Role of XR wearables in intralogistics field
Insight into AR applications

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### Abstract

The world is rapidly changing because of globalization, trade volumes are increasing and e-commerce becomes bigger influencer on shopping patterns, customers’ demands are increasing as well competition on the markets. These factors have significant impact on supply chain, forcing it to be more adaptable and agile to maintain high service level.

The aim of the thesis was to see, are wearable technologies the key for successful supply chain functioning, errors and inner bottle-necks prevention, especially in such important part as intralogistics. The research was mainly focused on augmented reality wearables and gives answers to questions, regarding place and role of such technologies within the intralogistics industry.

For research there was used data collected from scientific literature, company press releases and research, conferences and news sources, additionally real company cases were taken into account as well as companies representative’s opinions and comments. The research was started form the bigger scope of intralogistics key functions and step-by-step approached via various types of wearables and extended reality applications towards the main research subject of augmented reality and its role in warehouse and, as a consequence, in supply chain.

In the end it was determined that augmented reality is very important component of warehouse activities and supply chain operations. Smart glasses, as AR wearables, help to reduce or even eliminate waste activities and significantly improve workforce performance in many intralogistics operations.

### Keywords/tags

Intralogistics, wearable technologies, augmented reality, extended reality, smart glasses

### Miscellaneous

Confidential information
Contents

1 Introduction .......................................................................................................................... 5
  1.1 Thesis objectives ........................................................................................................... 5
  1.2 Research process and questions ................................................................................... 5

2 The world changes, so logistics is .................................................................................... 7

3 Intralogistics as a crucial part of supply chain ................................................................. 9
  3.1 Role of a warehouse in supply chain ........................................................................... 9
  3.2 Warehouse operations ................................................................................................. 10
  3.3 Warehouse “waste” activities ..................................................................................... 11

4 Intralogistics 4.0 ................................................................................................................. 13
  4.1 Industry 4.0 and warehousing ..................................................................................... 13
  4.2 Understanding the role of technology advancement .................................................. 16

5 Wearable technologies as a part of modern warehouse .................................................... 18
  5.1 Mobile computers, ring scanners and voice-directed headsets ................................ 19
  5.2 Extended Reality (XR) ............................................................................................... 22
    5.2.1 Virtual Reality ..................................................................................................... 25
    5.2.2 Mixed Reality ..................................................................................................... 30

6 Augmented reality .............................................................................................................. 34
  6.1 AR history of the development .................................................................................... 34
  6.2 Augmented Reality today ........................................................................................... 41
  6.3 Augmented reality in the future .................................................................................. 48

7 Augmented reality in intralogistics .................................................................................... 51
  7.1 Logistics as a main smart glasses customer ............................................................... 51
  7.2 Applications in warehouse processes ......................................................................... 52
    7.2.1 Picking ................................................................................................................. 52
7.2.2 Maintenance ........................................................................................................ 54
7.2.3 Training ............................................................................................................. 54
7.3 AR in practice: case DHL .................................................................................... 55
7.4 Things to consider ................................................................................................. 59

8 Conclusion ............................................................................................................. 60

References ................................................................................................................ 63

Figures

Figure 1. Thesis research process ................................................................................. 6
Figure 2. Value and volume of world merchandise trade, 2012-17 ......................... 7
Figure 3. Number of Establishments in Private Warehousing and storage in U.S ...... 8
Figure 4. Bottlenecks preventing supply chain adaptability ...................................... 9
Figure 5. Warehouse operation requirement throughout the supply chain ............... 10
Figure 6. Typical warehouse functions in a stock-holding warehouse ...................... 10
Figure 7. Intralogistics operations approximate cost breakdown .............................. 12
Figure 8. Patent Number Development for Industry 4.0 Related Topics 2010-2015 .. 14
Figure 9. Patent Numbers for Industry 4.0 Related Topics 2010-2015 ..................... 15
Figure 10. Use of Wearable Technology in the Supply Chain and Manufacturing..... 19
Figure 11. Warehouse wearables, from left to right: VDS-headset, ring scanner, wearable computer .............................................................................................................. 19
Figure 12. Paper, RF and Voice picking ...................................................................... 21
Figure 13. Multi-modal wearable combination: wrist terminal, ring scanner and voice headset ..................................................................................................................... 21
Figure 14. XR elements along Reality-Virtuality Continuum .................................... 23
Figure 15. Top industry use-cases for business XR according to XR stakeholders ..... 24
Figure 16. Forecast AR and VR market size worldwide from 2016 to 2022 .............. 24
Figure 17. AR, VR, MR headset sales revenue worldwide from 2015 to 2020 .......... 25
Figure 18. VR Headsets: Google Cardboard and HTC Vive .................................... 25
Tables
Table 1. EU-28 employment in transport and storage services sector .................. 13
Table 2. From Industry 1.0 to Industry 3.0 .............................................................. 13
Table 3. Vision of future technology investments decisions by regions .................. 17
Table 4. HoloLens and some popular AR wearables comparison .......................... 34
Table 5. Augmented Reality for Maintenance Assistance as seen through HMD ...... 38
Table 6. AR most common SDKs comparison ....................................................... 41
Table 7. AR Smart Glasses examples ................................................................... 44
Table 8. AR wearables cases in enterprise sector .................................................. 46
Table 9. AR market growth expectations from different analytic sources ............. 48
Table 10. Envision of AR applications in logistics ................................................. 50
Table 11. Examples of AR smart glasses application in intralogistics ................. 52
Table 12. DHL pilot AR project in Netherlands .................................................... 56
1 Introduction

1.1 Thesis objectives

This work is dedicated to Extended Reality (XR) components: Virtual (VR), Mixed (MR), and especially Augmented realities (AR) in intralogistics. Technologies are the thing of the future, and I, as a logistics engineer, think that it worth to study this field and its application in intralogistics industry.

The target of the thesis is to see whether high-technology tools can be the key for successful supply chain functioning, errors and inner bottle-necks prevention, especially in such important part as intralogistics. The expected results of this work will show the impact of innovative technologies (VR, MR and especially AR) on intralogistics world to the full extent, by means of research studies, existing and possible applications of these to the intralogistics world. The aim is to prove the efficiency of technologies, their beneficial effect on KPIs (Key Performance Indicators) and to show that despite XR is relatively new tool, it actively takes its own place in intralogistics world and for which future is reserved.

1.2 Research process and questions

The research will be performed by using qualitative and quantitative methods. For quantitative research statistical data will be collected and analysed. Interviews of authorised persons responsible for discussed questions and case studies will be part of qualitative research. All presented data in this thesis will be backed up with trustworthy sources, such as books, official corporate web-sites and press-releases of companies, white papers, researches, issue-related newspapers, as well as various scientific publications and researches. Controversial information has to be carefully checked, otherwise it would be considered as doubtful and not be taken into account.

Inasmuch discussed topic concerns such high developing area as technologies, another requirement for information sources is modernity. Old sources related to exploring subject may not reflect current situation because of the fast pace of events
in the logistics technology area, the same is applicable for statistical data. However, old publications will be taken into account for tracking history changes and evolution to determine how and in which direction the development goes. For each data there will be determined and used original sources if possible.

Research questions are formulated as follows:

1. Is it beneficial to use AR in intralogistics?
2. What is the place of AR within intralogistics?
3. Can AR be the key to strengthen intralogistics as part of supply chain?

To gain answers for these questions, research will be conducted in a way that it will be started from broader subjects such current situations on the global markets, undoubtable biggest supply chain influencers, and the role of intralogistics within it. Progressively, this work will delve onto more narrow areas, step-by-step approaching to the core research subject and conclusions (figure 1). No less important during this way through all research steps is to understand the prerequisites for technology creation, its origin, trace its development and determine how it took its place in enterprise sector. AR retrospective and prospects will help deeper understanding of this phenomenon and there will be defined core driving factors and field features forcing intralogistics managers and decision-makers adopt discussed technologies. The research will also touch upon other 2 elements of XR, virtual and mixed realities, their working principle, hardware and applications in intralogistics.

![Figure 1. Thesis research process](image-url)
2 The world changes, so logistics is

It is well-known that globalization, increase in consumption and demand for certain things, and many other factors have significant impact on trade volumes. According to WTO, because of rising import demand, in 2017 world merchandise trade has its strongest growth in six years – 4.7% in volume terms and by 11% in value terms (WTO Statistical Review 2018, 10, 27). Moreover, it continues to grow: from January to September of 2018 trade volume increased by 3% compared with the same period in 2017 (WTO Statistics on merchandise trade).

WTO experts predict further trade growth and obviously, logistics area needs to accept changes and go with the times, considering that flawless of goods movement depends on the efficiency of its operations. In other words, world situation increases demands for logistics sector as well, compelling it to become more flexible, quick-response, adjustable and able to handle performance targets with maximum quality and accuracy.

Statistics show that warehouse business is expanding as well, and this fact reflects demand for this sector. As from the date of 2017, United States of America rank in world merchandise trade is first for imports (13.37% share of word total) and second for exports (8.72% share of word total) (WTO USA Trade profile). Alongside with that number of establishments in warehousing and storage industry in the same country has been increasing from 2009 to 2017 by almost 15% (figure 3), and during the first two quarters of 2018 number of warehouses increased by 776 (The U.S. Department of Labor).
Additionally, fast growing e-commerce created “the Amazon effect” - impact created by e-trade on traditional commerce model because of the change in shopping patterns - that seriously affected whole logistics sector worldwide. Global e-commerce has increased from $19.3 trillion in 2012 to $27.7 trillion in 2016 (WTO Statistical Review 2018, 21). According to DHL, e-commerce exponential growth and its significant impact on supply chain was identified by 65% of companies (DHL supply chain invests $300m to accelerate integration of emerging technologies into North American facilities 2018). Internet trade increases batch quantities, making them smaller in the same time, according to Richards (2011, 19), quite often warehouses process single-item low-value items with the same amount of labour and equipment involvement as high-value ones. Moreover, people want to have fast, next-day and cheapest possible, even free delivery of ordered items and as the case may be easy return of these goods – returns can reach up to 40% of outward volume and items go through quality check again (ibid.). Numbers of product lines, delivery destinations are increasing as well as picking locations, reducing free available space and there is zero-tolerance for picking mistakes.

Recent research by Honeywell Intelligrated, Modern Materials Handling and the Peerless Research Group (The Extent that e-Commerce Impacts Fulfillment Operations 2019) revealed that inventory management was named as major bottleneck that prevents supply chain adaptability in most cases. Order fulfilment and processing was second largest bottleneck named. Both named activities are intralogistics responsibility.
Inasmuch markets are rapidly changing and developing now, so the world is, industries operating within this busy environment oftentimes standard problem-solving approaches became unsuccessful, or even out-of-dated and non-applicable in nowadays environment, for example pen and paper approach in warehouse operations. Such situation requires deployment of effective control tools which are able to simplify the material and goods flow processing and replace old methods, so wearable technologies can be considered as a key to reach the goal.

3 Intralogistics as a crucial part of supply chain

3.1 Role of a warehouse in supply chain

The research is primary focused on intralogistics area not without a reason: largely because warehouses are essential part of any supply chain and facilitate the movement of materials and goods along the whole way from raw materials to the final customer. The main logistics principle, also known as “The Seven Rights of Logistics”, is to deliver the right products in the right quantity to the right customer at the right place and right time in the right condition. Indeed, it is impossible to diminish intralogistics role in these operations. Right product and quantity depend on picking accuracy, delivery to the right customer at the right place and time requires correct labelling and loading for dispatching. Right condition means that all storage
requirements were met and quality was not declined. The right price is guaranteed by effective management that eliminates non-value added operations.

Warehouses may be required in majority parts of supply chain, as it can be seen in figure 5. It can therefore be said that wise intralogistics operations guarantee high service level and, as a consequence, profitability and a strong position in the market.

![Diagram of warehouse operation requirement throughout the supply chain. Source: Richards 2011, 10.](image)

**3.2 Warehouse operations**

![Diagram of typical warehouse functions in a stock-holding warehouse. Source: Ruston, Croucher, Baker 2010, 230](image)

*Receiving* - unloading, quality checking and recording goods into the system, possible unpacking and repackaging, put away.
Reserve storage - goods are taken to the reserve storage area. When needed, the goods are used either to replenishment or moved directly to marshalling area.

Order picking – goods are collected in received order. Order picking is considered as a key warehouse operation in terms of cost, service level and staff involvement. Full unit load order line can be taken from the reserve storage, and less order lines are retrieved from the picking location. In some cases the reserve and picking stocks may be combined in one consolidated area, for instance, if only small quantities of a product are stored in a warehouse.

Collation and added value services - goods are collated into complete customer orders. Value added services might be such as kitting, packing, pricing, labelling, tagging, subassembly or bundling (Richards 2011, 121).

Sortation - small sizes of order might be consolidated together and considered as one order for picking purposes. This batch is sorted down back to individual orders later before dispatch.

Marshalling and dispatch - goods are marshalled together in the dispatch area and loaded to vehicles.

3.3 Warehouse “waste” activities

This waste is standing for non-value adding work. Lean management defines such activities and even gives it a special name in Japanese “Muda”. Despite the fact that Lean came from manufacturing industry of Toyota, it can be harmoniously settled in intralogistics operations also. Lean concept implies continuous improvement of processes and elimination of all activities that consume resources such as time, money or effort, but do not create additional value. In other words, Lean approach aims to lower costs and increase quality and efficiency of warehouse operations by removing of all waste on the way of goods from receiving to outbound. In warehousing sector waste activities are common and can be found as well:

Transportation and Conveyance – employees and inventory sometimes are moved over long distances because of bad warehouse layout or area planning. This cause time losses and delays.
Waiting – inefficient labour and processes management, paperwork, poor software work, waiting for instructions or equipment and other factors might cause delays and as a consequence, significant time and money waste.

Defects and Rework – warehousing is a big and important part of supply chain operations that consists of even more inner processes. Mistakes within every step may make all thereafter processes and whole work a pure waste, violating “The Seven Rights of Logistics” and reducing service level. Errors fixing requires extra work and resources that may be used in another value-adding operations.

Over-processing – it may happen when warehouse processes are unreasonably complicated and require unneeded steps. Additionally, non-optimized processes may lead to unnecessary processing when, for instance, several shipments are sent to certain area separately in situations when they could have been consolidated in one big shipment.

Bad inventory control – keeping inventory level under control helps to avoid many problems such as unavailability for shipment and subsequent backorders, or expensive overstock.

Described activities require very high personnel involvement level, so the success of logistics operations depends mostly of labour performance level. Additionally, labour costs form a major part of expenses, so it is essential to pay highest attention to this sector and eliminate all wasteful actions and therefore expenses for higher viability.

Figure 7. Intralogistics operations approximate cost breakdown. Data sources: Richards 2011, 212; Emmet 2005, 175; Bartholdi, Hackeman 2002, 13.
Table 1. EU-28 employment in transport and storage services sector. Data sources: EU transport in figures statistical pocketbook 2017-2018

<table>
<thead>
<tr>
<th>Transport and storage services sector employees in EU-28 total (million people)</th>
<th>Among which work in warehousing and supporting activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.2</td>
<td>11.5</td>
</tr>
</tbody>
</table>

As it can be seen, every fourth employee in discussed sector refers to warehousing. According to European Union statistics (EU transport in figures statistical pocketbook 2017-2018), more employees than in this sector work only in land transportation (such as road, rail and pipelines): 52% in the years of 2015-2016. This fact also proves the important role of workforce in intralogistics and need of focusing on solutions to improve their total effectiveness and productivity by means of wearable technologies.

4 Intralogistics 4.0

4.1 Industry 4.0 and warehousing

Intralogistics 4.0 term is quite commonly used in tight relation with Industry 4.0, so-called 4th Industrial Revolution, and certainly can be considered as its derivative. Because of this reason one should gain insight into Industry 4.0. Prior to this there were three other consecutive steps (table 2):

Table 2. From Industry 1.0 to Industry 3.0. Source: Nicol, 2015

<table>
<thead>
<tr>
<th>Year</th>
<th>Distinctive features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry 1.0</td>
<td>1784</td>
</tr>
<tr>
<td>Industry 2.0</td>
<td>1870</td>
</tr>
<tr>
<td>Industry 3.0</td>
<td>1969</td>
</tr>
</tbody>
</table>

Many experts say that Industry 4.0 already today’s reality; it spreads around the globe and changes traditional ways of manufacturing by bigger and closer interaction between human, machines and data exchange systems. It optimized and developed...
what was in established in Industry 3.0 and embodied smart factory reality: computers and devises are digitally connected in one network, creating and sharing information, making decisions even without human involvement. Industry 4.0, based on cyber-physical systems, makes the processes more effective and less wasteful (Bernard, 2018).

The main key elements of Industry 4.0 can be defined as follows:

- Cyber physical systems;
- Cloud computing;
- Big data and analytics;
- Internet Of things (IoT);
- System security;
- Additive manufacturing/3D (3-Dimensional) printing;
- Augmented reality;
- Robotics.

Innovation activity in Industry 4.0 technologies sector was investigated by IoT Analytics (Williams 2016) by determining the number of patents over a period of 5 years. The study found that number of patents has grown by 12 times and increased from 421 in 2010 to 5107 in 2015. The results related to each Industry 4.0 technology can be seen in figure 8 and figure 9:


Obviously, augmented reality is one of the most fast-developing Industry 4.0 technologies, which maintains its position among top three: it has showed constant growth without drops outdone only by cloud computing and 3D printing.

Returning to the subject of intralogistics, it is fitting to recall William Edwards Deming, leading quality management originator, who said: “It is not necessary to change. Survival is not mandatory”. It is safe to say that Industry 4.0 has a significant impact on the whole world, industries and societies, and logistics has to change as well in order to survive in new realities.

Intralogistics becomes essential part of evolving Industry 4.0 and global industry in overall in turn for several factors. Supply chains become more and more complex because of high degree of interconnected logistics networks in terms of globalization. In addition, the complexity and amount of data produced and transmitted by digital supply chains is growing as well as the elaboration of products and demand for individually-tailored products: "Batch size one" is becoming more and more common (Lerher, Sgarbossa 2018).

Many technologies of industry 4.0 are actively implemented by intralogistics nowadays. IoT and its enabling technologies allow devices “talk” with each other and create secured data networking and processing systems, big data analysis can lead to smarter operation decisions. Integrated software analyses and controls flows of materials, goods and resources, collects and compares data from KPIs, providing real-
time situation picture. Augmented reality simplifies and guides employee’s working process, but about this will be further discussed in later chapters in more detail. All these represent one big interconnected system across locations serving as an instrument for maintaining flexible and fast-adapting to customers’ requirements intralogistics facility. In such a manner Intralogistics 4.0 may serve as a perfect stage on the way toward Lean operations.

4.2 Understanding the role of technology advancement

Researches show that warehouse owners and managers want their warehouses to be “smart”. In other words it means that they are willing to implement technologies into intralogistics processes to keep up with increasing SKUs number and maintain a high KPIs level.

Motorola Solutions (was acquired by Zebra Technologies on the 27th of October, 2014 and renamed later), also specialized in transportation and logistics solutions, conducted a survey among warehouse IT and operations decision-makers in 2013, its results revealed the future vision of warehousing. Thus, 66% of responders expressed a wish to equip staff with new technology solutions (From cost center to growth center 2013, 3). Besides, in the report was noticed that the usage of multimodal voice and screen guidance expected to grow almost 2.5 times (142%) by 2018, so it shows growing interest in this types of wearable equipment (ibid., 3, 10).

In the same time, it was reported that respondents’ primary focus was on picking and replenishment processes, since these are 70% of warehouse operating costs and this area is a top priority for respondents’ technology investment (From cost center to growth center 2013, 10). Indeed, their aim is to reduce costs and increase workers’ productivity in these crucial processes, make supply chain more flexible and agile by eliminating waste, so warehouse professionals have their regards to advanced innovative technology solutions. Rapid and significant technology development and implementation as well as strict KPIs’ frames change the situation towards reduction of voice- and scan-only solutions in replenishment and picking processes, giving way to more effective new wearable devices (From cost center to growth center 2013, 7, 10).
Two years later was released another issue-related research by the same company. The survey was conducted again to determine how the expectations in 2015 versus 2020 have been changed. Some of the results can be seen in the table below:

Table 3. Vision of future technology investments decisions by regions. Sources: Building the Smarter Warehouse: Warehousing 2020, EMEA, North America, Asia Pacific, Latin America reports

<table>
<thead>
<tr>
<th>Countries</th>
<th>Plan to equip staff with technology</th>
<th>Share of total respondents</th>
<th>IoT</th>
<th>Wearables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia, China and India</td>
<td>74%</td>
<td>21%</td>
<td>72%</td>
<td>58%</td>
</tr>
<tr>
<td>France, Germany, Italy, Spain, U.K.</td>
<td>66%</td>
<td>35%</td>
<td>58%</td>
<td>43%</td>
</tr>
<tr>
<td>United States and Canada</td>
<td>76%</td>
<td>28%</td>
<td>52%</td>
<td>45%</td>
</tr>
<tr>
<td>Brazil and Mexico</td>
<td>80%</td>
<td>14%</td>
<td>73%</td>
<td>64%</td>
</tr>
</tbody>
</table>

It revealed that in 2 years number of warehouse professionals who saw technologies as a necessity and planned to equip stuff with technologies has increased in overall by 7% and accounted for 73%.

EFT Supply Chain and Logistics Business Intelligence specializes in providing logistics industry with data and information in the form of reports, news, benchmarking data and white papers. Their recent researches also showing that industry is aimed at modernization: company differentiation (33.7%) and taking advantage of new technologies (21.2%) are the main drivers for increased spending on technologies.

Mr. Paul Richardson, DHL Chief Innovation Officer, is sure that customer satisfaction underlies technological implementation and indeed, the customer demands, as a investment driver, has risen from 9.5% in 2017 to 20.2% in 2018. In general, 48.3% of responders in Europe and 42.3% worldwide admitted technology as their biggest priority in 2017 (The State Of Logistics Technology 2018, 7; European Logistics Report 2017, 5). Finally, 2019 MHI (material handling, logistics and supply chain association) Annual Industry Report says that currently wearable adoption rate is 24% and it expected to be at 50% by 2021 and at 73% by 2024 (2019 MHI Annual Industry
Moreover, 78% of executives consider that wearables will cause substantial impact on their supply chains (ibid., 7).

5 Wearable technologies as a part of modern warehouse

Wearables are seen as a potential improvement solution for industry nowadays. Modern wearables are far beyond just physical tool, they are worn on worker’s body enabling them to interact with different devices within the system via wireless networks while they perform multiple physical tasks without any distraction because wearables allow remote access and transfer of needed data and information. The interaction between human and device takes place through gestures, vision, and voice or by combinations of those. Wearables remain hands free. This feature increases convenience of usability, drastically reduces equipment damages due to fall from one’s arms, and chance of device losses somewhere in premise. Employee can grab items with both hands and stay more focused on work process without distractions on paperwork for instance. Moreover, without extra actions (pick the device, use it, put away, and dozens of such repeated cycles per shift) the chance of getting trauma reduces, speed of operations and workforce performance increase, what leads to higher and pick rate with decent accuracy and on-time order delivery level.

Wearables not only provide smooth operation cycle of a product within warehouse by means of workflow digitization and real-time inventory updates with connection to Enterprise Resource Planning (ERP) system or Warehouse Management System (WMS), but also provide guidance to a worker on spot reducing human-factor mistakes and increase productivity by minimizing times when worker is confused and unsure of relevancy of further actions. Additionally, managers gain good opportunity to track employees’ activities by monitoring their transactions and, as a consequence, accurately evaluate their performance level.

Productivity is still the main field to improve by means of wearable technologies. VDC research for Zebra Technologies (Roche, Koval 2016) showed that 85% warehouse end-users are motivated to invest in wearables because of this very reason. The key market pressures for productivity improvement were defined as follows: reducing
shipment errors (55%), improving inventory accuracy (45%), achieving on-time shipments (40%) and cost-effective track and trace (36%), improving mobile workforce productivity (31%).

Figure 10. Use of Wearable Technology in the Supply Chain and Manufacturing. Source: Robinson 2016.

5.1 Mobile computers, ring scanners and voice-directed headsets

There is a broad range of wearables presented on the market and used in intralogistics nowadays. Typical and most common are wrist computer terminals (mobile computer), ring scanners and headsets (figure 11).

Figure 11. Warehouse wearables, from left to right: VDS-headset, ring scanner, wearable computer. Source: zebra.com

Scanners refer to RF-picking and this is easiest and most flexible solution to implement, but it is not very productive (A Vision of the Future of Each Picking 2016). Ring scanners are used to read 1D, 2D barcodes, and connected with computer terminal via cord or Bluetooth. These wearable computers can be attached to wrist, bicep or belt, they are usually with small keypad and touch screen for a text input, but some types support voice recognition and voice input also. Scanning in some
cases can be quicker and more accurate than speaking, especially in noisy environments (Bond 2019; Haase, Beimborn 2017).

Headsets with headphones and microphone refer to pick-by-voice or Voice Directed Picking (VDP) or Voice Directed System (VDS) method. Voice picking (VP) is more expensive than RF-picking, in the same time it is much more productive, but its flexibility is lower (A Vision of the Future of Each Picking 2016). Voice picking provides audio guidance to an employee during working process, it connected to a management system (ERP, WMS) and says to employee with computer generated voice where, what and how much to take. Operator also uses their voice to communicate (confirm actions) with the system that implies speech recognition and speech synthesis. Picker usually reads back last 2-3 digits of picked item, and this way system checks the correctness of selected item. Then WMS gives operator further instructions (Murray, 2018). Voice headsets were employed more than 20 years ago for usage in cold facilities, where it was difficult to use scanners (Richards 2011, 100), however, today these devices can work at temperatures above -20° (Zebra RS419 ring scanner spec sheet). VDP also very convenient when scanner is not applicable: for instance for picking nonbarcoded fresh products, such as fruits and vegetables (Murray 2018). During voice picking there is no need to look at screen on wrist (eyes-free) like it happens with scanner picking that provides non-distractive and safety work process especially in busy warehouses. VP error rate is about 0.18%, in comparison with 0.35-1.5% of list-based picking (Haase, Beimborn 2017). Optiscan Warehouse solution which includes voice wearable implementation in Verkkokauppa.com helped to reduce picking errors by 90% and reach 10% higher efficiency and for Posti Oy voice picking and by 10-30% and 50% errors reduction, as well as clear supervision, tracking and control of the work (Optiscan verkkokauppa.com case; Optiscan Posti Oy case). As well as scanners, voice headsets are also in use for other warehouse operations that change inventory’s locations and need in status updates: receiving, put-away, inner transfers, replenishment, marshalling, and dispatch.
Figure 12. Paper, RF and Voice picking. Data source: Dematic Logistics

However, nowadays more executives prefer use multimodal solutions, not just solely voice, preferring to combine it with scanners (Bond 2019). It caused by e-commerce impact on supply chain and warehouses especially, so multi-modal wearable combinations are used, that includes wearable computer, ring-scanner and headset (figure 13).

Figure 13. Multi-modal wearable combination: wrist terminal, ring scanner and voice headset

Usage of device combinations proves its worth: overall 15% increase in productivity and additional 39% of picking mistakes reduction (A benefit analysis: The advantages of multi-modal speech-directed solutions 2016). Unlike VP, multi-modal solutions enable additional input modes that simplify multi-order picking, adding screen with instructions and scanner that saves time and replaces need for speaking verification.
or even several repeats when system does not recognize speech. According to Zebra Technologies tests, multi-modal solutions show 16.7% faster picking, and 14% faster travel to locations and items identification (ibid.).

Wearables also have positive impact on workforce from another point of view: technological advancement is important in today’s realities and people enjoy working in a company that deployed up-to-date solutions, it makes workplace more attractive. Studies from WERC (Warehousing Education and Research Council) say that 43% of DC executives have troubles with turnover and low employee morale is one of the biggest problems that cause it (Bond 2018). Mr. Bruce Stubbs, director of supply chain marketing at Honeywell Safety and Productivity Solutions, confirms that technology makes working process more interesting and says: “If you’re not using the latest and greatest, not only will you be less profitable, you will have a hard time capturing and retaining employees. The workforce is much more tech-savvy than ever before, and when they enter the workforce they want to be empowered. If you are operating in a way that does not provide that kind of work satisfaction it can erode morale” (ibid.). Indeed, technologies really simplify work and reduce number of mistakes, these factors can improve stuff’s attitude towards their duties and increase job satisfaction. Additionally, tech-savvy workplace shows the attitude to business and staff and financial situation, so it makes employees feel more confident in employer. Wearables also eliminate paper forms in many processes that definitely positively influences environment and makes one big step forward green policy and decrease in expenses for paper and printing.

5.2 Extended Reality (XR)

Extended reality (XR) covers under itself full spectrum of both real and digital realities, mixed environments and human-machine interactions created by wearables and computer technologies. This concept combines three components under one umbrella: virtual reality (VR), augmented reality (AR) and mixed reality (MR) (figure 14)
Figure 14. XR elements along Reality-Virtuality Continuum

VR fully immerses user into fully digital artificial environment, expelling real word. Simulation is projected by a headset, quite often they can be used along with headphones to increase the perception rate and additional input devices such as haptic controllers (Wearable example: Oculus Rift, Playstation VR, HTC Vive, Google DayDream). In AR and MR reality and virtuality are related with each other - these are not separated, and user is able to interact with both of them in real time. The point is that in MR digital content interacts with real world, as if appends into it as projected hologram (Wearable example: Microsoft HoloLens). In AR virtual content is overlayed on reality, so the user sees it above real-world objects and environment, but it will be discussed in detail later in further chapters.

However, during my researches I noticed that very often AR and MR concepts are mixed and overlapping. In many companies’ web-publications and journals MR headsets mentioned as part of AR as self-contained augmented reality, and additionally MR and AR are considered as synonyms. But despite these technologies have many similarities in common. Anyway, some notice MR as an advanced case of AR, or just a type of AR (Mixed Reality vs Augmented Reality: What's the difference? 2018; The Difference between Virtual Reality, Augmented Reality and Mixed Reality, 2018; XR for business, 2018) or a product of AR (Glockner, Jannek, Mahn, Theis 2014).

Gartner analysts predict that 20% of large-enterprise businesses will adopt XR technologies by 2019 and Accenture Technology studies reveal, that 27% of executives consider crucial to be a pioneer in XR solutions (XR for business, 2018).
Figure 15. Top industry use-cases for business XR according to XR stakeholders. Source: XR for business 2018

According to worldwide statistics and forecasts, VR/AR market growth might reach of more than $209.2 billion by 2022; that means more than 34 times growth in 6-year period and big XR technology outburst in upcoming years.

Figure 16. Forecast AR and VR market size worldwide from 2016 to 2022. Source: statista.com

Additionally, XR technologies are real-fast developing area: the growth of XR headset sales is increasing across the globe and it is still growing, expecting to double just in two upcoming years and reach 84.7 billion US dollars (figure 18).
Virtual reality does not have many applications in intralogistics, in spite of the fact that VR is rapidly developing technology. However, various companies are developing VR solutions for intralogistics sector, that are aimed to be designed both for blue and white collars. All of them use wearables: input controllers along with VR headsets, that are referred as head mounted displays (HMD). In order to immerse into VR it is enough to use a smartphone and a special tool to keep display in front of user’s eyes, for instance Google Cardboard (figure 18, on the left), but also there are more expensive and higher quality headsets suggested on the market.

The principle of work is following: input to a headset goes either from smartphone, or PC connected via High Definition Multimedia Interface (HDMI). Inside of VR headset there can be one or two screens and two autofocus lenses placed between...
screen(s) and user’s eyes. These are very important components inasmuch these lenses create convincing 3D experience and tricking human brain that there is space around by light focusing. Fully-immersive VR requires minimum 60 frames per second and 100-degree field of view (How VR Works? Know the Technology Behind Virtual Reality 2018; How Virtual Reality Works 2018). Built-up positional sensors (magnetometer – function of a compass, accelerometer - measuring the speed of head moving, gyroscope - measuring the head tilt and orientation) track head movements, so that it is possible to look around in VR environment with head movement. Other tools for VR interaction are wireless motion controllers, hand tracking and voice input (Messner 2016; How Virtual Reality Works 2018).

The first VR application in intralogistics is 3D visualisation. One is suggested by Swisslog Logistics Automation, this is simulation through visualization: to run through “what-if” scenarios to see effects of changes in warehouse driven by various modifications in processes, management, like staff changes, new equipment deployment, or variability in external factors such as demand fluctuation or forecasts. Digital copy of a warehouse is created by merging 3 components: sensor data acquired from monitoring equipment and processes, warehouse and simulation models. It allows seeing precise process modelling for a wise decision-making, for example adding new conveyor or forklift and predict their impact on the whole process prior to physical implementation, enables real-time material flow and equipment condition monitoring, helping maintenance crew to prevent failure and waste downtime (Eick 2017 (Industry 4.0: How Virtualization is Changing Warehouse Operations)).

Combination of warehouse model, simulation and real-time data allows creating VR warehouse environments. It grates opportunity to fully immerse user into digital warehouse and allow them to explore and test it prior to real actions. It also can help to analyse performance, correct errors train personnel to improve availability and performance (Eick, 2017 (Industry 4.0: Promising Warehouse Applications for Virtual and Augmented Reality)).
In the future it will be possible to “visit” premise without travelling, remotely monitor and track live operations at warehouses anywhere in the world. This is possible with IoT-enabled devices, sensors and scanners, which collect real-time data and provide actual picture. This real-time data is especially useful in condition monitoring: data is analysed for temperature, variations, location and other factors of components and then the analysis calculates the error risks to prevent failure and disruption (Industry 4.0 Smart Factory 2017).

Another VR application in intralogistics is staff training process. It is used primary for pickers and for forklift truck (FLT) drivers. In the first case in VR environment picking station is replicated so that employees can get acquainted with and learn picking process, and thereafter continuously improve their skills. This approach especially useful in busy premises where there is difficult to spend time on training new inexperienced employees during real operations jeopardizing their accuracy and productivity (Boost your warehouse performance using big data). SynQ VR Training Manager VR environment can be seen on figure 20.
Mr. Stuart Dunn, Product Manager CS Software & Controls, confirmed to me that Swisslog SynQ VR Training Manager is ready to be introduced to the market via email on March 2019: “VR Training Manager product has been completed in the past month, and yes this is commercially available for Swisslog customers who have a CarryPick solution in their Warehouse operations. The next SynQ software release (SynQ2019) will have this product, and this has been presented at LogiMat 2019 in Stuttgart last month. We will also be presenting and sharing this at ProMat in Chicago next month”. The product uses HTC Vive VR-headset, for training process it is possible to connect it to Swisslog SynQ WMS that is deployed with a 3D Visualisation which is used to build the footprint of the warehouse – it enables loading and creation of unique VR environment (warehouse digital copy) and each WMS solution Swisslog deliver has unique properties (Dunn 2019).

Additionally, together with Oculus VR and Immerse DHL Express will be using VR for unit load device (ULD) training. It is aimed to help stacking process and cargo space optimization improvement and, as consequence, reductions of costs, CO₂ emissions, and injures. Via VR multi-user environment trainees learn right loading process together as if co-located, additional elements such as scoring, global leader boards, highlighted mistakes are added for better training process. DHL is currently uses standard training methods such as presentations, printouts or practical activities, but the company wants to implement VR technologies and take them to the next level (DHL Build-Up Exercise 2018; Announcing Oculus for business: bringing VR into workplace 2017).
In the second case training is designed for forklift drivers. According to Raymond Corporation (Raymond Virtual Reality Simulator brochure, 2018), about 74% of forklift ownership costs accounts for labour and because of this particular attention need to be paid for proper operator training. Thus, there are quite many different suggestions of VR FLT training simulators.

Some companies are developing training systems, consist not only of VR headset, but also of forklift simulator with control set-ups similar to real FLT, depending on its type, and hand tracking technology that allows seeing projection of own hands in VR. One vivid example of such is Forklift-Simulator from PlayWerk, Industrial VR Company. The product has already been adopted by many companies for employees training, including DHL, Nestle, 3M, Nissan, Mercedes, BMW and others (Forklift-Simulator brings virtual reality technology to industrial workplace 2018; Forklift-Forklift-Simulator product webpage).

Also it is possible to learn with real FLT in real premise with another notable market player - Raymond VR Simulator: operator can study how to drive and operate with the same FLT and controls they will use the warehouse. The system is plugged in forklift via special simulation port, operator wears VR goggles, and the VR Simulator is ready to be used; instructor can work alongside with operator and track trainee’s actions via screen as they goes through modules of varying degrees of complexity and provide real-time feedback. This approach increases total operator productivity, skills, abilities and reveals weak areas (Patch, 2018).

These trainings can help to reduce workplace injuries, damage to FLT and storing items, mistakes in picking and put-away activities. Additionally, cost of mistakes in VR
is nothing in comparison with real accidents, so it guarantees quick ROI (Forklift-Simulator product webpage).

Figure 22. VR FLT operator training from Raymond (on the left, source: raymondcorp.com) and Forklift-Simulator (on the right, source: Forklift-Simulator instagram)

5.2.2 Mixed Reality

Microsoft promotes HoloLens as the first self-contained holographic device and the most vivid example of MR technology nowadays. As it was discussed in chapter 5.2, sometimes there are uncertainties regarding boundaries between MR and AR technologies. Despite the fact that HoloLens 2.0 are pushed as MR product, many call it as next-gen AR technology and refer it in press-releases as such. For instance, big Medias (BBC, CNN) even Wikipedia, and AR professionals refer HoloLens to AR technologies. To resolve this issue I requested technical assistance from Mr. Shahed Chowdhuri, Microsoft software engineer, who also focuses on HoloLens. He answered me the following: “By definition, HoloLens is considered “Mixed Reality”. There is nothing like it in the marketplace, so competitors and journalist may refer to HoloLens as VR or AR or both. Although it is commonly called AR or “advanced AR”, the correct term is still MR” (Chowdhuri 2019).

The idea of blending reality and virtuality along the reality-virtuality continuum is common for both AR and MR, but the main difference is in vision of these digital objects and their “place” in reality: overlaying or combining. MR covers big space
between these two end points but does not include them, on figure 23 the MR Microsoft spectrum can be seen related more detailed Reality-Virtuality Continuum.

![Figure 23. MR and Reality-Virtuality Continuum](Images credits: Microsoft.com, Quora.com)

According to Microsoft (Bray, McCulloch, Schonning, Zeller 2018), holograms, digital representation of person or object, are big component of MR. However, so-called holograms are not projected in reality: they are not seen with naked eye, only via lenses, so, users see added digital objects only when they wear the device, this is probably one of the main reasons of categorizing HoloLens as AR.

The first HoloLens was introduced in January of 2015, the device supports holograms - objects made of light and sound, interacting with real-world surfaces and responding to gestures (Air tap and Bloom), head gaze, and voice specific commands. In HoloLens 2 (announced in February 2019) support of articulated hands and eye targeting were added. Holograms appear in front of users’ eyes in the holographic frame, they can be pinned steady in the real world or they can be positioned relative to the user and hologram will follow the person with optimal placing zone 1.25 - 5 meters (What is a hologram? 2018).

To produce 3D images, there are 2 light engines (projectors) above the see-through holographic lenses (waveguide), small screens hidden inside the glasses, create an image by sending millions of light rays into lenses 140 times per second (Alex Kipman - HoloLens: mixed reality smart glasses, 2018). The light goes in the following order: imaging optics, waveguide, combiner (device combining projection and real world
image), hits diffraction gratings - a special coating on the glass surface that perform exit pupil (projection) expansion and direct the image at entrance pupil (human eye) (Colaner 2016).

Figure 24. HoloLens light direction inside its lenses. Source: Alex Kipman - HoloLens: mixed reality smart glasses, 2018

HoloLens are equipped with depth camera that is designed to scan and analyse space around user, detect physical objects in order to project images on top or inside them, and interpret hand gestures (Colaner 2016). As well as in VR-headsets, there are accelerometer, magnetometer and gyroscope. But as a distinct from VR headset, MR headset does not require smartphone or computer. HoloLens is equipped with integrated microphone that enables voice commands and in-built speakers creating binaural sound for 3D effect based on user’s position relatively to digital object (Limer 2015). To process terabytes data per second from the sensors holographic processing unit (HPU) was specially invented for these purposes.

In intralogistics processes MR is also applicable. Mr. Trever Ehrlich, Creative Solutions Manager at Kenco Innovation Labs described his experience in Microsoft HoloLens usage in warehouse environment and defined main applications in the industry (Friedman 2017). One applicable is remote assistance: AR-headsets have cameras that enable diagnostics and remote assistance of maintenance professional, but MR-headset allows professional virtually “reach” into needed space. HoloLens support Skype, so it is possible to start a conversation via app right on the warehouse floor. Technology supports not only voice assistance, maintenance professional is able to interact with environment: add marks, circles and arrows, diagrams and other useful virtual objects to simplify the process while looking at fixed item in real-time. Swisslog currently suggests support with the aid of AR service for their customers
using HoloLens and Skype for remote maintenance processes help (Swisslog Technical Support: Count on a rapid response).

Another possible MR application is similar to VR: in 3D it is possible to build a warehouse model reflecting layout, traffic flow, objects movement and interaction as a miniature virtual maquette (Friedman 2017). Holograms can be on future applications when system is connected to WMS creating a tool that enables to observe warehouse performance via 3D model, there is no such vital market suggestions yet.

The technology is still in development stages, but has future potential. Microsoft reports, that about 50000 pieces of HoloLenses were sold (Alex Kipman - HoloLens: mixed reality smart glasses 2018).

![Figure 25. HoloLens remote assist (on the left) and digital building model (on the right). Image credits: Microsoft](image)

MR is not common thing in intralogistics nowadays and as for picking processes, situation is equivocal nowadays. Some applications are developed and tested nowadays, for instance Virtual Manufacturing AB has developed picking application for HoloLens in 2017, aiming to guide the operator to the right location and kit in the cart, take needed number of items (Pick by Mixed Reality with Microsoft HoloLens 2017), Leitwert GmbH (PickAR - Pick by vision with Augmented Reality - Microsoft HoloLens 2017) or PickAR by students from Georgia Tech (Bonasio 2017) or Swisslog also researches possibility of HoloLens picking applications (Swisslog Technical Support: Count on a rapid response). On the flip side of the coin, Mr. Jim Bast, vice president and general manager of Matthews Automation’s Lightning Pick brand, whose company has developing with HoloLens for picking purposes, said that device is not very suitable for warehouse purposes: “...but we believe that as these solutions...
become more industrialized, and frankly, more cost effective, there may come a time when maybe there won’t be physical lights needed for applications like put walls” (Michel 2017). Mr. Eric Cameron, vice president of software sales for Bastian Solutions, after testing HoloLens for virtual picking also said that this device is not yet rugged enough for warehouse use (ibid.).

Indeed, Microsoft HoloLens is quite expensive equipment and this really questions cost effectiveness in terms of use; additionally it has disadvantages in comparison with common AR-headsets, for example there is a comparison of some features of discussed headset and some common AR wearables (table 4) that can be defining in usability and comfort for pickers during long shifts.

Table 4. HoloLens and some popular AR wearables comparison. Sources: Wearables in the Spotlight - February: Vuzix M300, 2018; M300 Smart Glasses product page. Page on Vuzix website; Lang, 2019; Zeller, 2018; Moverio BT-300 Specifications; Meet the ORA-2 Professional Smart Glasses and “Work Smarter”

<table>
<thead>
<tr>
<th>XR-headset</th>
<th>Microsoft HoloLens</th>
<th>Vuzix M300</th>
<th>Moverio BT-300</th>
<th>ORA-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price (device only)</td>
<td>≈ 3000$</td>
<td>≈ 1000$</td>
<td>≈ 1000$</td>
<td>≈ 800$</td>
</tr>
<tr>
<td>Battery life of active use</td>
<td>≈2-3 hours</td>
<td>≈3 hours</td>
<td>≈6 hours</td>
<td>≈5 hours</td>
</tr>
<tr>
<td>Weight</td>
<td>579 grams</td>
<td>140 grams</td>
<td>69 grams</td>
<td>90 grams</td>
</tr>
</tbody>
</table>

6 Augmented reality

6.1 AR history of the development

The term “Augmented Reality” was firstly announced in the very beginning of 1990-s by Tom Caudell, a Boeing researcher. The aim of the invention was to help airplane construction workers with their jobs in complex manufacturing processes. The idea
was to enable worker to get access to digital CAD data during operations and replace assembly guides and templates, drawings and location markings on the floor to reduce errors. By means of display with workplace registration systems and head position sensing, Caudell and Mizell expected to supplement workers’ vision with useful and dynamically changing information (Caudell, Mizell 1992, 659-660). To a headband there was attached head mounted PC display called the Private Eye (720H x 280) with receiver unit used to calculate its position up to fifty times a second relatively to transmitting unit that was attached to the demonstration platform. Beam splitter of the HUD set enabled to see real and digital world simultaneously. HUD set was connected to waist-mounted microcomputer system. The Private Eye, of the demonstration system was not designed for metrology, so for its eyepiece it was problematic to maintain alignment. Other obstacles were troubles with “see-through” and image perception especially for people with eyesight problems, field of view that was about 7°, and time lag between head motion and change in the graphics. However, the system had its weaknesses, related with imperfection of technologies about 3 decades ago, especially position sensing that was the biggest limitation of AR in those days. Also during research troubles of registration calibration in the factory environment were faced because of HUD set’s movement on the user’s face caused errors (ibid., 667-668). Anyway, the system was received well and proved its potential for industrial applications. It is noteworthy that Boeing uses AR in industry nowadays for the same purposes: AR smart glasses with voice commands helps employees with wire assembly, augmenting vision with diagrams, videos instructions. It cut built time for 25% and increased productivity by 40% (Boeing Tests Augmented Reality in the Factory 2018; Upskill and Boeing Use Skylight to Reinvent Wire Harness Assembly 2017).
Another AR system called “Virtual Fixtures” that enabled the overlay of information on a work environment to increase productivity was created two years later by Louis Rosenberg at United States Air Force Research Lab in order to achieve improvements in remote manipulated tasks. The idea is that operator performs a task (peg insertion into holes of a task board) in remote environment from operator space that requires hand coordination, and the fixture serves as a computer-generated perceptual “ruler” overlay in this case that provides guidance and prevents from destructive actions. It was useful, because it was not always possible to place a physical “ruler” in operating environment (Rosenberg 1992, 2-4, 7). Operator controlled robot arm via exoskeleton, he wore monocular vision system with 7x binocular optics to focus on distant monitor that displayed remote environment via camera; this created illusion of full immersion like operator’s board was within operator’s hand reach (ibid., 14).

It was possible to implement haptic fixtures via exoskeleton movement restrictions because of acrylic sheet barriers on fixture board, virtual fixtures were able to reduce
processing demand of the task by operator’s sense of presence and perception of workspace (Rosenberg 1992, 9). In other words, “ruler” is not only felt physically, but also could be seen as projected on onto the task board via vision system, embodying the AR concept. Virtual fixtures are defined by Rosenberg (1992, 3) as *abstract sensory information overlaid on top of reflected sensory feedback from a remote environment*, virtual fixtures had the same functions as physical fixtures, being computer simulation that interacts with user, not with working environment.

In 1993 was introduced Knowledge based Augmented Reality for Maintenance Assistance (KARMA), that enabled to find certain objects and perform simple actions on them using knowledge-based graphics component IBIS (Intent-Based Illustration System) adjusted for AR purposes. System was tested on printer maintenance task (to refill paper tray), for The Private Eye display was used with mirror beam splitter as it happened in case of Caudell and Mizell. The system involved several triangle-like transmitters with three small ultrasonic sources located near its corners (figure 28) for position and orientation-tracking system; two small triangles mounted on printer and head-mounted display were the tracker receivers with 3 microphones mounted in each: top small triangle was for head and lower one for the sensors that track paper tray and lid (Feiner, Macintyre, Seligmann 1993, 55).

![Figure 28. KARMA operating environment. Source: Feiner, Macintyre, Seligmann 1993](image)

The system tracked user’s and printer components’ position generated 3D instructions, overlaid on real world. Despite the prototype produced relatively dim image and overplayed graphics on a narrow portion visual field, it still was able to perform it main communicative goals (Feiner, Macintyre, Seligmann 1993, 55).
Table 5. Augmented Reality for Maintenance Assistance as seen through HMD. Source: Feiner, Macintyre, Seligmann 1993

<table>
<thead>
<tr>
<th>Show toner cartridge and identify paper tray</th>
<th>Show action of pulling out paper tray and resulting change in its state</th>
<th>Show action of pulling lid lever</th>
<th>Show lid and change in its state</th>
</tr>
</thead>
</table>

In 1995, unlike previous AR-systems based on head-mounted displays, Jun Rekimoto developed the magnifying glass approach: a palmtop-sized video see-through device, called NaviCam. This invention can be considered as an AR mobile device precursor. The device was equipped with CCD camera, LCD-TV screen, gyro-sensor, that determined NaviCam orientation. Real world images were captured via camera and sent to Unix workstation, where they were merged with computer-generated text or graphics, and then sent back to the screen (Rekimoto 1995, 4).

Figure 29. Magnifying glass augmented vision and attached tags. Source: Rekimoto 1995

Rekimoto’s (1995, 6) system engaged colour code ID-tag recognition that was attached to various objects and enabled to present information regarding that object on the screen. This approach of ID-awareness brought a big advantage in AR-systems development, inasmuch it was made possible to augment information on a movable object. Feiner (Feiner, Macintyre, Seligmann 1993) used position sensors to augment printer movable parts, but it was problematic to attach sensor to all movable objects within a big AR system. Later, J. Rekimoto and Y. Ayatsuka (2000) developed a
CyberCode - visual tagging system working with 2D tags and enabling to determine its location in 3D. CyberCode was also possible to combine with other technologies, for instance, with spatial awareness. By applying NaviCam to CyberCode, system determines location information from it; system continues to track the device position by gyro sensor and displays navigation information (Rekimoto, Ayatsuka 2000, 5).

There were many other AR applications in various fields in the end of 90-s such as navigation: AR hybrid synthetic vision was used for NASA X-38 spacecraft by overlaying map data for a convenient navigation in conditions of poor visibility; business, education: Studierstube - multi-user AR in the same shared space (Szalavári, Schmalstieg, Fuhrmann, Gervautz 1998) and TransVision (Rekimoto 1996; TransVision: multi-user handheld augmented reality 1996), or for urban environment exploration: a Touring Machine, head-worn display controlled by backpack computer and handheld display with stylus, GPS and magnetometer were used for orientation (Macintyre, Höllerer, Webster 1997).

Big leap in AR technology happened with the invention of ARToolKit AR tracking library by Hirokazu Kato in 1999. This software allows building AR applications, solving main previous problem – to track adequately users’ viewpoint and, as a sequence, virtual object interaction. Software is able to determine camera’s position in real time by means of special markers (black squares). Once marker found, virtual model is drawn from that same position on top of the real world video (How does ARToolKit work?).

Figure 30. ARToolKit work principle. Source: How does ARToolKit work?
From August 2004 to March 2019 ARToolKit have been downloaded more than 767000 times (ARToolKit download statistics 2019). Nowadays it is at free access and can be downloaded by everyone; with release of this library new age of AR technology has started.

AR applications expand their limits along with technological progress. In 2000 it found its place in gaming with release of ARQuake. Virtual monsters were overlayed real world (indoor and outdoor) via head-mounted displays (HMDs), user with a laptop computer on their back could freely move in physical world with combination of a GPS (1 update per second/compass (15 times per second) system (Piekarski, Thomas, 2002). Game also was based on ARToolKit technology that required square markers in the environment (Thomas B.het al., 2000).

![Figure 31. ARQuake AR vision and hardware. Source: Piekarski, Thomas, 2002](image)

In 2004 AR ARToolKit was ported to mobile Symbian OS by Anders Henrysson that enabled creation AR applications on mobile phones, so in 2005 was released AR Tennis - game for Nokia. Players sat across a table with a paper with ARToolKit markes (Henrysson, Billinghurst, Olivia 2006).

![Figure 32. AR Tennis – first mobile AR. Source: Henrysson, Billinghurst, Olivia 2006](image)
The period of global AR recognition started in 2008 when it entered mobile phones area. Wikitude is considered as a first AR browser, released in the same year, using sensor data such as GPS, accelerometer, compass and gyroscope for overlaying on mobile screen virtual information about local interest points or markers (See Wikitude’s ‘AR window’ live on a mobile web page, 2012; Wikitude AR Travel Guide 2008).

6.2 Augmented Reality today

There are two main types of AR working principles – marker based (as ARToolkit) and markerless, also known as location-based (Wikitude for instance). The first case is about image recognition, there are used markers (color, 2D-codes, picture) recognized by camera and virtual image superimposed reality on the screen. Majority of AR systems are capable of 3D objects recognition as a marker also (table 6). Location-based approach uses features suggested by modern mobile devices, GPS defines the device location and sensors recognize the orientation, based on this software offers relevant data that overlays the real world environment.

SDK (Software Development Kit) is AR engine and important software component; it enables AR recognition, tracking and image rendering (Prabhu 2017). There are many offerings on the market, the choice among which depends on AR application purposes. The table below (table 6) illustrates most common and comprehensive AR ADKs’ capabilities, including AR smart glasses support that has common application in warehousing operations.

Table 6. AR most common SDKs comparison. Data sources: Augmented Reality SDK Comparison 2019; Best AR SDK for development for iOS and Android in 2019; Mykola, Bryksin 2017; Prabhu 2017.

<table>
<thead>
<tr>
<th>Platforms supported</th>
<th>3D recognition</th>
<th>GPS</th>
<th>Smartglasses Support</th>
<th>Cloud Recognition</th>
<th>SLAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vuforia</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Wikitude</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>ARToolkit</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

Platforms supported: Android, iOS, UWP
3D recognition: Y
GPS: Y
Smartglasses Support: Y
Cloud Recognition: Y
SLAM: N
<table>
<thead>
<tr>
<th>Technology</th>
<th>Platforms</th>
<th>Support</th>
<th>Support</th>
<th>Support</th>
<th>Support</th>
<th>Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Google ARCore</td>
<td>Android, iOS</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Apple ARKit</td>
<td>iOS</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Kudan</td>
<td>Android, iOS</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>EasyAR</td>
<td>Android, iOS, UWP, Mac</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Maxst</td>
<td>Android, iOS, Windows, Mac</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Xzimg</td>
<td>Android, iOS, Windows</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

Servers also play an important role in image rendering; they can provide higher speed of processing and quality in comparison with devices because of higher power. System requests previously created and uploaded virtual objects from web of cloud server database, from which they are sent to device. Needed data can also be stored in-device, but SDKs cloud recognition allows to use remote data storage.

Another notable markerless AR supported technology is SLAM (Simultaneous Localization and Mapping). SLAM is in its "infancy" stage, but it already showed itself as an important part of AR applications with big potential. Technology is useful in indoor where GPS tracking does not work or among tall skyscrapers or in deep canyons - environments, where GPS signal can be lost or work improperly. Additionally, only visual SLAM technology offers more precise mapping accuracy level that is an essential condition of adequate virtual objects overlaying in AR systems (What is Visual SLAM Technology and what is it used for? 2018). SLAM requires depth camera, that was mentioned in chapter 5.2.2, by means of which it recognizes surroundings. ARKit (Apple) and ARCore (Google) are major market SDK players that use SLAM, capable of not only floor recognition and positional tracking, but also walls, furniture and other obstacles (Kollegger 2018). SLAM performs hundreds of estimations per second of where surfaces might be and "pins" those with points or vertices (figure 33 a). Reconstruction of dense point cloud (figure 33 b) is built to help to recognize space around and memorize objects’ position in space (ibid.). Virtual objects can be “attached” to arbitrary places and stay there even while user moves around.
Wide variety of AR devices is presented on the market for personal and enterprise purposes. These devices can be divided in different ways based on various specifications, after careful research of such I built mind map of AR based on their types and specifications (figure 34).

Figure 34. AR devices mind map

Wide group of devices is known as mobile AR, they are hand-held and AR content is overlaid on image (video) on the mobile phone or tablet screen, so they are referred to video see-through. Although majority of mass consumers relate AR with mobile phones (mobile applications such as games or photo filters), industry is mostly counting on free-hand devices, such as wearables. AR wearables, such as smart glasses, are mostly referred to OST-HMDs (optical see-through HMDs): technology of placing partially transmissive optical combiners in front of the user's eyes, so she/he can see the real world through them (Azuma, 1995). Smart glasses can be two types: binocular (display optic in front of each eye) and monocular (display optic in front of only one eye), the last type, in turn, is not always see-through HMD: some monocular
devices can be so-called “look-around” types because occluded microdisplay there is mounted in front of the eye (as Vuzix M300 or RealWear HMT-1 (table 7)), such devices sometimes also called as Assisted Reality (Picavi Hardware; The RealWear HMT-1, 2018). In see-through monocular smart glasses, like Glass Enterprise Edition (table 7), image is sent to a transparent prism display right in front of user’s eye, overlaying AR content over reality. Some see-through binoculars’, like Meta 2 (table 7), and its work principle is similar to HoloLens waveguides (chapter 5.2.2).

Table 7. AR Smart Glasses examples. Images credits: Ubimax

<table>
<thead>
<tr>
<th>See-through HMD</th>
<th>Monocular</th>
<th>Binocular</th>
</tr>
</thead>
<tbody>
<tr>
<td>See-through</td>
<td>Glass Enterprise Edition</td>
<td>Optinvent ORA 1</td>
</tr>
<tr>
<td></td>
<td>ODG R-7</td>
<td>Meta 2</td>
</tr>
<tr>
<td>“look-around”/occluded display</td>
<td>RealWear HMT-1</td>
<td>Vuzix M300</td>
</tr>
</tbody>
</table>

Smart glasses are used in installation, maintenance, production/assembly, warehousing, medical and construction – in areas where hands-free aspect is in high demand (Paul 2017). ABI Research (Paul 2017; Augmented Reality Hardware Market at Innovation Inflection Point 2018) predicts smart glasses market shift towards binocular options closer to 2021 along with significant market growth, but nowadays monocular devices are prevail because of availability, costs and acceptable performance, and this situation is expected to be the same in next few years. Predicted changes are based on expectations of future technology improvement, costs and average selling prices decrease, and devices capability fully realization (Augmented Reality Hardware Market at Innovation Inflection Point 2018). However, nowadays monocular wearables are generally cheaper, lighter, less obtrusive and these factors ensure them big place in enterprise sector (Paul 2017). Smart glasses shipments can archive 32.7 million in 2022, growing from 225 000 in 2017 (Augmented Reality Hardware Market at Innovation Inflection Point 2018).
Technavio (Global Smart Glasses Market 2018-2022, 2017) names DAQRI, Epson, ODG, Optinvent, Vuzix as the leading vendors of smart glasses market. They also predict $262.21 million incremental growth of smart glasses market from 2017 to 2022. According to Technavio report on the global AR market 2017-2021, technology research and advisory company (Augmented Reality Market to Grow at 65% CAGR Through 2021, 2017), global share of each device group in 2016 was as follows on figure 36, and their rise at a CAGR (Compound Annual Growth Rate) by 2021: 77% for mobiles, 69% for HMDs and 35% for smart glasses. But worth to notice that in their market analysis HMDs are considered as both AR and VR helmet-like devices (DAQRI Smart Helmet or Sensics zSight-FL) without segmentation while mobile and smart glasses are pure see-through AR technology. However, this also reflects good position of AR and high interest of certain areas in technology in today’s state and future. Capgemini research institute reports results of their survey (Augmented and Virtual Reality in Operations 2018), according to which about 66% of organizations said that AR is more applicable than VR and 45% of organizations are implementing AR (in comparison with 36% of VR) with main focuses on remote assistance, reference videos, manuals and instructions view and visualization of components functions behind physical barriers. Vuzix, leading supplier of Smart Glasses and AR technologies, reports that their revenue in 2018 was 46% more than in 2017 due to smart glasses sales. Total company’s sales


<table>
<thead>
<tr>
<th>Company</th>
<th>Area of implementation</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airbus</td>
<td>Manufacturing - cabin installation marking process</td>
<td>Time/workforce savings: 3 people 3 days -&gt; 1 person 6 hours for task</td>
</tr>
<tr>
<td>Boeing</td>
<td>Production</td>
<td>-25% - production time ≈0% error rates</td>
</tr>
<tr>
<td>KPN</td>
<td>Maintenance - technicians receive tasks, remote help and guidance</td>
<td>5% - faster completion times -11% - operating costs -17% - error rate reduction</td>
</tr>
<tr>
<td>Johnson &amp; Johnson</td>
<td>Training</td>
<td>Instructions from senior specialists are recorded via smart glasses for younger new employees</td>
</tr>
<tr>
<td>Coca-Cola</td>
<td>Maintenance of bottling equipment</td>
<td>Time and costs savings by eliminating the need to call for an expert on site, reduce downtime</td>
</tr>
<tr>
<td>Bosh</td>
<td>Workshop – repairs</td>
<td>-15% of time per step</td>
</tr>
<tr>
<td>AGCO</td>
<td>Manufacturing</td>
<td>-30% inspection time elimination of paperwork and manual uploading -25% production time and complex assemblies -50% learning curve for new employees</td>
</tr>
<tr>
<td>Porsche</td>
<td>Maintenance – step-by-step instructions and drawings</td>
<td>-40% service resolution times</td>
</tr>
<tr>
<td>Siemens</td>
<td>Manufacturing - quality control, circuit boards inspection</td>
<td>20-25% quality improvement</td>
</tr>
<tr>
<td>GE</td>
<td>maintenance on</td>
<td>59% more maintenance tasks per hour</td>
</tr>
</tbody>
</table>
Nevertheless, despite smart glasses are popular in enterprise sector, they are still not very popular option for personal usage, this fact also explains their market share in comparison with mobile AR for instance. Google smart glasses released in 2013 as consumer device flopped due to high price (about $1500), privacy issues (camera), unclear functions and weird appearance (Levy 2017). In 2017 the vector has changed towards industry applications with Glass Enterprise Edition announcement, new smart glasses are implemented by such companies as GE, Boeing and Volkswagen (Langley 2018).

Digi-Capital (For AR/VR 2.0 to live, AR/VR 1.0 must die, 2019) defines major challenges that smart glasses need to deliver on to become a mass market product:

- became notable device (i.e. Apple-image device);
- increase battery life, that can stand whole day;
- improve mobile connectivity;
- increase app ecosystem;
- reduce the prices.

Apple CEO Tim Cook announced that AR is profound core technology, and his company is expected to release their AR Glasses powered by iPhone in 2020 (Smith 2019). This event can impact on public perception of smart glasses, making it mass-product, but also influent AR market.

Another AR technology is HUD (head-up display). This is a usually fixed screen on which needed information is projected. HUDs have wide applications in military for pilots, but nowadays it paves its way into car navigation. For instance, company WayRay introduced its Navion AR navigation system that uses GPS and SLAM for effective and safe real-time navigation and gesture input. This technology is also suitable in logistics field in terms of fast navigation in transportation (Navion – the first holographic AR system for cars). HUDs already adopted in such cars as Jaguar, BMW, Range Rover, Lexus, Audi, Hyndai and some others.
6.3 Augmented reality in the future

AR is a hot topic nowadays, and worth to notice that many research companies introduce their own predictions about this technology development. The technology growth is immutable by all research experts, but and these predictions vary in numbers inasmuch all forecasts are predictions only, based on the current market situations. Below are related research results in the form of table (table 9):

Table 9. AR market growth expectations from different analytic sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Publication year</th>
<th>Expected market growth (in billions $) for a certain time period</th>
</tr>
</thead>
<tbody>
<tr>
<td>MarketsandMarkets</td>
<td>2017</td>
<td>$2.39 in 2016 and $61.39 by 2023</td>
</tr>
<tr>
<td>Statista</td>
<td>2018</td>
<td>$3.5 in 2017 and $198 by 2025</td>
</tr>
<tr>
<td>BusinessWire</td>
<td>2018</td>
<td>$11.14 in 2018 and $60.55 by 2023</td>
</tr>
<tr>
<td>BIS Research</td>
<td>2018</td>
<td>$198.17 by 2025</td>
</tr>
<tr>
<td>Orbis Research</td>
<td>2017</td>
<td>$5.24 in 2016 and 165.32 by 2022</td>
</tr>
<tr>
<td>ZionResearch</td>
<td>2018</td>
<td>$3.33 in 2015 and $133.78 by 2021</td>
</tr>
<tr>
<td>Consultancy.uk</td>
<td>2018</td>
<td>$4 in 2016 and $161 in 2022</td>
</tr>
</tbody>
</table>
As it can be seen, despite quite big number variation, the growth tendency is remaining in upcoming years, and AR has its future potential. The researches have moved towards the consensus that main factors for such AR growth are:

- Increasing availability to users;
- More technology startups suggest new solutions;
- Increasing awareness and interest in technology;
- Technology development (5G wireless internet, IoT connected devices etc);
- Increased use of smartphones, tablets and other mobile AR-supportive devices.

In chapter dedicated to AR history it was notable that full ideas’ potential was not possible to embody in full extent due to current technology state, so along with technology development there will be more applications and possibilities. SLAM can be implemented into logistics area for objects clear recognition without markings, AI will be cleverer and be able to analyze increasing mounts of data more effectively. For instance, smart AR-lenses are in development stage and may be released in the future (Parviz 2009; Glockner, Jannek, Mahn, Theis 2014).

Figure 38. Analytical predictions of AR market

Figure 39. AR-lenses. Source: Parviz 2009
As for logistics field, there are some implied applications that will be developed with technological progress (table 10). John Gilbert, DHL member of the board of management supply chain, said that AR will have an impact on logistics industry in upcoming years and noticed that this is a promising technology (Fink 2017).

Table 10. Envision of AR applications in logistics. Data source: Glockner, Jannek, Mahn, Theis. 2014

<table>
<thead>
<tr>
<th>Logistics area</th>
<th>AR-Applications</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warehousing</td>
<td>Pick-by-Vision</td>
<td>AR for picking process with more advanced technologies.</td>
</tr>
<tr>
<td>Warehouse Planning</td>
<td></td>
<td>AR to overlay digital representation of possible future modifications, adjust design and new workflows in real warehouse before construction process.</td>
</tr>
<tr>
<td>Optimization</td>
<td>Completeness Checks</td>
<td>Replace manual or barcode check of dispatched goods with AR scanners and 3D depth sensors to determine right batch assembly, volume, quantity etc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Check shipments for international import/export regulations and documents, other requirements.</td>
</tr>
<tr>
<td></td>
<td>Dynamic Traffic Support</td>
<td>AR navigation with real-time route optimization with HUDs or glasses.</td>
</tr>
<tr>
<td></td>
<td>Freight Loading</td>
<td>Digital cargo lists and load instructions, live guidance for loading with arrows and highlighted places, generated either in advance by planning software or on the spot by ad-hoc object recognition.</td>
</tr>
<tr>
<td></td>
<td>Last-mile Delivery</td>
<td>Augment vision with critical information about cargo (specifications), such as content or type, handling instructions etc.</td>
</tr>
<tr>
<td></td>
<td>Parcel Loading and Drop-off</td>
<td>Building and environment identification and indoor navigation with LLA (latitude, longitude, altitude) markers for fast delivery, connected with database or based on user-generated content.</td>
</tr>
<tr>
<td></td>
<td>Last-meter Navigation</td>
<td>Identification of receiver by face recognition, ID</td>
</tr>
<tr>
<td>Value-added Services</td>
<td>Assembly and Repair</td>
<td>Generate AR instructions for such value-added warehouse services as assembly and repair processes with object recognition with error detection.</td>
</tr>
<tr>
<td>----------------------</td>
<td>---------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Customer Services</td>
<td>Overlay AR representation of shipping boxes in real world to determine correct shipping options.</td>
</tr>
</tbody>
</table>

7 Augmented reality in intralogistics

7.1 Logistics as a main smart glasses customer

Augmented reality is one of the biggest and most significant technologies used in intralogistics industry. According to ABI research (Logistics Leading the way in Augmented Reality Usage and Adoption 2017), 24% of Smart AR glasses shipments are accounted for logistics. Logistics was one of the first sectors to implement AR, and maintains its position as a leading vertical for AR glasses and total value chain revenues: in five years it is predicted increase in revenue of AR glasses shipments for logistics, 52.9 million in 2017 to 4.4 billion in 2022. David Krebs, vice president of research at VDC Research and Spencer Gisser, a researcher at VDC, estimate 27,000 units of smart glasses shipped in 2017, 50,000 in 2018 and "hundreds of thousands" by 2021 (Forger 2018). ABI Research also defines logistics is one of the biggest AR revenue generators (figure 40).

![Figure 40. AR world market revenue by vertical, 2017-2022. Source: ABI Research](image-url)
### 7.2 Applications in warehouse processes

#### 7.2.1 Picking

AR smart glasses are used by workers in many warehouse operations along all way of goods within the premise: receiving, loading/unloading, picking and kitting. Picking is a major process in warehouse activity – about 50% of warehouse working hours (DHL makes augmented reality a standard in logistics, 2017).

Picking by means of smart glasses called vision picking or pick-by-vision, or even smartpick. It is aimed to replace less modern and standard methods like pick-by-paper approach when picker uses paper (pick slip/picking list) to determine needed items, their quantity and location. In overall, process goes in following way: picker wears smart glasses and logs in into the system with special card, smart glasses augment picker’s vision with needed for each step of executed process information from WMS or ERP. Picking is confirmed either via smart glasses camera or voice (convenient for forklift drivers), or by other connected wearables: ring scanner and FRID-wristband. Packing list is updated automatically, system prevents mistakes and lets user know about it (Ubimax xPick Vision Picking for logistics and warehousing, 2019; Vision Picking with Smart Glasses - Samsung Cello. 2017; Picavi: Vision Picking with Smart Glasses. 2015).

Table 11. Examples of AR smart glasses application in intralogistics. Data sources: Kloberdanz, 2017; Volkswagen rolls out 3D smart glasses as standard equipment, 2015; xPick at Intel cuts picking time by 29%, 2017; Scherer, 2017; Vision Picking with Smart Glasses - Samsung Cello, 2017; Augmented Reality Based, Hands Free Order Picking & Sorting; Speed Increase and Quality Upgrade with Ubimax Vision Picking Solution xPick, 2015; Stewart, 2017; Spinger, 2014; Augmented Reality: Picking And Sequencing With Google Glass; Schnellecke Logistics Sequencing, 2018; KSB Case; The Fiege Group Case.

<table>
<thead>
<tr>
<th>Company</th>
<th>Reported Impact</th>
<th>Company implemented</th>
<th>Smart glasses</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE Healthcare</td>
<td>46% - performance improvement in order fulfilment; Error reduction; Speed increase.</td>
<td>Upskill</td>
<td>Google glass</td>
</tr>
<tr>
<td>Volkswagen</td>
<td>work process simplification and</td>
<td>Ubimax</td>
<td>Google glass</td>
</tr>
<tr>
<td>Company</td>
<td>Features</td>
<td>Vendor 1</td>
<td>Vendor 2</td>
</tr>
<tr>
<td>-------------</td>
<td>----------------------------------------------------</td>
<td>------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>Intel</td>
<td>-29% picking time</td>
<td>Ubimax</td>
<td>Recon Jet Pro</td>
</tr>
<tr>
<td>Opel</td>
<td>no mistakes; rework reduce; work process simplification.</td>
<td>Ubimax</td>
<td>Google glass/ Vuzix M300</td>
</tr>
<tr>
<td>Samsung</td>
<td>+22% picking performance 10% quality increase</td>
<td>Ubimax</td>
<td>Google glass</td>
</tr>
<tr>
<td>Audi</td>
<td>Mistakes reduction</td>
<td>Ubimax</td>
<td>Vuzix M100</td>
</tr>
<tr>
<td>John Deere</td>
<td>Target productivity, speed and error rate enhancing</td>
<td>Ubimax</td>
<td>Vuzix M300</td>
</tr>
<tr>
<td>DB Schenker</td>
<td>No time waste</td>
<td>Picavi</td>
<td>Recon Jet Pro</td>
</tr>
<tr>
<td>Bosch</td>
<td>less errors; hands-free; no need for PCs to enter info.</td>
<td>Picavi</td>
<td>Vuzix/Epson</td>
</tr>
<tr>
<td>Schnellecke Logistics</td>
<td>20% time saving</td>
<td>Ubimax</td>
<td>Google Glass</td>
</tr>
<tr>
<td>KSB</td>
<td>35% more productivity; Time savings without time-consuming searching.</td>
<td>Picavi</td>
<td>Google Glass</td>
</tr>
<tr>
<td>FIEGE</td>
<td>Time saving; 5% productivity in comparison with voice and 10% pick-by-scan.</td>
<td>Picavi</td>
<td>Presumably Google Glass</td>
</tr>
<tr>
<td>DHL</td>
<td>-50% training time; 15% more productivity Increased accuracy and picking time; 20% speed increase.</td>
<td>Ubimax</td>
<td>Vuzix M100, Vuzix M300, Google Glass</td>
</tr>
</tbody>
</table>

There is no need to distract on RF-scanner display all the time for each item taken, but in the same time smart glasses provide more information right in front of the eyes. Although they are capable of taking over ring scanner functions with a camera, they are still applicable when it is not possible to point smart glasses camera at barcode, for example when item is too low and it is more convenient to reach it by arm than by camera of head-mounted device (A Vision of the Future of Each Picking, 2016).
7.2.2 Maintenance

AR smart glasses applicable for remote maintenance in warehouse for forklifts, automated material handling systems or other equipment for technicians and operators. Downtime costs money so call for a technician also. With a smart glasses on it is possible to connect to a specialist, camera and microphone capture information on site and it is possible to receive real-time guidance. Additionally, AR makes possible to overlay downloaded videos, schematics and instructions to simplify maintenance process even for qualified technicians. Some specialists also predict new maintenance applications with smart glasses along with technology development: for instance microphone may detect and recognize abnormal noise. ROI (return of investment) for such solution is estimated to be less than a year; investments can be covered quickly by possible service fee or a single incident (Forger 2018).

Figure 41. AR remote maintenance. Image sources: Connect Smart Glasses and SAP with the Simplifier, 2013; Essert’s Remote Support System with Vuzix M100 Smart Glasses, 2015

7.2.3 Training

Smart glasses especially good during peak season periods, when all elements of supply chain are under pressure. And to withstand peak periods in many warehouses there is requirement in staffing increase. According to Upskill, AR industrial software developer, that there is that typically 2 times increase in workforce during seasonal hiring, lasting in average 60 days, and 50% of peak time is spent on training (Using Augmented Reality to Manage Peak and Seasonal Surge, 2017). Sometimes training
includes classroom studies or e-learning before new employee gets to real warehouse operating environment, smart glasses can skip this step by providing information access to workers on the move: videos, step-by-step instructions and other materials in digital form. Moreover, system allows instant and on-site connection with supervisor or another colleague for guidance, video and audio transfer allows fast and effective question resolve or report if some items are damaged, lost or other problems with inventory (ibid.). And it is really convenient, taking into account that vision is dominant human sense and that is why visual information is perceived and processed better.

It is possible also to adjust smart glasses profile for certain worker depending on their experience. For instance, for an employee who just started working and has difficulties in new environment with tasks they did not perform before it is possible to add to profile extra instructions and tutorials. This feature is especially convenient in high peak seasons of public holidays when number of orders increase significantly and there is a need for extra workers, and it is really important to raise their productivity up to possible maximum. It is possible literally to talk with smart glasses and ask for certain instructions inasmuch it has almost the same functions as Smartphone (A Vision of the Future of Each Picking 2016).

Positive aspect is language independency that also convenient for foreign employees or in areas with not only one official language, by using different languages libraries that can be added to individual user’s profile and it significantly radices the language barrier. DHL defines his technology as a very potential as well as “the next big thing” in their operations”, and it has big economic potential as it has the same price as scan solution but has higher productivity and wider applications range (A Vision of the Future of Each Picking, 2016).

7.3 AR in practice: case DHL

DHL was one of the first companies in the world that widely implemented AR in their operations (DHL rolls out global augmented reality program, 2016). Mr. Markus Voss, DHL Supply Chain CIO and COO, said: “As one of the first logistics companies using the technology, we have truly established a new way of order picking in the industry”
and “we can now say augmented reality technology is one of our standard offerings at DHL Supply Chain” (DHL supply chain makes smart glasses new standard in logistics, 2017). DHL has deployed its first AR pick-by-vision pilot project in December 2014 in Ricoh premise in Bergen op Zoom, Netherlands, together with their customer and Ubimax (enterprise wearable computing and augmented reality solutions provider). The aim of the project was to see whether smart glasses can be used for order picking in a more cost-beneficial manner than existing combination of RF-picking and pick-by-paper approaches, and subsequently be replaced after with more advanced, lean and user-friendly smart glasses. There were problems with picking errors in the first place when workers did mistakes (for instance, picked 3 packages instead of units), it took time to think and define after reading pick list what to put in each of 15-30 bins of a trolley and picking lists were inconvenient for usage (DHL Global Technology Conference 2015).

Warehouse staff was equipped with Vuzix M100 and Google Glass wearables, in 3 weeks 10 employees have picked about 20,000 items and have fulfilled 9,000 orders. Picker logs in into the system and scans their trolley (where all picked items will be put), and the information regarding current picking process is overlayed in front of vision, trolley is also displayed schematically to guide picker, what needs to go where – directed sorting and placement with colours (what items, each colour references to each item) and numbers (how many).

Table 12. DHL pilot AR project in Netherlands

<table>
<thead>
<tr>
<th>Before</th>
<th>Manual scanning, markings in picking lists by pen</th>
</tr>
</thead>
</table>

After

Task information is displayed in front of the vision, system shows items’ location number, identifies number of items picked and shows in which trolley box what item to put (trolley is displayed graphically as a matrix)

Smart Glasses camera scans barcode, information updates in WMS automatically. Next, system guides further pickers actions

Figure 42. DHL picking processes before and after smart glasses project. Data source: A Vision of the Future of Each Picking, 2016
Smart picking takes steps out of the process making it shorter by saving valuable time and that leads to significant savings in a long run. After pilot project implementation it was indicated added value to intralogistics operations and customers with 25% productivity increase in picking, much faster and error free (DHL successfully tests Augmented Reality application in warehouse, 2015). During the pilot accuracy went up even though amount of scanning and verification decreased due to tips on HMDs, because what employees see digitally they can match with real world tasks, so there is no need to memorize things or perform extra actions to make sure that the task was accomplished in a correct way (A Vision of the Future of Each Picking, 2016).

As for employees’ feedback, it was positive as well. They noticed that equipment is easy and comfortable to wear, it is convenient to have free hands all the time and AR smart glasses allowed them faster easier operation. They also noticed that it is good to see all information available in one place and that it improved their team work in multi-operational environment (“Vision Picking” in the Warehouse - Augmented Reality in Logistics 2015; DHL makes augmented reality a standard in logistics, 2017). Mr. Gilbert also added that “staff is really impressed” (Fink, 2017). Ubimax additionally claims that technology had high acceptance rate among employees (DHL rolls out global Augmented Reality program 2016).

Figure 43. Handheld and smart glasses picking productivity. Source: DHL

DHL reported to continue AR research in logistics operations and that they were open for collaboration with new partners (“Vision Picking” in the Warehouse - Augmented Reality in Logistics, 2015). In 2016 after successful deployment of technology in Netherlands they stepped out from exploration stage to the next step in smart picking program on a global scale in USA, Mainland Europe and the UK (deployment period - summer 2016). (DHL rolls out global Augmented Reality program 2016).
In 2017 it was reported that DHL deployed vision picking in more warehouses worldwide and established vision picking for the long run, making it a new standard and replicable technology in intralogistics operations, which easy to implement in a “plug-and-play” manner and that brings significant benefits via productivity, speed and accuracy, suitable both for single and multi-order picking. International trials showed 15% rise in productivity and overall higher accuracy, as well as 50% less onboarding and training times for new employees with learning-by-doing approach. (DHL supply chain makes smart glasses new standard in logistics, 2017; Vision Picking Driving Innovation for Modern Supply Chains). Such advantages are especially valuable on such high-competitive industry as logistics.

Figure 44. DHL vision sorting. Source: DHL Global Technology Conference 2015

DHL also created marker-based AR environment with marker cubes for vision sorting (figure 44). Sorter took item from a conveyor and scanned it with Epson Moverio smart glasses. Then, digital instructions showed with arrows where exactly to put the scanned item, increasing accuracy and time (DHL Global Technology Conference 2015).

7.4 Things to consider

In DHL case they used external battery because smart glasses could not stand the whole shift without additional power supply. And indeed, in table 4 there are some AR-devices battery life examples and it is obvious that devices cannot work for the whole standard warehouse shift (≈8 hours) without extra external power bank or spare battery. System is also dependable of IT support and stable connection with other systems, and strong data protection. Additionally, employees with certain eyesight problems may have difficulties with smart glasses. Moreover, there are
some discussions regarding safety issues of such devices on human’s health in terms of almost every day and several hours per day usage. As wireless device, smart glasses have SAR (Specific Absorption Rate - at which human body absorbs RF energy), which is within the allowed limits, but many consider dangerous to have effects similar to phone emission near head for several hours. Allowed SAR rate is 1.6 W/kg (over a volume containing a mass of 1 gram of tissue, US FCC limit), and 2.0 W/kg (averaged over 10 grams of tissue, council of the EU limit). For head for instance, Vuzix M300 SAR 1g (W/kg) is 1.0687, and Vuzix Blade maximum detected SAR was 1.49 W/kg (M300 Smart Glasses FCC Statement; Vuzix Blade FCC Statement). For comparison, for head SAR Apple iPhone X is 1.08 W/kg and Samsung Galaxy S10 is 0.39 W/kg, so in some cases it literally means to have working cell phone near head during the whole time.

8 Conclusion

It was noticed that pressure on logistics and especially on intralogistics fields increasing, it is impacted mostly by increase in trade volumes and e-trade consequences (the “Amazon effect”) that changing shopping patterns. Customer demands are also changing, becoming more strict and zero-tolerable for mistakes and in terms of high competition high service level becomes essential for business viability. Along with these changes it is natural that warehouse decision-makers are highly interested in technology deployment for their premises. Among all technologies wearables are a major interest area for them because these devices support labor-intensive operations, and workforce is in charge for major part of operations’ efficiency.

Mixed reality has a potential, it is used mostly for remote maintenance, but such devices are still not well-tailored for most important warehouse needs. Virtual reality has limited area of use due to independency of real world and impossibility to see virtual and operating environments simultaneously, but is still have good place in training processes and as well as mixed reality, it has potential to gain more applications over time. It was seen, that AR is an absolute winner for applications: most applications are for picking, but it can be applicable in each operation from receiving to dispatch where real-time connection with management system can
provide further instructions and accept changes in their status. Moreover, AR can take over other XR applications: it is capable of remote maintenance assistance and training, and together with all other capabilities and application areas it can be a multi-tool for effective intralogistics premise functioning. Indeed, logistics, as a main AR-smart glasses consumer and not without a reason. Over brief history AR showed itself as a device with pure enterprise origin, designed to help employees with their tasks, and despite AR devices are changing and developing, the main initial purpose and function has remained the same. Additionally, smart glasses provide best information perception – visual, they are more advanced than other wearables for warehouse operations (VDH, scanners) and provide more information and interaction.

Facts, numbers and figures in enterprise sector reflect good position of AR and high interest of industry in this technology in today’s state and predict significant market increase in the future, especially concerning smart glasses. AR has a huge potential and promising applications due to fast pace of certain supporting technologies and such companies as DHL have envision of AR applications in intralogistics in the future.

Operations with smart glasses prove their worth: it is possible to cut off most “waste” activities in warehouse and implementation cases show that additionally to all said before, the main improvements due to smart glasses usage are also the following:

- Overall increase in productivity, efficiency and accuracy;
- Less time spent on walking and searching due to digital tips and instructions, WMS updates instantly and there is no need to travel to floor computer and input data manually;
- Less training time because smart glasses can be some sort of “instructor” whom always possible to ask (request by voice) certain videos, instructions and guidance. If needed, it is possible to establish connection with manager and vividly report about unclear situations;
- Can be tailored for each employer specific needs, depending on their skills;
- Better workforce management because it is possible to track remotely performance and overall productivity;
- Safety: both hands are free, easy to grab items and no distractions on the screen or other devices;
- Considered as most advanced wearable;
- Green policy: less papers used.
Warehouses are located in majority parts of supply chain and each of these can become a very dangerous bottleneck that jeopardizes whole efficiency and mistakenly can put orders in a new loop from customer back to distribution center and some steps within premise have to be started again. Picking can be considered as a most costly and labour intensive activity within supply chain, so it has to be controlled most, and smart glasses as main AR enterprise wearable, can provide this opportunity.
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