonomics and wearability must also be considered to ensure that the smart glasses can be worn for an entire shift; otherwise, they are less suitable for intralogistics processes. In addition, a high resolution for the display is crucial so that the user can read the information easily. The variable positioning can even be adjusted so that the display is on the dominant side of the eyes. The camera quality is vital for identifying objects and reading barcodes and QR codes to ensure a smooth workflow with smart glasses. If the camera quality is low, the user may have to read the object several times until it is recognised, which leads to an increased usage of time and thus increased costs. Finally, variable interaction possibilities are essential for easy handling with such an HMD. Options such as voice input, gesture recognition, control buttons and a lateral touch input enable interaction in a wide variety of ways (Thomas et al. 2020: 12).

3.2 State of the art

This section compares a suitable selection of smart glasses to demonstrate the current state of the art. The comparison of the smart glasses' technical properties is provided in Table 4. Major manufacturers in the current market for use in intralogistics include Vuzix, RealWear, Google and Epson.

Table 4: Comparison of technical properties

Feature		Vuzix M400	Vuzix M4000	RealWear HMT-1	Google Glass	Epson MOVERIO BT-300
Display description		OLED	DLP display	LCD micro display	Prisma	OLED
Display resolution		640x360 pixels	854x480 pixels	854x480 pixels	640x360 pixels	1,280x720 pixels
Display position		adaptable	adaptable	adaptable	right only	binocular
Camera		12,8 MP	12,8 MP	16 MP	8 MP	5 MP
Connection	Wi-Fi	✓	✓	✓	✓	✓
	GPS	✓	✓	✓	✓	✓
	Bluetooth	✓	✓	✓	✓	✓

Battery runtime		2-3 h	2-3 h	5 h	1 h	5 h
Interaction possibilities	Button control	✓	✓	-	✓	✓
	Touchpad	✓	✓	-	✓	✓
	Voice control	✓	✓	✓	✓	-
Storage capacities		64 GB	64 GB	16 GB	16 GB	16 GB
Operating system		Android 8.1	Android 9.0	Android 8.1	Android 4.4.2	Android 5.1
Weight		180 g	95 g	380 g	46 g	69 g
Industrial suitability		available	available	available	limited	available
Price		1,700 €	2,300 €	1,800 €	1,000 €	800 €

(Own representation based on Thomas et al. 2020: 13, Bitnamic 2021, RealWear 2021, Epson 2021, Rise-Rs 2021, VR-Expert 2021, Unboundvr 2021)

The different displays are divided into liquid-crystal display (LCD), liquid crystal on silicon (LCoS), organic light-emitting diode (OLED) and digital light processing (DLP). LCDs use the properties of liquid crystals in combination with polarisers to block or transmit light from a backlight. The pixels are formed by arranging the crystals in a matrix shape; they do not emit light themselves but can transmit a certain amount of background light due to a certain voltage. One advantage of this approach is that resolutions of all sizes can be created, which has led to LCD being a widely used technology for HMD devices. LCoS is a special form of LCD. Contrasting LCD, LCoS does not transmit light but reflects it (Kemeny 2020: 65).

With an OLED display, the screen consists of an LED matrix, a luminous thin film component made of organic semiconducting materials. The electrical current density and luminance are lower than with conventional LEDs. OLEDs are thinner and lighter than LCD screens since they do not need a backlight, because LEDs emit the light directly, and are hence increasingly replacing them. For headsets, this weight increase is crucial for the user's comfort as it means less weight on the head (Kemeny 2020: 65).

Finally, with DLP displays, microscopic mirrors arranged in a matrix on a semiconductor chip generate the image. Each mirror represents one or more pixels in the projected image, and the number of mirrors corresponds to the resolution of the projected image (Kemeny 2020: 67).

The display resolution is between 640x360 and 1,280x720 pixels. Furthermore, the display position is adaptable on most of the compared models, which means that the display can be on the right or left eye. The Google Glass display is not adaptable and is static on the right side. With the binocular solution, the user sees the display through both lenses. The integrated cameras in the displays of the models listed above have resolutions between five and 16 megapixels.

All devices can be connected through Wi-Fi, GPS and Bluetooth, which enables interaction with the devices, resulting in a broader field of application. The data capacity varies between 16 and 64 GB depending on the device. According to the use case, this is how data can be stored on the glasses. For documenting different conditions, sufficient storage should be available to cover an eight-hour shift.

The operating system offered for the selected smart glasses is Android; only the versions of the various operating systems differ. The operating systems represented are 4.4.2, 5.1, 8.1 and 9.0. As these glasses are operated via a smartphone or a notebook, the operating system of the data glasses must be considered to ensure that both devices are compatible with each other.

The current state of the art of battery life is between one and five hours. However, using the smart glasses for a complete shift is possible with an external battery. The interaction options differ between button, touchpad and voice control. The advantage of combined interaction options is that the system works with different framework conditions. Background noise in the warehouse and language barriers can thus be overcome.

Finally, the weight of the smart glasses differs significantly between the five models. The Google Glass has the lowest weight at 46 g, and the VUZIX 400 is the heaviest model at 180 g.

The industrial suitability of the smart glasses is also critical since, due to external circumstances, these glasses should not be fragile. Depending on the application, the smart glass requires certain robustness to withstand the environment. Except for Google Glass, all devices are suitable for industrial use. Due to the glass prism, the Google Glass model is vulnerable when dropped on the floor. The price range of the selected smart glasses varies between 800€ and 2,300€.

One common disadvantage of these five smart glasses is that they do not work on the powerful 5G network. Nevertheless, manufacturers must still enable their models for 5G as this should be the mobile phone standard of the near future.

Figure 7 illustrates each of the selected smart glasses to reveal how the manufacturers implemented the individual features.

Figure 7: Photographic representation of the selected smart glasses

(Unboundvr 2021)

3.3 Deployment scenarios for using smart glasses

Since smart glasses are used in a wide range of fields, the deployment scenarios described below are divided into seven areas: computer science, health care, education, industry, service, social science and agriculture. Figure 8 presents an overview of the deployment scenarios (Dawon, Yoyoon 2021: 4).

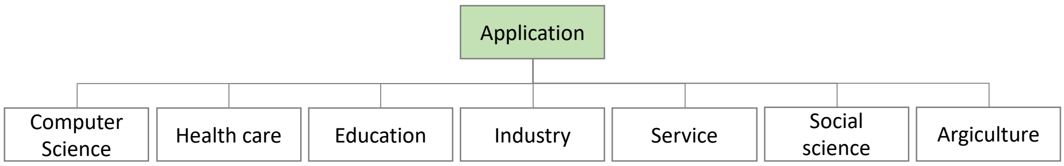

Figure 8: Overview of deployment scenarios

In computer science, smart glasses technology is used for object recognition for the visual representation of data for the user, whereas in the health care sector, this technology is used to support medical facility staff using smart glasses (Dawon, Yoyoon 2021: 6). In education, the technology is used to quickly train people or familiarise them with scenarios that are too dangerous in real-life situations. It can also help support physical and mental disabilities to effectively strengthen patient treatment. The industrial sector includes smart glasses use in maintenance for safety precautions and work support (Dawon, Yoyoon 2021: 8). In the service sector, the technology is applied in culture and tourism. The understanding of works of art can be improved through a descriptive method of expression with the help of smart glasses (Dawon, Yoyoon 2021: 9). In addition, in the e-commerce sector, smart glasses can be used for purchasing products online (Dawon, Yoyoon 2021: 4); however, they are not yet used in this sector due to security issues. Finally, in agriculture, smart glasses are used to improve the performance of livestock farms. Specifically, they are used to read, identify and group different content (Dawon, Yoyoon 2021: 11).

3.4 Advantages of using smart glasses

One advantage of using smart glasses is that they cognitively relieve workers during their work. The display of the smart glasses presents the employee with the work-specific information required for the next work step. The worker can rely on the smart glasses and therefore reduce possible errors as they have access to the information they need anytime (Theis et al. 2015: 7). The errors are thus reduced, while the quality of the work is enhanced (Wang et al. 2019: 67).

Another significant advantage of using these glasses is the user's ability to access information hands-free (Niemöller et al. 2016: 753, 761). Information-intensive activities that leave the hands free for essential work are a substantial advantage. Moreover, a high staff turnover occurs due to the repetitive nature of the work (Berkemeier et al. 2019: 308); the use of smart glasses can make it easier for new employees to start working.

Finally, since the required information is presented on the display of the smart glasses, no other medium – including paper – is needed. The process can hence be more ecological and reduce waste (Rejeb et al. 2021: 3762).

3.5 Challenges of using smart glasses

Despite the many advantages of using smart glasses, some challenges concerning the effects of this technology have emerged. Due to the lack of long-term use with smart glasses, concerns about health consequences persist (Rejeb et al. 2021: 3762). Indeed, some studies confirm undesirable results from using smart glasses for several hours. For instance, in 2018, Vujica et al. tested this matter in a picking activity and discovered that differences in the users' visual acuity occurred after use. Furthermore, one-sided use strongly strains the right eye, on which the information is projected (Vujica et al. 2018: 426). Another study found that users suffered visual fatigue and mental stress when using such an HMD device (Wang et al. 2019: 58). In 2018, Tsai and Huang learned that users perceive headaches due to screen resolution and size limitations (Tsai, Huang 2018: 172). Finally, smart glasses can be distracting and annoying for users, especially when switching between a visual display and the real world (Grabowski et al. 2018: 25).

3.6 Summary

This chapter explains the smart glasses technology. It also describes all the features of smart glasses and puts them into a practical context. The possibilities range from simple tracking to extended communication. Furthermore, the technical construction is clarified. A distinction between see-through glasses and look around glasses is made. Depending on the application, a virtual environment and augmented reality can be implemented. The criteria for a suitable selection of data glasses for a process in intralogistics are established and elaborated. The relevant decision criteria are industrial suitability, ergonomics and wearability, the resolution and positioning of the display, the quality of the camera and interaction possibilities. The current state of the art of smart glasses is demonstrated, and different models are presented and compared. In addition, application scenarios beyond intralogistics are revealed, such as computer science, health care, education, industry, service, social science and agriculture. Finally, the advantages and challenges of the technology are described.

4 Methodological approach

Smart glasses technology offers potential for a wide variety of areas. The possibilities that arise from using smart glasses technology in intralogistics are examined more comprehensively in Chapter 5. The use cases are intended to illustrate exemplary, practical possibilities for using the technology in intralogistics and to explain the changed process completely. The processes are thus described theoretically with and without the use of the technology.

For this thesis, the identification of the use cases was performed through the literature review. The individual processes from the literature are assessed further in Chapter 2, and various forms of these processes are listed in Chapter 5. The deployment scenarios for using smart glasses technology in intralogistics were then evaluated to assess the individual deployment scenarios in terms of added value for companies. Evaluation criteria were determined to evaluate the use cases in schematically structured and comparable manner.

The need for efficient processes is indispensable in a company that operates economically. As mentioned in Chapter 2, logistics costs represent a significant proportion of the costs that the company incurs and account for more than 50% of industrial value creation. The following criteria needed for a sufficient evaluation of the deployment scenarios are defined in the following four paragraphs:

1. process transparency
2. lead time reduction
3. process quality and
4. workplace improvement.

On the one hand, *process transparency,* which represents a maturity level of a company's transformation into the Industry 4.0 vision, is chosen. Increased process transparency facilitates data collection and analysis for companies, allowing them to investigate cause-and-effect relationships and to monitor the supply chain in real time. Process transparency therefore supports the visibility and understanding of the respective process flows (Geutebrück 2020: 21). Processes that provide little to no information on their exact sequence, as well as non-transparent processes in the warehouse, are thus reduced. On the other hand, transparently designed processes can be controlled better and used for analysis based on of the newly acquired information. The processes' design is hence more effective, and optimisations can be performed due to the collected data.

Lead time reduction is one of the four goals of the magic quadrilateral of logistics. Moreover, accelerating the flow of materials allows existing capacity be used more efficiently, and costs can be saved.

Chapter 2 also mentions the importance of *process quality,* specifically a high-quality grade. If the wrong materials are provided, the customer who initiated the process will be dissatisfied. Especially in logistics processes, the 0 error rate is one of the most important goals for ensuring a continuous production. Furthermore, quality directly impacts costs, if a fault occurs, it must be corrected at expense, and in the worst case, it leads to a recall in the automotive industry. The later in the. Process the failure is detected, the more expensive the correction becomes.

The last criterion for the process evaluation is the impact on the person who executes the process. When evaluating a process, one must therefore assess the *workplace improvement*, which affects employee satisfaction.

The evaluation was performed based on the comprehensive literature review in Chapter 2. In addition, the authors' assessment shines through. The author has gained a great deal of experience with logistics planning in the automotive industry and consulting for different companies; this experience flows into the description of the process in Chapter 5. This knowledge was also be used to evaluate the use cases in this thesis.

The processes with smart glasses technology were evaluated according to the identified criteria to determined how beneficial using this technology is for the companies considered.

After the evaluation through the literature review and the author's knowledge was completed, the results were finally verified with the expert, Dr Martin Riester, Head of Business Unit Logistics and Supply Chain Management at the Fraunhofer Institute Austria.

5 Identification of deployment scenarios

Smart glasses technology offers potential for a wide variety of areas. This chapter takes a closer look at the possibilities that arise from using an HMD in intralogistics, focusing on the identification and description of deployment scenarios. The processes listed in Chapter 2 (i.e., transport, handling, storage, picking and packing) are investigated, and the various forms of these processes are clarified. Afterwards, a description of the identified processes with and without the use of smart glasses technology is presented, and the differences and the similarities are determined. An evaluation of the processes through the literature review and the author's practical experience follows. Finally, the results of the evaluation are verified with the expert Dr Martin Riester, Head of Business Unit Logistics and Supply Chain Management at the Fraunhofer Institute Austria.

5.1 Storage and retrieval

Storage and retrieval can be assigned to the handling and storage processes in Chapter 2. While this activity falls predominantly under handling, it includes overlap with storage. The following subsections describes the process of storing and retrieving without and with the use of Smart Glasses technology. An evaluation of the process follows with regard to the criteria defined in Chapter 4 process transparency, lead time reduction, process quality and workplace improvement.

5.1.1 Process without smart glasses technology

This section explores the storage process first. Storage usually occurs in a company’s goods receiving department, which receives goods from outside the company or an external warehouse. The task is to perform technical and organisational work and prepare the goods for storage. Depending on the material, a quantity check and a quality check are conducted. Assessing quality control varies greatly between companies and can involve a qualitative or quantitative check or, for example, colour, material or surface check. The goods are released for the storage process only when the test result is positive (Martin 2016: 353), which means that the goods receiving department takes the delivered goods over from suppliers or forwarding agents. The goals of material receiving in the goods receiving department are thus to record material data and control deliveries by avoiding congestion and reducing the standing times of trucks (Klug 2018: 233). The following list describes, the standard process of storing goods, which is common in the automotive industry, in individual steps:

1. The truck arrives at the goods receiving station.
2. The freight documents and delivery notes are accepted, checked and processed.
3. The order is checked for the type and quantity of goods and the delivery date.
4. The load carriers are checked for conformity with the packing instructions according to the packing plan.
5. Release for unloading the containers is acquired.
6. The delivered containers are unloaded, usually via forklift truck.
7. A visual inspection of the delivery for identity, quantity, weight, load carrier and quality is performed. The information on the goods receipt slip, which is available to the worker in printed form, is required. The employee generally goes through the individual items one after the other and manually marks whether all items are correct on the goods receipt slip.
8. In case of damage, notification is sent to the internal quality assurance department for inspection. This department decides whether the materials will be returned, scrapped or used. Damages are usually recorded manually and entered into the system later.
9. In case of delivery in the wrong or a damaged container, the material is repacked into the correct container, and supplier management is notified. Details are usually recorded manually and entered into the system later.
10. The delivery note is acknowledged, usually via hand scanner.

11. After the delivery note is acknowledged, the materials are automatically booked in the system.
12. A material tag is printed out in accordance with VDA 4902.
13. The material label is attached to the container.
14. The material is released for storage or direct transport to production depending on the urgency of the materials (Klug 2018: 233).

Figure 9 outlines the entire process. A diagram illustrates each of the 14 process steps listed and described above in the overall process flow.

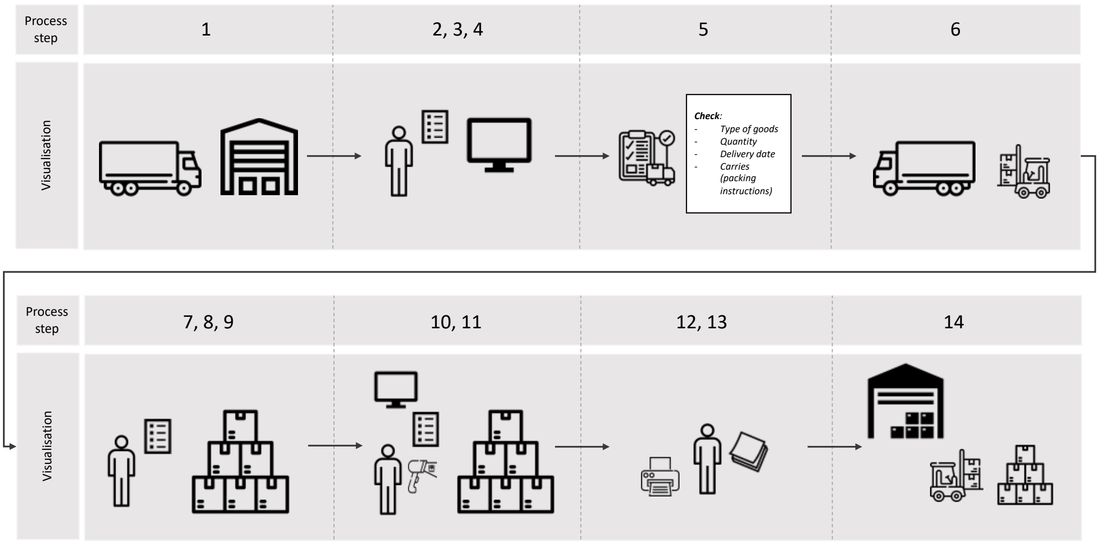

Figure 9: Process illustration for the storage of materials without smart glasses technology

(Own representation based on Klug 2018: 233)

* This cover has been designed using resources from Flaticon.com

The process may deviate from the standard depending on how many different specifications of special tasks are present in the plant. The processing of customs goods, hazardous goods or complaints is a different matter. The process with customs goods and the process with dangerous goods have a special release process. For example, customs goods cannot be stored or opened until the customs office releases them (Arnold 2006:197). However, the basic principle of the process remains the same; only individual process phases are more elaborate than in the standard process. Due to the large overlap, a detailed process description of customs goods, hazardous goods and complaints can be dispensed with in this thesis, as the essential elements are all considered in the standard process.

The retrieval process is detailed below. Due to its similarity to the storage process, a detailed description is not provided, however the differences between the processes are highlighted. When materials from the warehouse are retrieved, a differentiation is made according to the consumer. In the automotive industry, the company's production is assumed to be the largest source of demand from the resident warehouse. Other demand sources can include sister plants, subsidiaries and the aftersales market. An enterprise resource planning system (ERP) or warehouse software controls the demand. In a manually operated warehouse, the required material is commonly requested via a so-called retrieval document in the warehouse. The retrieval document is printed in the warehouse and contains all the necessary information needed to make the material available for production, such as part number, quantity and storage location. The forklift driver picks up the retrieval document and stores the required material. In the process, the forklift driver scans the retrieval document and confirms it when transferring it to production. The material is then booked in the system accordingly. Depending on the company, the forklift driver transports the container directly to the production line or to a picking zone. Another variant is a planned tugger train, where the different materials are brought to production together. As in the storage process described above, the storage or retrieval document is generally printed out and scanned with a hand scanner.

5.1.2 Process with smart glasses technology

This subsection describes the above process when the involved employees from the goods receiving department and the warehouse are equipped with smart glasses. In process steps 7-11, the employees are equipped with smart glasses. According to German law, every vehicle that transports goods by road must carry a consignment note, which is why the smart glasses cannot replace paper in this process. The individual steps from seven with the data glasses are listed and explained below. Steps 1-6 correspond to the same process steps in Subsection 5.1.1. Figure 10 shows the process flow with smart glasses.

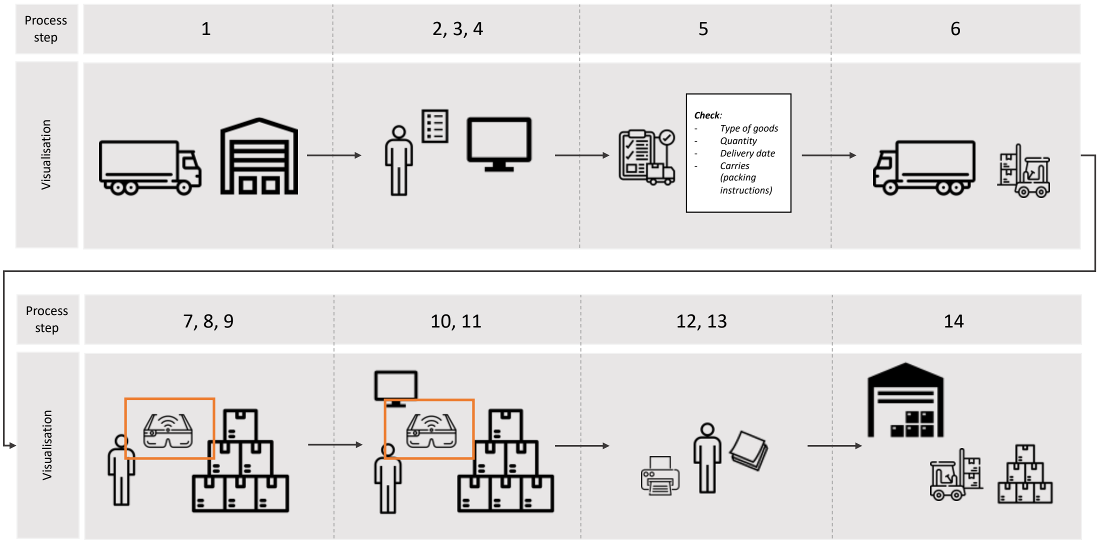

Figure 10: Process illustration for the storage of materials with smart glasses technology

(Own representation based on Klug 2018: 233)

* This cover has been designed using resources from Flaticon.com

7. A visual inspection of the delivery for identity, quantity, weight, load carrier and quality is performed. The worker requires the receipt slip for verification. The logistician can call up this slip via their smart glasses and thus has all the information needed for the check available in the field of vision. The worker can also use the smart glasses to confirm the different positions simultaneously.
8. In case of damage, notification is sent to the internal quality assurance department for inspection. This department decides whether the materials will to be returned, scrapped or used. If such a situation arises, the worker can immediately start a corresponding workflow to the quality assurance department via the smart glasses.
9. In case of delivery in the wrong or a damaged container, the material is repacked into the correct container, and the supplier management is notified. If such a case arises, the worker can immediately start a corresponding workflow to the supplier management department via the smart glasses.
10. If all items on the delivery note have been confirmed, the delivery note is confirmed via an automatic workflow. The worker must confirm this note once on the smart glasses.

11. After the delivery note is acknowledged, the materials are automatically booked in the system.
12. A material tag is printed out in accordance with VDA 4902.
13. The material label is attached to the container.
14. The material is released for storage or direct transport to production depending on the urgency of the materials (Klug 2018: 233).

5.1.3 Evaluation

This subsection evaluates the storage and retrieval process with the smart glasses technology is evaluated according to the defined criteria.

Transparency increases with the introduction of smart glasses technology in this process. Since the software monitors and confirms the individual steps, evaluating, how long sub-processes take is possible. Moreover, maximum transparency in a process facilitates assembling a system of key figures and thus controlling the result in a targeted manner. Without the use of additional software, only the total time of a process, not the individual sub-processes, can be evaluated with the ERP system.

Once adaptation to the new technology occurs, the *lead time* can be reduced using the smart glasses technology as certain process steps can be combined or omitted. When visually checking the delivery for identity, quantity, weight, load carrier and quality, the worker can use the smart glasses to directly indicate whether all items are correct. The worker's hands remain free as the delivery note is presented to them on the display, and they can confirm one position after the other via the touchpad or voice recognition. If a deviation in quantity or a quality issue arises, a workflow can be started immediately, and the corresponding interface departments (i.e., quality management or supplier management) receive an action item that must be addressed. Without the smart glasses, the worker must first return to their computer workstation and enter all the data; with the smart glasses, the worker can complete the work step immediately after each position.

The *quality* in this process may be considered neutral due to the use of technology. However, the data quality is assumed to increase with smart glasses technology because handwritten notes do not have to be made on the delivery note but can be processed using a workflow. The information can be noted directly in the system and checked on-site if any ambiguity occurs.

The *workplace* is improved to the extent that the worker does not need an additional scanner and no longer has paper documents and thus has their hands free. The logistician can retrieve all the needed documents using the smart glasses. Table 5 summarises the arguments of the evaluation.

Table 5: Summary of the evaluation criteria for storage and retrieval

Criterion	**Argument**
Process transparency	- Transparency about partial steps - Detailed KPI system possible - More precise control
Lead time reduction	- Direct confirmation of the materials during the visual inspection via the smart glasses - No need to go to the stationary workplace - In case of deviation, simultaneous reporting to interface departments
Process quality	- No delay between input into the system and recognition, thus fewer error transmissions
Workplace improvement	- Hands free when carrying out the activity

(Own representation)

Dr Martin Riester, Head of Business Unit Logistics and Supply Chain Management at the Fraunhofer Institute Austria, agreed with the above assessment and added additional arguments. For instance, the transparency of the sub-processes that the smart glasses technology generates can be used as resource utilisation planning, which provides an additional I-point in the logistics chain and can proactively control the deployment of staff. Furthermore, a proof photo can be taken for the supplier during the visual inspection of the materials, if a deviation arises. Another raised argument is that information can also be shared in advance using the display.

Indeed, before a delivery, the logistician receives information that special features should be considered during the inspection as a conspicuous features have been observed (Martin Riester, Head of Business Unit Logistics and Supply Chain Management, Fraunhofer Institute Austria, February 24, 2022, personal interview).

5.2 Picking

Picking is assigned to the picking process in Chapter 2. This activity is allocated to only the picking process. The following subsections elaborate the common characteristics of the picking process in the automotive industry. The process is presented without and with the use of smart glasses technology. An evaluation of the process in terms of process transparency, lead time reduction, process quality and workplace improvement follows.

The order picking part is comparatively high in the automotive industry because the number of variants is substantial. An optimal assembly has space for all the materials needed in the assembly station. Due to the high number of variants, providing sufficient space for all materials is impossible in most production lines. A picking process is therefore particularly suitable for low runner parts since the materials are pre-picked and delivered to the assembly station in the correct sequence. A tugger train usually controls this process.

5.2.1 Process without smart glasses technology

The picking process without the use of smart glasses technology has four common variations: paper picking list, pick-by-light, put-to-light and pick-to-voice. These variants are described in detail below.

a) Paper picking list

   The paper picking list contains all the information needed to complete the picking order, including the pick position, the required material, the quantity and the storage position. The order picker often finds paper in the immediate area and starts the order to be fulfilled. As a rule, only one picking order is displayed per paper parts list. The picker holds the pick list in one hand and assembles the parts with the other hand. Depending on the volume of material, the picking list must be put aside repeatedly. The paper picking list is the most widespread picking method (Martin 2016: 408). Depending on the volume of parts of the picking order, the order is assembled on a trolley or basket. The common standard in the automotive industry is a picking trolley. The material is usually acknowledged via hand scanner and the individual materials at the corresponding removal tray via a barcode or the picking list. Figure 11 provides an example of a paper picking list.

Picking list

Date: Januar 6, 2022
Time: 9:53 am

Order: 789456123

Turbocharger

material number	pick position	storage position	quantity
852 657 424 524	12	1	1
456 528 766 985	4	2	1
524 635 752 455	9	3	1
894 752 256 452	3	4	1
758 456 622 411	7	5	1

Figure 11: Example of a paper picking list

(Based on own experience)

If a quantity error occurs, it is first noted on the paper picking list and later entered into the ERP system (Günther 2009:12). This list includes a picking order consisting of five materials. The picker on this list is assigned to the Turbocharger aisle and must assemble a trolley of five different turbochargers for this order. The worker obtains the material number (852 657 424 524), the rack from which the material must be taken (12) and the position where the turbocharger must be placed on the picking trolley (1) from the list.

b) Pick-by-light

With the pick-by light system, the rack or system from which the parts are picked is equipped with a display that is connected to the ERP system. The display of the rack of the required material then lights up, which is how the picker knows which material must be picked. The display comprises a screen that indicates the quantity and normally a button for confirmation. As soon as the order picker has removed the required part and acknowledged it, the lamp goes out again (Martin 2016: 410). Figure 12 provides an example of a pick-by-light system.

Figure 12: Example of a pick-by-light system

(LUCA Logistics Solution GmbH 2021)

On the left is the green light that starts to light up if this material is needed. The quantity is revealed in the middle; in this case, three pieces are needed. The picker's hand presses the acknowledgement button to confirm that the parts have been picked. With the pick-by light system, the length of the picking area is limited as the worker should be able to see all the lights at a glance to recognise which one is lit (Günther 2009: 14).

c) Put-to-light

The put-to-light system is similar to the pick-by-light system. The last step of the picking process is monitored by equipping the picking trolley with lights that light up accordingly so that the picker knows where to place the material (Günther 2009: 14). The paper picking list is used in practice to pick the materials in the first step.

d) Pick-by-voice

With the pick-by-voice system, the picker must be equipped with a headset. Via the headset, the worker receives all the required information, such as the pick location, the material, the quantity and the deposit location. The picker also tends to have a scanner to confirm the material when it is picked (Martin 2016: 410).

5.2.2 Process with smart glasses technology

Using smart glasses technology in the picking process is usually described as pick-by-vision, which is a combination of pick-by-light, put-to-light and pick-by-voice. The visual display on the HMD device facilitates integrating the different approaches. The display indicates the rack tray from which the required part is to be taken. The view is freely programmable, which is why the route and the tray can be visually displayed to the worker. After removing the materials, the worker can acknowledge the removal using the glasses. The glasses also have a scanning function so that no additional hand scanner is needed. In the last step, the picker is provided with the storage location of the material (e.g., the picking trolley). The whole process is visually supported by the smart glasses and can be supported by voice if desired. This function can be activated or deactivated on the glasses. In addition, the touchpad on the side of the voice recognition function can be used to access further options, such as when a material has a quality defect or an urgent order must be processed in advance. After completing the order, the picker is presented with the next order. Figure 13 depicts a picker inspecting the HMD display and using the touchpad. One can assume that the worker selects another option in the menu and does not do so using voice control.

Figure 13: Using smart glasses technology in practice

(TeamViewer Germany GmbH 2022)

5.2.3 Evaluation

This subsection evaluates the picking process with the smart glasses technology according to the defined criteria.

Transparency increases with the introduction of smart glasses technology also in this process. However, in this case, the individual steps can be monitored and reported through the software, which enables one to evaluate how long sub-processes take. Again, only the total time of a complete process, not individual sub-processes, can be evaluated with the ERP system without the smart glasses technology. One can thus evaluate how long individual picking orders take to complete. In addition, the foreman or executive employee can gain insight into the dashboard during the process and estimate how long the order will take. Without the smart glasses, the foreman must first call or visit the responsible picker in their picking lane to inform about the urgent material. In the case of an urgently needed material on the assembly line, further information can be accessed using this function.

Compared to using a paper picking list, using smart glasses technology can reduce the *lead time* in any case. The worker does not have to acquire a new picking list after the material pick as it is automatically presented to the worker in the display. The system also reveals an optimal route to minimise fetching times. Moreover, not having to hold an extra sheet of paper in one's hand means that the activity can be performed more quickly, which leads to an improvement compared to the paper picking list process. With pick-by-light, put-to-light or pick-by-voice, the lead time can be considered neutral as the worker still receives this information but via a different stimulus.

The most significant benefit of introducing smart glasses technology in the picking process is the increase in *process quality*. Due to the precise control of the proper removal and placement of the materials, the wrong part cannot be picked. If the wrong part is picked, the order cannot be processed until the error has been corrected. This facilitates aiming for a 0-error rate, which has a significant positive effect on the logistics key figures and significantly secures the production supply.

The *workplace* improves as the picker is more comfortable working with their hands free. Furthermore, the technology offers them psychological relief since the picker cannot commit a human error. The worker does not have to fear consequences because they can rely on the technology. The worker can also choose to operate the processes via voice or touchpad. Table 6 summarises the arguments of the evaluation.

Table 6: Summary of the evaluation criteria for picking

Criterion	Argument
Process transparency	- Transparency about partial steps - Detailed KPI system possible - More precise control
Lead time reduction	- No need to pick up paper lists, all information available via the display - Hands are free, so the activity can be carried out more quickly - Placement of urgent orders - Elimination of manual quality control
Process quality	- Smart glasses technology takes over control, thus 0% error rate possible
Workplace improvement	- Hands free when carrying out the activity - Psychological relief, as no mistakes can happen

(Own representation)

Dr Martin Riester, Head of Business Unit Logistics and Supply Chain Management at the Fraunhofer Institute Austria, agreed with the above assessment and added additional arguments. For instance, the QR codes or RFID tags could be eliminated using an AI database trained to recognise the parts with their characteristics and part numbers. The recognition would work using the photo function of the glasses. Furthermore, the process quality also increases because an individual choice of language can be selected with the smart glasses technology, which allows a targeted reduction in complexity and minimises errors. In addition, the predefined process enables employees to be onboarded rapidly, which makes assigning employees extremely flexible as managers can use them across departments (Martin Riester, Head of Business Unit Logistics and Supply Chain Management, Fraunhofer Institute Austria, February 24, 2022, personal interview).

5.3 Assembly line feeding

The material supply to the assembly line is assigned to the handling process in Chapter 2. This operation can be conducted using various means of transport. The task is to bring the required material from the warehouse, picking area or other storage locations for materials to the production in time. Fixed forklift and tugger transports generally manage this process. Since an autonomous tugger train and smart glasses technology are mutually exclusive, this thesis does not discuss the autonomous tugger trains further. As an example for tugger trains, Figure 14 illustrates a tugger train for large load carriers and Figure 15 one for small load carriers.

Figure 14: Tugger train for large load carries

(Paul Müller GmbH 2022)

Figure 15: Tugger train for small load carries

(BMW Group Plant Dingolfing 2016)

Again, the process is presented without and with the use of smart glasses technology. An evaluation of the process in terms of process transparency, lead time reduction, process quality and workplace improvement follows.

5.3.1 Process without smart glasses technology

The assembly line feeding process without the use of smart glasses technology has two common variations: transport via forklift and transport via tugger train. These variants are described in detail below.

a) Assembly line feeding via forklift

In the past, the automotive industry used mainly forklifts to supply materials to the assembly line. Forklifts are now used only for certain material groups and in urgent cases (Klug 2018: 311). Forklift transport is usually used exclusively for large load carriers (GLTs); nevertheless, a pallet with small load carriers (KLTs) is sometimes also transported. For the materials that this process controls, a material label triggers the demand. The material label is printed at a central printer where the forklift driver accesses it. The worker can then learn from the material label which storage location to retrieve the load carrier from and where to take the material. The forklift driver acknowledges the removal via hand scanner. It is often used for fast single transports (Klug 2018: 311). The following seven steps are included in this process:

1) Retrieval documents are printed in the central printer area.
2) The forklift driver collects the required retrieval documents.
3) The worker drives the forklift to the storage compartment of the required material and removes it, usually a GLT.
4) The forklift driver scans the removal using a hand scanner.
5) The forklift driver transports the required material to production. The exact assembly line station can be learned from the retrieval document.
6) When the material is delivered to the production line, it is acknowledged via hand scanner.
7) After processing all retrieval documents, the forklift driver collects new ones in the printer area.

b) Assembly line feeding via tugger train

Due to the increased transport capacity and the trend towards providing more smaller containers (i.e., KLTs), most transports in the automotive industry have been replaced with tugger trains. Various containers are prepared and loaded in sequence onto the tugger train, which brings them to production. Here, the required materials are also printed via retrieval documents; the workers pick the containers together and place them on the tugger train. The tugger train drivers drive a timed route and must deliver the corresponding containers to the correct assembly station. The corresponding assembly station is indicated on the material removal document. Due to the routine, the tugger train driver can assign most of the materials after a certain time without having to read all the material slips repeatedly. When unloading the material, the tugger train driver scans the receipt for acknowledgement (Klug 2018: 312). The following six steps are included in this process:

1) Retrieval documents are printed in the central printer area.
2) The materials are removed from storage and acknowledged via hand scanner.
3) The tugger train is loaded with the appropriate materials. GLT and KLT tugger trains are used.
4) The tugger train driver drives a timed route and must read the unloading documents to learn where to unload the individual GLTs or KLTs.
5) When the material is delivered to the production line, it is acknowledged via hand scanner.
6) The tugger train driver returns with the empty tug and loads new materials.

5.3.2 Process with smart glasses technology

This subsection describes both processes, production supply via forklift and production supply via tugger train, with the use of smart glasses technology.

a) Assembly line feeding via forklift

In this process, the forklift driver is equipped with data glasses and can see the next order on the display. The worker obtains the removal location and the material number from the display and can take the material booking over with the scan function of the glasses. The GLT is transported to the production area, and the display provides the forklift driver with the exact drop-off location at the assembly line. After depositing the material, the forklift driver scans it with the glasses for acknowledgement.

b) Assembly line feeding via tugger train
Compared to the process described above, the tugger train driver has many different delivery locations along the assembly lines. The individual delivery locations for each KLT or GLT are noted on the removal document. The smart glasses let the tugger train driver know which materials should be brought to which delivery point. The pick-up and drop-off of the materials are again completed via the scan function of the glasses. The optimal route with the corresponding stops on the assembly line is indicated on the display.

5.3.3 Evaluation

This subsection evaluates the assembly line feeding process with the smart glasses technology according to the defined criteria.

Similarly, to the storage, retrieval and picking processes, *process transparency* increases with the introduction of smart glasses technology as every sub-process can be traced in detail at any time. In addition, determining how long it takes to complete the individual steps is possible. Based on the findings, precise process planning can be executed.

The significant advantage when the *lead time* is reduced is that the display of the glasses reveals the work steps again. No retrieval documents must be collected, and the driver is informed where to deliver the material to the production line. It significantly affects the tugger train driver who transports numerous containers, GLTs or KLTs. Via the display, the driver learns each delivery point on the assembly line and does not have to reread the material labels on the individual containers.

Process quality can increase as the error rate can improve. With the support of the smart glasses technology, the driver is notified where the individual materials should be placed. Especially for tugger trains with many KLTs, the driver might mix up the KLTs and bring them to the wrong stations in the assembly line.

Using smart glasses also affects improving the *workplace* as the driver no longer has to remember where the individual containers should be delivered and does not have to constantly reread the retrieval documents since all the information is available on the display. Table 7 summarises the arguments of the evaluation.

Table 7: Summary of the evaluation criteria for assembly line feeding

Criterion	Argument
Process transparency	- Transparency about partial steps - Detailed KPI system possible - More precise control
Lead time reduction	- The removal and storage location is shown on the display - Placement of urgent orders - Elimination of manual quality control
Process quality	- No depositing of wrong containers at the assembly line possible due to the technology
Workplace improvement	- Hands free when carrying out the activity - Psychological relief, as no mistakes can happen

(Own representation)

Dr Martin Riester, Head of Business Unit Logistics and Supply Chain Management at the Fraunhofer Institute Austria, agreed with the above assessment and added one additional argument: the worker can be controlled via smart glasses technology if a change occurs at short notice, which facilitates optimally utilising the worker's productivity (Martin Riester, Head of Business Unit Logistics and Supply Chain Management, Fraunhofer Institute Austria, February 24, 2022, personal interview).

5.4 Summary

Chapter 5 identifies different deployment scenarios based on the literature review in Chapter 2 and the author's many visits to automotive factories. These deployment scenarios were discussed with the expert, Dr Martin Riester, Head of Business Unit Logistics and Supply Chain Management at the Fraunhofer Institute Austria. Three processes that have the potential to adopt smart glasses technology are determined: storage and retrieval, picking and assembly line feeding. The individual processes are described without and with the use of this technology and then compared and evaluated. The evaluation criteria are established in Chapter 4; the criteria applied here include process transparency, lead time reduction, process quality and workplace improvement. Finally, Dr Martin Riester verifies the evaluation.

6 Implementation industry example: Creation of a picking concept

This chapter illustrates a real industry example from practice. The process described involves a company from the automotive industry. First, the general requirements placed on the process by the stakeholders are outlined. Next, the process that existed prior to the implementation of the new picking concept is explained, followed by a design and description of the concept after the implementation of smart glasses technology. Subsequently, the differences and commonalities are discussed. Finally, the implementation of this pilot is evaluated, and an outlook for the process and the company's strategy is given.

6.1 Requirement analysis

The following describes the motivation and criteria for why this company decided to change the picking process and use smart glasses technology. In the organisation, more than one third of the materials are picked due to a lack of space on the assembly line. Due to the high number of parts to be individually picked, the costs for this step are high. The error rate is large because of the manual and monotonous method of execution for the worker, which results in expensive downstream activities to correct the faulty picks. Consequently, another expensive control process was also introduced, which is described in more detail in the next subchapter. Due to these aspects, the management has set the following requirements for the process:

1. Quality improvement
2. Process improvement in terms of time
3. Cost reduction

The aim is to achieve a success rate of 99%, which means that a process is needed that can ensure the picked parts are correctly transferred to production. The target is to reduce the error rate to almost zero. The only exceptions are special circumstances that cannot be avoided and do not constitute a rule in any case. Due to the large number of parts, order picking is a time-consuming process therefore a reduction of the process time should be aimed. The final criterion is a reduction in picking costs. No percentage of reduction is given, but it is important that the target can be achieved with the implementation of the first objective. Management has determined that, of the three criteria listed, the goal of quality improvement should be prioritised.

6.2 As-is state

The following describes the process prior to the changeover to the new concept. Due to significant space problems in this company, the picking zone is shared with the storage zone. The picking zone is on the first level of the storage rack. For a better illustration, the set-up is visualized in Figure 16.

Figure 16: Section of storage and picking zone of the automotive company plant

(Own representation)

In each picking aisle, there is at least one employee responsible for the materials. The following aisle is for the forklift driver, who provides the required materials for the production from this row. This system ensures that the order picker and the forklift driver do not endanger each other. The illustration is not true to reality but serves as an example for illustration purposes. In the figure, various materials picked on the first level of the warehouse can be seen. Other materials are stored above this level, but they are not assigned to the picking process. These are made available directly in production if required. Each picking aisle is equipped with a printer, and from this printer, all picking orders that exist for this aisle are made available to the worker using this medium. The printouts have a preceding number, so the worker knows which document has to be served first. The picker can obtain all the necessary information from the document, and there is an individual picking slip for each material. The worker takes the material from the shelf and puts it in the right place on the picking trolley. It is also possible for several materials to end up in one place on the picking trolley. The picking trolleys are all individual, as they are adapted to the components. The worker has to scan the picking slip to book out the material of the shelf. In addition, the picker places this slip on the picking trolley. Figure 17 shows an example of two different picking trolleys. On the left trolley, power lines can be seen in addition, the picking document can be seen on the side. The picking trolley on the right has different materials in the same place. The blue slip is the pick slip.

Figure 17: Example picking trolley

(Internal source)

When all the materials are on the picking trolley, the picker has to check the trolley once again and indicate that the trolley is complete by placing a large magnet on the trolley. The large magnet signals for a second worker the so-called Quality-gate (Q-gate) worker. A Q-gate employee is responsible for several picking aisles and has to check the complete picking trolley to ensure the right materials have been picked. As soon as the Q-gate worker has finished this review task, the trolley is released for production, and the picking trolley is taken by a tugger train, which collects it.

In Table 8, the weak points of the as-is process are listed and allocated to the respective goal that is negatively influenced by them.

Table 8: Comparison of pain points to goals

	Pain Point	Impact Target
1	Pick list is printed for each part	Cost reduction
2	Manual sorting and checking of picking lists according to series, picking part family and sequence	Quality improvment
3	Picking on the basis of the slips	Cost reduction, Quality improvment
4	Manual comparison of picking slip and material	Quality improvment Process improvment in terms of time
5	Manual comparison of picking slip and designated space on the picking trolley	Quality improvment Process improvment in terms of time
6	Manual control by the picker	Quality improvment
7	Manual control by Q-gate worker	Quality improvment Process improvment in terms of time

(Own representation)

The fact that a paper slip is printed for every single part that is picked and the number of paper slips is in the six-digit range per month means higher costs due to paper and toner. Sorting the picking lists manually can lead to errors, and the worker can assemble the materials in the wrong order. This has a negative impact on the process quality. Paper picking has an effect on both costs and quality. Manual comparison of the picking list, the material and the space on the picking trolley has an impact on the quality, as it relies only on the employee. Due to the monotonous and repetitive nature of this activity, it is especially error prone. In addition, the picker has to compare the next step with the picking list again and again, which influences process time. The manual control of the picker and the Q-gate worker has an influence on the quality if an error is not detected. In addition, the Q-gate worker repeating the same process step again also has an influence on the process time.

6.3 Concept description

The new concept must enable the achievement of the three goals: quality improvement, process improvement in terms of time and cost reduction. To achieve the goals, the concept of smart glasses in combination with a radio-frequency identification (RFID) wristband has been chosen. In the following, the pilot concept is explained in more detail, as are its weak points regarding the goals.

6.3.1 Theoretical concept description

Each picker will be equipped with smart glasses and an RFID wristband. All order picking storage locations will receive an RFID tag so that they can be clearly assigned. The different places on the picking trolley are also equipped with an RFID tag.

The order picker must wear the data glasses for a complete shift, which is eight hours, so a light pair of glasses has been chosen. In addition, the glasses must be cost-effective due to the target achievements. For these reasons, Google Glass were chosen for this project. The battery life of the Google Glass is only about one hour, so the order picker is also equipped with an external battery.

Table 9 compares the pain points listed above with the new concept. The picking order is directly shown on the display of the smart glasses and there is no longer any need to print out picking slips. Furthermore, it is no longer necessary for the picker to put the slips in the correct sequence, as this is already shown on the display. Picking is performed using the smart glasses' display, where the worker can get all the needed information. The RFID wristband confirms the removal and placement of materials both when they are removed from the storage rack and when they are placed on the picking trolley. The control function is no longer manual but is performed through technology. In addition, no control by a Q-gate workers is needed, as this is taken off over by the combination of the glasses and the wristband.

Table 9: Comparison of pain point to goals

	Pain Point	**New Concept**
1	Pick list is printed for each part	Pick list is shown on the display of the smart glasses
2	Manual sorting and checking of picking lists according to series, picking part family and sequence	The order of the materials to be picked is specified by the smart glasses
3	Picking on the basis of the slips	Picking based on the indication on the display of the smart glasses
4	Manual comparison of picking slip and material	Control over RFID wristband and smart glasses
5	Manual comparison of picking slip and designated space on the picking trolley	Control over RFID wristband and smart glasses
6	Manual control by the picker	Control over RFID wristband and smart glasses
7	Manual control by Q-gate worker	Control over RFID wristband and smart glasses

(Own representation)

Accordingly, the new concept has positive effects on the goals. The Table 10 summarises which of the objectives are positively influenced by the introduction of a new concept. A large amount of paper can be saved by displaying information using the smart glasses instead. The worker cannot make a mistake as they could when sorting the paper slips, as this is predefined and done by the smart glasses software. The picker does not have to manually check whether the correct part has been picked but can rely on the RFID-technology tracking the right picking location. Moreover, technology control can eliminate the need for Q-gate staff. In addition to the cost reduction, quality improvement and a shortening of the lead time are also positively influenced. Management's prioritised goal, quality improvement, is realised through the use of smart glasses in combination with the RFID wristband. Scanning the RIFD tag indicates whether the material and storage location are correct and the smart glasses indicate where and what to pick next.

Table 10: Comparison of the new concept to the goals

	New Concept	Impact Target
1	Pick list is shown on the display of the smart glasses	Cost reduction
2	The order of the materials to be picked is specified by the smart glasses	Quality improvment
3	Picking based on the indication on the display of the smart glasses	Cost reduction, Quality improvment
4	Control over RFID wristband and smart glasses	Quality improvment Process improvment in terms of time
5	Control over RFID wristband and smart glasses	Quality improvment Process improvment in terms of time
6	Control over RFID wristband and smart glasses	Quality improvment
7	Control over RFID wristband and smart glasses	Quality improvment Process improvment in terms of time

(Own representation)

6.3.2 Practical realisation

The following describes how the concept was implemented in practice and how the process in the automotive plant works. The picker collects a pair of smart glasses and a wristband from the supervisor's office at the beginning of the shift. It is a premise of the works council that which employee is working with which set of glasses cannot be traced. This means that there is no clear allocation to protect the employees' working rights. The picker logs in on the smart glasses via a QR code and connects the glasses to the wristband. There is another QR code directly at the picking aisle, which the worker scans. The system then knows in which picking aisle the worker is in, and they receive the next orders on the display. When the first job appears on the worker's display, they learn which tray the material has to be taken from. After removal, the wristband scans to determine whether the material has been removed from the correct shelf. Only after this step has been successfully completed does the display change from "removal" to "deposit", and the worker is shown where to place the material on the trolley. After the material has been placed on the trolley, the location is counter-scanned, and the system jumps to the next material to be picked if the placement is correct. In this way, the entire picking trolley is loaded material by material until the order is completed. After successful completion, the employee receives the next picking order on the smart glasses. The employee can pause at any time and also accept a rush order. Moreover, users can decide for themselves whether to control the glasses via voice control or via the touchpad on the side of the glasses. Figure 18 shows a real photograph from the project and is described in the following.

Figure 18: Real section of the project

(Internal source)

1 Battery status, Wi-Fi connection, connection to the RFID-wristband

2 Position of the order, in this case at Position 1 out of 10

3 Removal location

4 Part number (partly blackened)

5 Part number as word (blackened

6 Designation of the material, in this case cylinder head cover (partly blackened)

7 Illustration of the picking trolley, highlighting the correct storage place

The upper-right corner shows the section the worker sees on the display of the smart glasses. The display recording shows that the worker has just removed the material “cylinder head cover” and placed it on the picking trolley. The cylinder head cover is placed in Position 1 and then confirmed by the RFID tag. Furthermore, the order picker is shown where the picker is currently located in the order. In this case, it is still at Material 1 of 10. The part number, the pick location and the storage position are displayed.

After the end of the shift, the smart glasses are cleaned and handed over to the next employee, who works with the smart glasses for the following shift.

6.4 Evaluation after a pilot phase

This pilot was tested for five months in four representative picking aisles. In the following, the conversion of the process and the satisfaction of the employees is discussed. Subsequently, the management's criteria are compared with the findings.

The connection to the company's own ERP system was a manageable scope and could be realised in a short period of time. The training of the staff was quick and simple because of the very intuitive handling of the smart glasses. Due to the fact that many employees own a smartphone, the operation of this technology is typically straightforward. If an employee had problems with speech recognition, it was possible for them to switch to the touch function and perform all activities. Wearing the glasses was perceived as pleasant by the employees and was no longer noticed after a few hours. Even spectacle wearers were able to pull the smart glasses over their normal glasses and could work without restrictions. In addition, the technology provided significant psychological relief for the employees. The fact that mistakes could no longer be made had a positive influence on the workers. The workers were able to be more relaxed in the workplace. Furthermore, the glasses made for a more pleasant workflow, as the hands were free and no picking slip was needed. Moreover, it should be mentioned that the employees from the other picking aisles were also enthusiastic about the use of the technology.
The management prioritised the following three objectives, which are described in more detail in the previous alongside the impact of the new concept.

1. Quality improvement
2. Process improvement in terms of time
3. Cost reduction

In this picking process, the technology used means no mistakes can be made due to the technology usage. However, a problem arose during the pilot phase: some errors still occurred in this area because the upstream process introduced errors. The technology of the glasses and wristband requires that the right materials are available in the storage area. If an employee from the upstream process fills the wrong place with materials, the picking cannot occur correctly in the downstream. For this reason, a control instance must also be introduced in the submitted process to ensure the materials are always placed in the right location. There are two ways to do this: the material itself can be scanned instead of the picking location, or the container of the material can be equipped with an RFID tag.

The process time is shortened because the sorting of manual retrieval documents is omitted. In addition, the next order is always displayed directly, and it is not necessary to pick up another paper slip. Another important factor is the elimination of the Q-gate employee, this process step can be completely removed, as the technology takes over this task. Consequently, costs can be reduced based on the following criteria: elimination of picking errors, elimination of Q-gate employees and elimination of paper and ink. The costs of software, hardware (smart glasses, scanners, tags, etc.) and annual licensing costs with emergency support for the technology and its software must be added. The calculation basis is derived from the company's controlling figures, the KPI in logistics and offers from suppliers who can provide the hardware and software. The payback period will be less than a year when this concept is rolled out across the company's entire picking zone. The cost of the pick rate and the amount the company incurs for picking a part, is reduced by almost half of it with the use of this technology. The Table 11 compares the savings with the investments.

Table 11: Comparison of savings to investments

	Savings	Investments
1	No quality defects	Software
2	No need for Q-gate employee	Hardware
3	Saving process time	Ongoing licence costs
4	Savings on paper and printer cartridges	Emergeny support
	Payback period less than one year	
	Cost of pick rate reduction by almost 50%	

(Own representation)

6.5 Outlook in the company

After the successful pilot phase, the company decided to switch their process to this concept in the long term. In addition to the monetary evaluation, the consistently positive feedback from employees reinforced a decision to use smart glasses in the picking process. The company is not only planning a changeover in its own plant but also wants to assess to what extent subsidiaries and sister plants can convert their picking processes and leverage this new concept. The other essential factor for implementation is the achievement of the 0% error rate, which will have a great impact on process customer satisfaction. To achieve the full benefit, the upstream process must also be adapted accordingly so no incorrect materials can be delivered to the picking zone.

Based on the extensive research into which processes smart glasses can still be used for in intralogistics, the company will also review other processes. In addition, the company would like to examine other areas of the company where smart glasses technology could be implemented and improve processes.

6.6 Summary

Using the deployment scenarios from Chapter 5, the author has implemented a concept in practice. This chapter describes the implementation of an industrial example in the picking process. First, the management's requirements for the pilot test are listed. Specifically, the management wants a significant improvement in quality, a reduction in throughput and a decline in costs. Second, the actual state of the process is defined. The weaknesses of this process and how its goals are influenced are also highlighted. The concept is then described with the introduction of smart glasses technology to the process. A theoretical description and the practical realisation are included. Third, the evaluation results are recorded after a three-month pilot phase. These results are put into context with the established goals, and an evaluation is made. The chapter concludes with an outlook on how the management decided to proceed after the pilot phase. Due to the excellent results of the pilot test, the company will institute the concept in the entire picking zone.

7 Summary and outlook

This thesis focuses on establishing and evaluating possible deployment scenarios for using smart glasses technology in intralogistics in the automotive industry. In addition, it details the execution of a pilot project to implement a deployment scenario.

At the beginning of this thesis, the relevant specialist literature is used to define intralogistics. Based on the intralogistics processes, the goals are identified, and challenges and opportunities are analysed. New challenges for intralogistics are then determined as a result of digitalisation. Smart glasses technology has become increasingly relevant due to the rising demands of the digital transformation and the Industry 4.0 trend. This thesis uses the fundamentals of smart glasses technology to identify deployment scenarios. The essential criteria for selecting data glasses for an intralogistics process are also identified. The analysis of the current state of the art of smart glasses technology reveals that the relevant decision criteria are industrial suitability, ergonomics and wearability, the resolution and positioning of the display, the quality of the camera and interaction possibilities.

During the identification process, deployment scenarios for using smart glasses technology in intralogistics were identified. These deployment scenarios include storage and retrieval, picking and assembly line feeding processes. This thesis examines these processes and describes their characteristics. The individual processes are presented without and with the use of smart glasses technology.

For the evaluation, criteria were determined as process transparency, lead time reduction, process quality and workplace improvement. The evaluation of the processes is based on the literature review, the author’s personal experiences and the expert interview with Dr Martin Riester, Head of Business Unit Logistics and Supply Chain Management at the Fraunhofer Institute Austria. The smart glasses technology significantly improved the processes in all three deployment scenarios.

For the pilot project, picking was used as the deployment scenario. This thesis therefore describes the implementation of an industrial example in the picking process. First, the management's requirements for the pilot test are listed. The management wants a significant improvement in quality, a reduction in throughput and a decline in costs. Second, the current situation before the introduction of smart glasses technology is described. A theoretical description follows, and the practical implementation of the new concept is then presented. The pilot project was conducted for three months to ensure a validated basis for an evaluation. Moreover, the pilot project was tested at a manufacturer of automobiles in a part of the picking zone. The observed results are related to the set objectives, and an evaluation is conducted. Due to the successful pilot project and the realisation of the set objectives, the management has decided to institute the technology in the entire picking zone and test the other identified deployment scenarios as well.

The results of this thesis provide an overview of possible deployment scenarios for smart glasses technology. In addition, the evaluation findings illustrate the added value of the scenarios for automotive companies' intralogistics areas and can be the basis for a decision for companies outside the sector.

In a world that is becoming more complex, smart glasses technology can simplify employees' daily work, with the additional benefit that no more errors can occur due to this safeguarding, and the process reliability can be proven to be considerably high. However, this argument can be considered critical since those involved in the process no longer have to grasp the use of technology, which can negatively affect workers. Humans could feel more like machines, which could lead to psychological problems. In the pilot project, this development was not observed as the employees were relieved that they could no longer make errors because the technology indicates errors for them. Due to the lack of long-term studies, the management should regularly check this argument to ensure that the positive criterion does not change.

Using smart glasses technology can positively influence the positive trend towards more sustainable production. Due to the frequent use of paper picking lists in the current state of the art, a great deal of paper can be avoided with the introduction of this technology. The challenge of high fluctuation in logistics activities can also be reduced. Furthermore, due to the predefined and leading way of working, employees can be flexibly deployed after a brief training period.

As Dr Martin Riester argued, this technology will undergo further development in the near future. Indeed, the combination of AI and smart glasses facilitates an even broader spectrum of deployment scenarios.

In summary, smart glasses technology is becoming increasingly relevant for developing intralogistics during the digital transformation. Using smart glasses will be crucial for companies as development progresses along the maturity stages of Industry 4.0. The deployment scenarios with the use of smart glasses technology offer practical potential with which companies can create added value for their current intralogistics processes, which will ultimately affect their success.

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9 List of Abbreviations

AR	Augmented reality
DLP	Digital Light Processing
ERP	Enterprise Resource Planning System
GLT	Large load carries
HMD	Head-mounted displays
KLT	Small load carries
LCD	Liquid-Crystal Displays
LCoS	Liquid-Crystal on Silicon
OLED	Organic Light-Emitting Diode
RFID	Radio-frequency identification
TUL	Transport, handling and storage
VR	Virtual reality

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