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How Disruptive Start-Ups Change the World of Warehouse Logistics

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Purpose: New technical solutions in logistics change the ways of working within warehouses on different levels, from warehouse layouts and concepts of goods picking to process planning and human resources. Thus, disrupting the previous practice in its core.
Methodology: In order to evaluate the impact of the new technologies on the warehouse operations, the multiple case study approach was used. To gain a deeper understanding of the changes within logistics processes, the results of the deep-dive analysis are summarized using morphologic box methodology.
Findings: Presented solutions such as AutoStore, Kiva and CarryPick can lead to a substantial increase in the speed of order picking while staying very flexible and demanding significantly less of expensive warehouse space. Still, the implementation of these technologies requires a systematic approach with clearly stated goals.
Originality: In contrary to available papers which are concentrating on a single case study with application of one technology at one particular company, the presented paper analyses several solutions comparing them with each other. Additionally, the research evaluates the impact of the technologies on logistic processes and warehouse layouts. Thus, creating value for practitioners looking for solutions to optimize intralogistics.

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1 Introduction

Due to the rapid development of e-commerce in the last decade (Statista, 2020b; a), the customer orders became small-sized, low-volume, but more frequent (Battini et al., 2015). Thus making "classic" picking operations, immensely dependent on manual labor (de Koster, Le-Duc and Roodbergen, 2007) and initially created for high-volume B2B picking, highly inefficient and cost-intensive. According to researchers the picking process is the most costly activity in the warehouse and can be responsible for up to 55% of warehouse expenses (D'Souza, Costa and Pires, 2020; de Koster, Le-Duc and Roodbergen, 2007).

Another challenge is increasingly low availability of workers for warehouse operations (BCG, 2014), which inevitably leads to the rise in salaries and thus, warehouse costs.

The rise of digitalization can be used to achieve the positive effects in logistics (Kersten et al., 2015), especially applying robotics for the support of warehouse personnel can lead to higher productivity in combination with lower costs (Robotics Business Review, 2020; Bonkenburg, 2016).

The main aim of this paper is to present short use cases and evaluate available technical solutions for the improvement of picking processes in times of e-commerce growth and personnel scarcity. Thus, supporting warehouse companies in decisions on the application of robotic solutions at their companies.

2 Methodology

To provide a clear structured information on different technologies and thus, creating a basis for further ana-lysis the method of a case study was chosen. According to Boer (2015) case research belongs to one of the most compelling research methods in operations, especially in the design of original theory. He argues that with recent fast developments in technology, researchers should rely more on field-based research methods. Other researchers (Ketokivi and Choi, 2014) add that some of the "breakthrough concepts and theories" (i.e. lean production and servitization) in operations were evolved from case studies. In other disciplines such as management and sociology case research is already acknowledged method and is broadly applied to study organizational behavior and strategy, perform ethnographic and anthropology studies (Karlsson, 2016, p.166).

In recent years case study as a research method gained recognition from experts in operations research. The Journal of Operations Management (JOM) stated in its mission “highest priority is thus given to studies that are anchored in the real world” (Karlsson, 2016). Additionally, researchers (Ketokivi and Choi, 2014; Boer et al., 2015; Yin, 2018) underline that results of a good case study can result in remarkably high impact.

Visualization of the main results was performed using the method of the morphological box, which main advantage is a presentation of different alternatives at the same time (Blecker et al., 2004; Koch, 2015).

The methodology consists of three main steps (Schawel and Billing, 2011) :
Step 1. Problem definition (s. chapter 3).
Step 2. Possible solutions (three case studies described in chapter 4).
Step 3. Evaluation of solutions based on defined dimensions and scores (as presented in chapter 5.1).

3 Problem Definition

Today's warehouse logistics is confronted by following main trends:

Growth of e-commerce sales. According to Statista (2020a)big e-commerce companies has grown substantially from 2009 to 2019, Amazon (worldwide) from 24,51 to 280,52 billion USD and Zalando (German e-commerce company) from 6 million to 6,48 billion USD. The study of DHL confirms that such rapid growth can only be achieved with appropriate warehouse capacities and optimization of all logistics processes (Bonkenburg, 2016).

Customer expectations. Amazon has pushed the expectations of the customers to the limits of possible, promising them next- or even same-day delivery (Bechtsis et al., 2017), putting competitors and warehouse logistics under strong performance pressure (Füßler and Boysen, 2017; Robotics Business Review, 2020).

Labor force shortfalls are predicted by BCG (2014) and based on the demographic risk would cause a considerable deficit of workers (in Germany, the shortage would be around 10 million workers by 2030). Since the "classic" order picking processes are highly dependent on the human workforce, they will suffer under a lack of personnel on the market.

Industry 4.0, digitalization or Internet of Things, which is connecting the processes, machines and even products in (near)-real-time enabling decentralized autonomous decisions (Wagner and Kontny, 2017) as well as adding flexibility and robustness to the system (Monostori, 2018).

The trend of digitalization, on the one hand, puts additional pressure on the companies to improve their processes, systems and spend money on technology in times of economic uncertainty (Feldt, Kontny and Wagenitz, 2019). On the other hand, it can provide solutions to the predicted labor deficit (Bonkenburg, 2016), enabling a high level of customer satisfaction through fast deliveries allowing companies to profit from the e-commerce growth. An additional argument for the implementation of digital solutions in warehouse logistics is the distribution of worker's time, which is according to De Koster (2007; 1999) in "classic" order picking process is shaped by walking and searching (around 70% of total work hours) while picking itself takes only around 15% of the time (s. figure 1). Although there are some robots on the market which could replace the picking part of the process, as described by researchers (Kohl et al., 2019; Mester and Wahl, 2019; Schwäke et al., 2017; Rieder and Verbeet, 2019), presented paper is focused on technologies for replacement of the walking and searching part of the process.

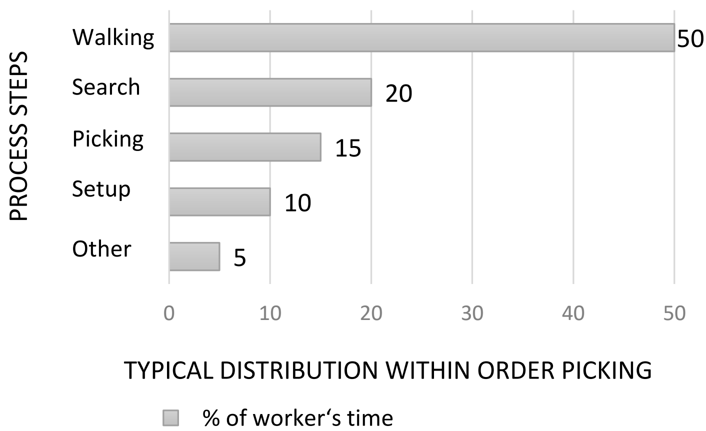

Figure 1: Time distribution within order picking process (according to de Koster, Le-Duc and Roodbergen, 2007)

According to the Robotic Business Review (2020) currently, there are over 50 warehouse automation companies with an overall revenue of 13 billion USD in 2018 with a predicted growth to 27 billion USD by 2025. To compare the automated solutions with the "classic" order-picking process, the focus was narrowed to the following technologies:

- Kiva systems, which were bought by Amazon and renamed to Amazon Robotics[1].
- CarryPick KMP600 AGV from Swisslog and KUKA.
- AutoStore as the most space-efficient goods-to-person storage systems (AutoStoreSystem, 2020).

The reasons for the choice as well as the case description of each technology are described in the respective chapters below.

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[1] Since Amazon Robotics contains more than just Kiva systems which are in focus of the research, we will continue to use the term Kiva systems in the paper.

4 Case Studies

4.1 Kiva Systems

In the year 2012, Amazon acquired a start-up company called Kiva Systems, a robot manufacturer, for 775 million USD (The New York Times, 2012). This way, Amazon has differentiated itself from other e-retailers and enabled fast deliveries within one or two days.

The main focus of the KivaSystems is to bring goods to the workers as in contrary to the initial person-to-goods concept, saving up to 10 miles per worker per day and up to 50% of workers time (D'Andrea, 2012). Thus, at that point in time, the KivaSystems used a highly innovative approach to the order-picking process supported by the new technology of autonomous mobile robotics (AMR).

As presented in figure 2, the KivaSystems needs less warehouse space due to narrow gangways and saves at least 50% of picking time of a warehouse worker, since it works

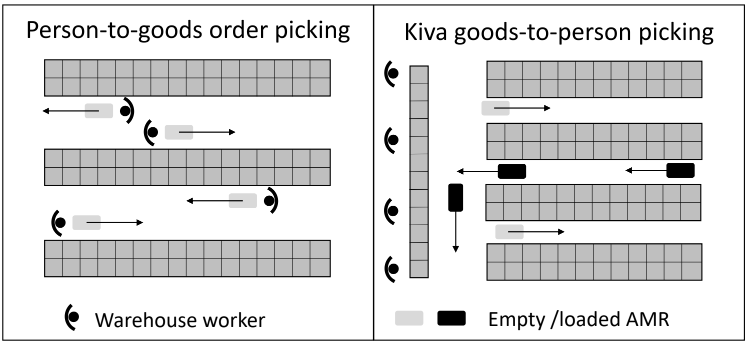

Figure 2: Classic order picking vs Kiva picking

based on a goods-to-person concept in contrary to time-consuming person-to-goods order picking. Due to the reason that Amazon uses KivaSystems exclusively and even renamed it into AmazonRobotics, next product which is available for any company will be evaluated in the next chapter.

4.2 CarryPick

CarryPick system was created for the warehousing and picking operations and can be applied in small or big-size warehouses due to its scalability. Similar to Kivasystem, CarryPick is based on goods-to-person picking concept, uses AMRs (automated mobile robots) to bring racks with goods to warehouse workers. Additionally, a worker is supported by "pick-by-light" technology which allows saving time for the search of the right product (which according to de Koster (2007) takes up to 20% of the overall picking time).

CarryPick system consists of mobile racks, AMRs, workstations for pickers and a warehouse management software for autonomous process steering; thus, the structure of the solution is very similar to the KivaSystems.

One of the most interesting features of the system is its ability for growth. If needed, additional AMRs can be added to an existing system in combination with additional racks for goods storage. Thus, making the system scalable, which is indispensable in times of strong and fast e-commerce growth. According to Swisslog (2020b), the whole racks structure is very efficient and is up to 300% better than a conventional rack system (s. fig.2).

Still, there is even more space-efficient system available, such as AutoStore, which contains no space between racks and can be build up to 5,4 meters high (AutoStoreSystem, 2020) in contrary to 2,5 meters CarryPick racks (Swisslog, 2020a). Thus, using the warehouse space in the best possible way.

4.3 AutoStore

AutoStore system consists of plastic bins, which can be filled with a single product or have up to 36 compartments with max. total weight up to 30 kg (AutoStoreSystem, 2020). The bins are stored in up to 24 different levels (AutoStoreSystem, 2020) in a system and can be transported by robots, which are moving on top of the rack system as shown on fig.3 and can "dive" in order to get the bin (as shown on the right side of fig. 3). The robots are quite fast, they move with a velocity of 13 km/h, which allows them to bring the bin to the "ConveyorPort" from any point of the warehouse within approx. 2 minutes.

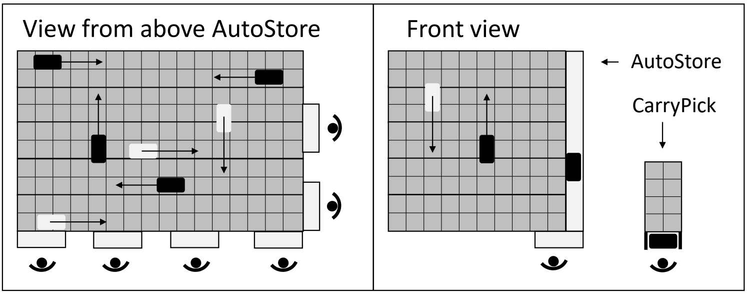

Figure 3: AutoStore view from above and from the front

The workers pick the goods from a bin at ConveyorPort and are additionally supported by pick-by-light and weight control systems. On the right side of figure 3, the difference between CarryPick and AutoStore is visualized and demonstrates the difference in height at AutoStore and thus, even more efficient use of cost-intensive warehouse space. On the other hand, AutoStore is limited to the products with maximal measurement of 649x449x425mm and weight of around 30kg (AutoStoreSystem, 2020).

Since most products which are sold online are still fitting in these constraints, AutoStore can easily be applied for e-commerce. If needed, the combination of both systems can be applied, due to their scalability and flexibility. The comparison of the systems is provided in the next chapter.

5 Results and Discussion

5.1 Morphologic Box

In order to evaluate different technologies and compare them with "classic" order-picking processes, the methodology of the morphologic box was chosen (as described in chapter 2). The scenarios of Kiva and CarryPick were evaluated as one since the differences between them are rather insignificant in comparison to other technologies. The dimensions for the evaluation are based on feedback from industry experts and the importance of those dimensions for the implementation as well as during the whole period of warehouse operation.

Due to the reason, that same value in different dimensions can have the opposite meaning, i.e. low investment in hardware or low personnel cost are rather positive while a low number of picks per hour or low scalability are negative, the dimensions were evaluated on efficiency. For example, low efficiency in warehouse space means that the technology demands extensive warehouse space. At the same time, low efficiency in picks per hour means that the productivity of the technology is lower than the productivity of the technology with high efficiency. This approach allows evaluation under a common denominator, uncomplicated assignment of scores (1 point for low, 2 for medium and 3 for high efficiency), and homogeneous visual mapping.

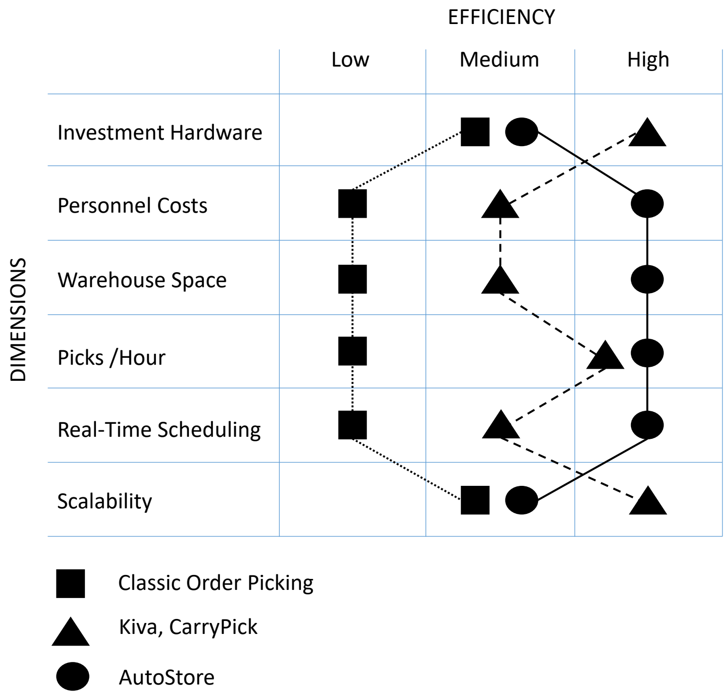

Figure 4: Analysis of Technologies Based on Efficiency in Six Dimensions

As shown in the figure above the "classic" order-picking processes are least efficient; they achieved only 6 out of 18 possible points. Although investment in hardware such as forklifts and warehouse racks could be evaluated as a medium; the high personnel costs, high usage of expensive warehouse space combined with low productivity (due to the extreme long ways up to 10 miles per worker per day for picking goods) as well as inflexible scheduling and thus low flexibility lead to inefficient processes. Considering the fact that e-commerce customers expect their orders to be delivered the next day, and the operations need real-time scheduling which would allow scheduling the customer orders for picking the same day. Otherwise, the order would be picked earliest next day, unnecessarily increasing the duration of the delivery.

Scalability is another crucial dimension of today's warehouse operations. Due to the constant growth of e-commerce each year by approx. 9%, companies need to regularly increase their warehouse capacities, building additional warehouse space, buying hardware, and hiring personnel.

The Kiva and CarryPick technologies demand lower investment in hardware in comparison to the "classic" system, have lower personnel costs (the workers are concentrating on a picking part of the process without "running"). Additionally, those technologies demand less space, due to the reason that the robots move below the racks in comparison to the forklifts which need their fixed "streets". The number of products which could be picked per hour is substantially higher than in "classic" process since in the "classic" process around 2/3 of the time are spent by running through the warehouse while looking for the right storage rack.

Moreover, real-time scheduling allows adapting the schedule for the day to the incoming customer orders, thus, providing additional flexibility to the process. The scalability of the systems is rather high. Hovewer additional robots and racks can cause re-routing of the robots to prevent the situations of the traffic jam as well as mutual lockdown by robots (Füßler and Boysen, 2017). Applying the score system described above, the CarryPick robots earn 15 out of 18 points.

The AutoStore system needs slightly higher investment in the hardware due to higher prices of the racks, which have up to 14 levels in comparison to rather low racks of Carry Pick. For the same reason, the scalability of the

AutoStore under consideration of the required investment is medium, since its efficiency is lower than in case of expansion of CarryPick system. Personnel costs in AutoStore scenario are the lowest, since the workers receive the highest possible support from the automation, thus increasing the number of picks per hour.

At the same time, AutoStore is the most space-efficient way of goods storage, due to the absence of any space between the shelves. Not only the movements of robots are scheduled in real-time modus, but also the customer orders can be translated in picking orders in (near)-real-time modus if needed, making this technology the most flexible and fast. Due to the above reasons, the system was evaluated with the highest score of 16 out of 18 points.

Although new technologies provide substantially higher efficiency to order-picking processes, they also have some limitations in their application, which need to be considered and are described in the next chapter.

5.2 Application Limitations

Despite the numerous advantages of the CarryPick and AutoStore technologies, they have some limitations for their application based on their technical data.

AutoStore can only be used for the products with volume in the same or smaller size as an AutoStore bin (AutoStoreSystem, 2020). Similarly, CarryPick and Kiva systems have restrictions on the volume of the products, although their volume is substantially higher than in AutoStore (based on a rack length and width in comparison to a size of a bin).

Still, even here, products with high-volume, such as furniture or bikes, which can be sold online, cannot be picked by CarryPick. On the other hand, such high-volume products have, as a rule, different delivery conditions (so-called two-man-handling) and would be sent separately to the small-size orders.

For example, if a customer orders a garden table and decoration to it in the same order in the same online store, he would receive two deliveries: one as a small package delivered by parcel company such as DHL or DPD and the other delivered by a truck company such as Kuehne+Nagel. For that reason, high-volume products can have separate handling in the warehouse and will not disturb high-automated processes of handling of the small and medium volume products.

Due to the above limitations in the application, it is recommended for the companies to perform an analysis of their current product structure and then to decide on the most appropriate system or a combination.

5.3 Discussion of Results

Application of new technologies leads to changes in different areas of warehouse logistics, such as:

Warehouse layouts. On the one hand, the expensive warehouse space can be utilized more efficiently using CarryPick or AutoStore technology, thus promising fast returns on investment. On the other hand, the warehouse layouts need to be re-planned, dividing the areas for human workers from the areas where only robots should move.

Concepts of goods picking. Since the "classic" concept of person-to-goods causes low productivity and is incredibly inefficient(de Koster, Le-Duc and Roodbergen, 2007), it would be replaced on a long-term by the concept of goods-to-person, where robots support warehouse workers by bringing them goods for picking (D’Souza, Costa and Pires, 2020).

Process planning. Reactive scheduling of orders in (near)-real-time modus would completely replace schedu-ling based on demand planning. Although demand planning processes are essential for the strategy of the company, they cannot be applied for the real-time scheduling of picking orders based on same-day customer orders. Thus, the planning processes would become decentralized and autonomous (Feldt and Kontny, 2020).
Human Ressources. Arising technologies such as CarryPick and AutoStore allow reacting to the increasingly low availability of the warehouse personnel (BCG, 2014), at the same time providing existing workers with more human-friendly work environment than initial order-picking systems, thus ma-king the job of warehouse workers more attractive.

5.4 Limitations of the Study and Recommendations for Further Research

Although during the research period different scenarios for the application of CarryPick and AutoStore were elaborated for an e-commerce company in Hamburg, including evaluation of the investment costs and impact of new technology on processes, the results cannot be presented here due to the signed non-disclosure agreement. Thus, limiting the presentation of results to the qualitative analysis.
For this reason, the authors can recommend other researchers to perform applied research on the topic of disruptive start-ups with innovative technological solutions in order to provide demanded support for the practitioners in the area of warehouse logistics.
Additionally, cooperation between practitioners (i.e. e-commerce companies or technology providers) and resear-chers is highly recommended. The researchers can support the practitioners with independent and unbiased

(in comparison to commercial providers) results while benefiting from the experience of the company experts. Thus, creating valuable benefits for the participants on both sides.

6 Conclusion

This study contributes to the topic of warehouse logistics in times of e-commerce growth by providing a multiple case study with evaluation of technology systems. Presented morphological box provides practitioners with the dimensions which should be taken into consideration for choice and (re-)design of order-picking warehouse systems. In combination with the description of main trends for the next ten years, it can reveal new perspectives on the operations and motivate companies to invest their financial resources in the same manner as Amazon and Zalando who has shown considerable growth in past years.

Additionally, it must be said that there is no technology which would fit best in every scenario. While looking for a proper solution, a company should perform an analysis of the own data (i.e. product structure, available warehouse area) prior to the investment in one technology over the other. In some cases, the combination of two or three technologies can be most beneficial.

Furthermore, the current development trends, such as tremendous growth of e-commerce, which was accelerated even further by the COVID-19 restraints as well as the expected shortage of the warehouse workers in the next years should be taken into consideration by companies.

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