The transformation from manual to smart warehousing: an exploratory study with Swedish retailers

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Abstract

Purpose – To meet customers' expectations on shorter lead times, high product availability, flexibility, and variation in delivery and return options, retailers have turned their attention to warehousing and are making big investments in technology. Currently, technology providers are pushing for smart warehousing, a new and under-researched phenomenon. This study aims to conceptualize the term and examine pathways toward implementing smart warehousing.

Design/methodology/approach – An exploratory survey was administered to 50 leading Swedish retailers in varying segments. A two-tailed *t*-test for equality of means was used to detect significant differences between current and future states.

Findings – The study found that future smart warehouses will be automated, autonomous, digital, and connected, but that retailers will follow different paths along this journey, driven by contextual trends, e.g. sales growth, wider product assortment, shorter lead-time offerings, and integration of brick-and-mortar and online stores. Interestingly, the study revealed that many of the retailers that aim to create smart warehouses in five years are not the retailers with the most developed technology today.

Research limitations/implications – The paper operationalizes smart warehousing in two dimensions: degree of automation and degree of digitalization and connectivity of information platforms. Based on the findings, 16 theoretical propositions are put forth that, based on contextual factors, explain different pathways for retailers to implement smart warehousing.

Practical implications – The empirical insights and theoretical discussions provide practically useful guidance, including outlined trends, for selecting and benchmarking automation and complementary technologies in warehouse operations.

Originality/value – This paper conceptualizes and operationalizes smart warehousing – an original approach. It is also one of the first to investigate the technological transformation in retail warehousing empirically, explaining how and why retailers choose different pathways toward smart warehousing.

Keywords Retail, Logistics, Warehouse, Automation, Technology, Smart, Context, Transformation

Paper type Research paper

1. Introduction

The retail industry has been undergoing a digital transformation coupled with customers' expectations of shorter lead times (i.e. demanding same-day delivery), high product availability, flexibility when and where to shop, and varying delivery (e.g. click-and-collect, pick-up points, home delivery) and return options (Galipoglu *et al.*, 2018; Tokar *et al.*, 2020). To meet these demands, the logistics network, particularly the warehouse, has been highlighted as a critical component (Kembro *et al.*, 2018). The warehouse, previously viewed as a "necessary evil" in the supply chain, now plays a key role in fulfilling customer orders and significantly influences both logistics costs and service levels (Faber *et al.*, 2018). As Rouwenhorst *et al.* (2000, p. 515) put it: "[T]he efficiency and effectiveness in any distribution

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network … is largely determined by the operation of the nodes in such a network, i.e. the warehouses."

To improve warehouse operations, online global giants, e.g. Alibaba and Amazon have made large investments in automated material-handling technology (Alibaba Cloud, 2019; Amazon, 2020). With increased competition and more mature and varied technologies, the automation trend also has spread among retailers and logistics service providers worldwide (Reiser, 2020; MH&L, 2020). An important driver is that the latest generation of automation technologies offers flexibility to handle different types of products and adjust to demand variations, enabling effective and efficient storage, handling, and sorting of large product flows (Azadeh *et al.*, 2019; Kembro *et al.*, 2022). To improve warehouse operations further, retailers couple automated material handling with digitalization and connectivity of information platforms. Examples of new technologies that are relevant for warehouse operations include artificial intelligence (AI), Internet of things (IoT), cyber-physical system (CPS), big data, 5G, and intelligent video analysis (IVA) (Kembro *et al.*, 2017; Kamali, 2019; Taboada and Shee, 2021; Winkelhaus and Grosse, 2020; Chung, 2021).

This combination of technologies sometimes is termed *smart warehousing* (Mahroof, 2019; Kamali, 2019), a term that is gaining increased attention, often in connection with Industry 4.0, Logistics 4.0, and IoT (Lee *et al.*, 2018; Winkelhaus and Grosse, 2020; van Geest *et al.*, 2021; Issaoiu *et al.*, 2021). It is used in tech blogs, industry reports, conference proceedings, and scientific journal papers. However, extant smart-warehousing research is fragmented when it comes to its substance (see, e.g. Bolu and Korcak, 2019; Chung, 2021; Zhang *et al.*, 2021). Previous research has instead listed or developed sub-applications of smart technologies that could be used. This gap is important to address to bring research together, facilitate joint discussions, and enable analysis of patterns on a more holistic level, instead of focusing only on specific applications of certain technologies. Another important research gap is the lack of clarity on how to implement smart warehousing (Azadeh *et al.*, 2019; Winkelhaus and Grosse, 2020; van Geest *et al.*, 2021). During the journey toward smart warehousing, companies operate in different contexts and, therefore, are likely to follow different paths (Kembro and Norrman, 2021). However, extant research does not provide any guidance or explanation for different pathways on how and why retailers calibrate their timing, technology, and focus to suit certain operations during their transformation from manual to smart warehousing.

To address these gaps, this study aims to conceptualize *smart warehousing* and explain pathways on how to implement it. By administering an empirical exploratory survey to 50 Swedish retailers, we make several contributions. Theoretically, we contribute by operationalizing smart warehousing in two dimensions – degree of automation and degree of digitalization and connectivity of information platforms – and by conceptualizing future smart warehouses as automated, autonomous, digital, and connected. We also contribute by identifying different pathways to smart warehousing and explaining how retailers calibrate their timing, technology, and focus to suit certain operations using 16 theoretical propositions. For managers, our study outlines pioneering practices that can help other retailers understand critical issues earlier, as well as how to address them. Our findings provide insights into technologies that are expected to grow in use and criticality to support material handling in single warehouses and in increasingly complex and decentralized networks.

The paper is structured as follows. In Section 2, we present a theoretical background on warehouse operations in retailing and technology's role in warehouse management. In Section 3, we describe our empirical study's design. In Section 4, the findings are presented and analyzed, describing how companies intend to transform from manual to smart warehousing. In Section 5, based on our findings, we submit theoretical propositions, then conceptualize smart warehousing and explain pathways. Finally, in Section 6, we outline conclusions and suggestions for future research.

2. Theoretical background

2.1 Warehouse operations in retailing

Warehouses represent "the points in the supply chain where [the] product pauses, however briefly, and is touched" (Bartholdi and Hackman, 2016, p. 3). In the retail context, warehouses primarily are used to consolidate and store a range of products to reduce transportation costs and lead times. Different types of retail warehouses include the distribution center (DC), online fulfilment center (OFC), and micro-fulfilment center (MFC). Warehouse operations include receiving, put-away, storage, picking, sorting, packing, and shipping. Along with managing increases in online orders, warehouses also might handle returns and cross-docking, in which goods move directly from receiving to shipping (Kembro *et al.*, 2018).

In a warehouse, arriving products are checked for quality, registered, and potentially re-packed before being put away in assigned storage locations (Frazelle, 2016). Storage, which includes a reserve and picking area, typically is divided into zones, depending on stock-keeping unit (SKU) characteristics (e.g. size and temperature requirements) and/or order characteristics (e.g. online orders vs store replenishment) (Eriksson *et al.*, 2019). SKUs can be dedicated or randomly assigned to a location. A common approach is to combine the two (also termed *class-based storage*), i.e. SKUs are placed randomly within a dedicated area, thereby reducing travel while avoiding congestion (Gu *et al.*, 2007). Picking comprises most of the operational cost and has been by far the most-researched warehousing topic. Picking efficiency can be improved by putting the fastest-moving products in the most convenient locations (Gu *et al.*, 2007) and by selecting appropriate picking methods. The four most common picking methods are single, batch, zone, and wave (Bartholdi and Hackman, 2016). Kembro and Norrman (2019) described the SKU extraction method as one "which implies that a large number of customer orders are accumulated, and the picker only goes to one or a few storage locations and (manually) takes out hundreds of the same SKU to a trolley or pallet. These products are then moved to a sorting system" (p. 521). Eventually, orders are packed and shipped. If an order involves multiple flows (e.g. wave picking or cross-docking), the first step is to sort and merge the various order lines per customer and destination. SKUs are registered thereafter for departure and positioned based on the designated gate and time window (Bartholdi and Hackman, 2016).

To improve warehouse operations' efficacy and efficiency, several configuration aspects are considered, including physical layout (e.g. placement of docks, aisle configuration, and lane depth) and storage and handling equipment (e.g. racks and forklifts for put-away and picking) (Kembro *et al.*, 2018). Important resources also include labor management (e.g. scheduling, rotation, and shifts) (De Leeuw and Wiers, 2015), information systems (e.g. warehouse management systems [WMS] and warehouse-control systems [WCS]) (Kembro and Norrman, 2019), and automation technologies, e.g. conveyors and robots (Baker and Halim, 2007; Azadeh *et al.*, 2019). These configurations' goal is to improve utilization of resources and capacities (labor, space, and equipment), increase throughput, reduce material-handling time, and increase operations and design flexibility (Kembro and Norrman, 2019). However, which warehouse configuration to use depends on a range of contextual factors (Hassan *et al.*, 2015; Faber *et al.*, 2018; Eriksson *et al.*, 2019; Kembro and Norrman, 2021), e.g. order-fulfillment time requirements, assortment range, number of transactions, and sizes of goods.

2.2 Technology's role in warehouse management

Just a decade ago, warehousing worldwide predominantly were manual operations, but increasing competition and expectations on shorter lead times (demand for same-day delivery), high product availability, and a variation of delivery and return options have necessitated improvements to transform from manual to smart warehousing (e.g. Chung, 2021; Kembro and Norrman, 2021; Zhang *et al.*, 2021). As described below, this transformation mainly involves technology, e.g. automated material handling and information systems.

2.2.1 Automated material handling. Warehouse automation has been around for many years. Defined as "the direct control of handling equipment producing movement and storage of loads without the need for operators or drivers" (Rowley, 2000, p. 38), it includes equipment, e.g. automated storage and retrieval systems (AS/RS), automated guided vehicles (AGVs), and conveyorized sorting systems. Positive aspects of warehouse automation include improved space utilization and service, as well as lower operating costs and reduced picking errors. However, it requires significant investments, and more static automation technologies may involve flexibility risks, e.g. during extreme demand peaks (Baker and Halim, 2007; Kembro and Norrman, 2020). Therefore, these investments require careful analysis, considerable scale, and a long-term vision (De Koster, 2018).

In recent years, retailers have increased the pace of implementing automation in warehouse operations, and various new technologies are being tested to make material handling more effective and efficient (Kembro and Norrman, 2020). Azadeh *et al.* (2019) conducted a comprehensive review of recent developments in various automation technologies in warehousing, identifying the following categories: Crane/Automated Forklift (e.g. AS/RS, push-back rack); Carousels and Dispensers (e.g. horizontal carousel, A-frame); Shuttle (aisle-based, e.g. horizontal AVS/R system; grid-based, e.g. robotic compact storage and retrieval systems); and AGVs (e.g. movable racks in robotic mobile fulfillment systems). One interesting development is the increased flexibility in automation technologies, with different solutions available for different SKU characteristics, while it is also less difficult to adjust to demand variations. It is also relevant to consider whether humans will work in warehouses in the future and what their role will be. Azadeh *et al.* (2019, p. 940) noted that: "Human picking in collaboration with AGVs is one of the most recent technologies that is becoming popular in practice because of its simplicity and flexibility."

2.2.2 Digitalization and connectivity of information platforms. Simultaneously, retailers develop information systems to manage and control their warehouse operations. As Kembro and Norrman (2019) asserted, the three most common systems include enterprise resource planning (ERP) systems; WMS; and WCS. ERP connects information across a range of organizational functions, e.g. sourcing, inventory management, production planning, and financial matters. WMS is used for shorter-term planning and control of resources and order fulfilment for various warehouse operations. WCS is used to control automated systems, e.g. robots and advanced sorting algorithms. A related system is the warehouse execution system (WES), which synchronizes various automation technologies' operation with workers and could be viewed as an integration or combination involving WMS and WCS. Several other systems besides these also exist, e.g. for labelling, administering, and transport administration system (TAS). With the increasing importance of sharing real-time inventory and order information, both internally and externally, it becomes vital for all systems within each warehouse and across the logistics network to be integrated. For this purpose, Kembro and Norrman (2019) noted that retailers increasingly use a distributed order management (DOM) system.

2.3 The transformation toward smart warehousing

Smart warehousing is a term that is gaining increased attention, often in connection with Industry 4.0, Logistics 4.0, and IoT (see literature reviews in Winkelhaus and Grosse, 2020; Chung, 2021; Issaoui *et al.*, 2021). The term has not been defined precisely, but generally has been described as something more than using automated material handling and traditional information and communication technology (ICT), e.g. ERP, WMS, and WCS. Chung (2021, p. 1) defined smart technologies as "applications of artificial intelligence and data science technologies, e.g. machine learning, big data, to create cognitive awareness (autonomous) of an object with the support of information and communication technologies, e.g. IoT and blockchain." Previous research often either has listed different smart technology applications

(Winkelhaus and Grosse, 2020; Chung, 2021; Issaoui *et al.*, 2021), developed focused algorithms (e.g. Jiang *et al.*, 2021), proposed IoT-based WMS (Lee *et al.*, 2018; Aamer and Sahara, 2021), or referred to architectures for information systems related to data collection and administration (Jabbar *et al.*, 2018; van Geest *et al.*, 2021).

Several studies have used *smart warehousing* to describe a warehouse that includes a combination of automated material handling and AI. For example, Bolu and Korcak (2019) discussed smart warehouses in terms of automation technologies that make warehouse robots and systems smarter, including autonomous robots that perform most activities in a warehouse, as well as information systems that keep track of every object's movement in the warehouse. Mahroof (2019) noted that these robots carry out most warehouse work, have Wi-Fi capabilities, and use self-charging batteries and laser-detection technology. Mahroof (pp. 178–179) concluded that "the new automation age is here, whereby industrial robots and computers are being used beyond their traditional scope of performing highly accurate repetitive tasks, routine physical work tasks, through to more complex tasks that require cognitive capabilities, e.g. making tacit judgments, sensing emotion, and driving processes which previously seemed impossible." Along the same lines, Zhang *et al.* (2021) investigated Alibaba's smart warehouses, which use a set of AI applications, along with collectively working robots and other related human and organizational resources, to improve key business processes' efficiency and efficacy. The researchers noted that while humans focus on higher-value tasks that require creativity, robots and AI are used to execute repetitive, time-consuming, and/or hazardous tasks. With WMS, WCS, and AGVs as foundational systems, AI uses algorithms as building blocks to automate, augment, or transform processes. Examples of algorithms include sales forecasting, location recommendation, 3D packing, order wave combination, route planning, robot scheduling, and robotic motion control.

Extending this perspective, Kamali (2019) described the smart warehouse as using a mix of technologies, including, e.g. robotics systems, IoT, radio-frequency identification (RFID), enterprise asset management (EAM), and digital twins with 3-D representations of objects and their components, e.g. sensors. Other relevant technologies include wide area network (WAN), cloud computing, automatic identification technology, CPS, and blockchain. Kamali argued that AI allows for gaining unprecedented insight into products, components, and even materials' life cycles, noting that smart warehouses make activities more efficient, save on labor costs, reduce errors, and generate higher productivity. Thus, the automation and AI focus is complemented (e.g. Lee *et al.*, 2018; Kamali, 2019; Issaoui *et al.*, 2021) by adding (inter) connectivity in terms of IoT and wide area networks/cloud for information management. Some studies have developed frameworks for WMS in the IoT context (Lee *et al.*, 2018; Aamer and Sahara, 2021) or reference architectures (Jabbar *et al.*, 2018; van Geest *et al.*, 2021). Another relevant technology is IVA, which enables advanced analytics and decision making in real time in the warehouse (Kembro *et al.*, 2017). Using a mix of technologies is supported by Attaran (2020), who pointed out that AI and robotics, cloud computing, 3D printing, advanced analytics, blockchain, AR, RFID, IoT, and cloud technology drive digital trends and elicit change in supply chain management. Similar reasoning can be found across tech blogs and suppliers. For example, Flytware (2021) stated: "Smart warehousing is essentially a set of interconnected and/or automated technologies for streamlining warehousing operations in an efficient manner." The connectivity dimension links the warehouse as part of a digital network, pointing to the growing importance of Industry 4.0, digitalization, and a unified platform for multiple device connectivity in real time, which can be implemented through 5G networks (Taboada and Shee, 2021). Another aspect sometimes stressed is robot autonomy (Winkelhaus and Grosse, 2020; Chung, 2021; Jiang *et al.*, 2021).

To sum up, smart warehousing is receiving increased attention in both practice and academia. but extant research is fragmented, with no consensus reached on a definition of *smart warehousing*. Previous research instead has listed or developed sub-applications of smart technologies that could be used. This literature gap is important to address to facilitate discourse and create a common understanding of what smart warehousing is. As a starting point, our literature review revealed two smart warehousing dimensions: the development of automated material handling and development of digitalization and connectivity of information platforms. The review also revealed that pathways toward implementing smart warehousing are missing. Previous studies emphasized contextual factors' importance, suggesting that companies may follow different paths. However, extant research has not provided any guidance or explanation as to how and why retailers calibrate their timing, technology, and focus to suit certain operations during their transformation from manual to smart warehouse management.

3. Research design and method

This study aimed to grasp and generate practically relevant insights and theoretical propositions about a new phenomenon – smart warehousing – on which current knowledge is scarce concerning both the current situation and future developments. By illuminating this area for consideration, we seek to influence the definition of its problem domain, leading to contributions of the "theoretical pre-science" type (Corley and Gioia, 2011).

For this, we used an exploratory survey (distinguished from explanatory and descriptive research). It is useful for becoming more familiar with a topic and identifying new possibilities and dimensions of interest (Malhotra and Grover, 1998), as well as identifying interesting patterns during the early stages of the research-maturity cycle (Malhotra and Grover, 1998; Edmondson and McManus, 2007), rather than testing a theory-driven hypothesis. The study is theory-elaborative and tries to adapt theory to contemporary practices and challenges (Corley and Gioia, 2011; Ketokivi and Choi, 2014). Therefore, conducting an exploratory survey is appropriate for revealing trends, interesting patterns, and facets of the phenomenon with the purpose of developing propositions for future research studies. In this way, exploratory surveys (conducted with experts in the field) are similar to case studies and other qualitative methods, which also are useful for discovering new facets of phenomena under study (Forza, 2002). Exploratory surveys have been used in supply chain and operations management research before, e.g. related to information systems: Themistocleous *et al.* (2001) examined problems related to ERP systems, and Kembro and Norrman (2019) investigated omnichannel logistics issues. These studies applied more open-ended research questions in combination with closed-ended survey questions using ranking or Likert scales.

3.1 Data collection

This study is the first part of a larger study, the Swedish Retail Logistics panel, in which Swedish retail companies (pure-play online retailers, henceforth referred to as *e-tailers*, as well as retailers with both online and brick-and-mortar stores) have been invited to participate in a series of exploratory surveys. The retailers were identified through addresses from different databases and listings of leading Swedish retailers (e.g. related to growth or turnover), e.g. the report "Who is who in Swedish retail 2020" (Lindecrantz, 2020). Altogether, 50 retail companies provided input for this study (out of 300-plus companies who were sent invitations). The retailers represent a wide range of retail sectors and product types (see Table 1; respondents could provide multiple answers). The major retail sectors, currently at the forefront of online sales, are well-represented by their leading companies in the survey. Most of the retailers that are part of the panel are top-five (Sweden) in their segments based on turnover.

Our empirical data collection is based on an online survey. The respondents were senior supply chain/logistics managers divided between the following positions: 37 directors (or

Retail sector/Product category	Sum	Share of all given product category
Fashion (clothes, shoes)	12	14%
Furniture and home decoration	8	10%
Jewelry, watches, optics, etc.	8	10%
Department store/market place (large mix of assortment)	8	10%
Consumer electronics	7	8%
Cosmetics and beauty	7	8%
Toys	6	7%
Sport and leisure (incl. car accessories/spare parts)	5	6%
Building materials/services, tools, working clothes, DIY	4	5%
Drugs and nutrition, etc.	4	5%
White goods and kitchen appliances	4	5%
Books	3	4%
Flowers and garden	3	4%
Grocery	2	2%
Music	1	1%
Office supplies	1	1%
Total	83	100%
Sectors per retailer	1.66	

Table 1. Retail sectors and product categories in the panel

heads) of supply chain management/logistics/operations; one CEO; four warehouse managers; five managers responsible for development/design of logistics and/or warehouse solutions; one innovation lead; one head of e-business; and one head of an online store. The survey was pre-tested on five company representatives to test the questions' general appropriateness, functionality, and structure. The feedback was used to modify the survey instrument, mainly by increasing clarity in survey questions and explaining terminology. The respondents were asked to use a perceptual Likert scale ranging from 1 ("agree to a very low degree") to 7 ("agree to a very high degree") to assess their current focus and development in different areas. To address the limitations of scales in an exploratory study, most questions that included statements with fixed-scale alternatives were complemented with open-ended questions to explore alternative answers on the specific topic.

The main survey questions focused on the following issues: (1) company data and contextual factors, e.g. size, turnover, type of products, type of channel, assortment range, and lead-time offerings; (2) to what degree the companies invest in and use automation in warehouse operations – both in general and for different material-handling processes; (3) to what degree companies use technologies (other than automation) in the warehouse, e.g. regarding information platforms and connectivity. The respondents were asked to list and explain their three main focus areas related to the implementation of warehouse automation. Some questions included pre-determined answering alternatives, e.g. different types of technologies (with clarifying examples to reduce the risk of misunderstanding). We used many different sources to develop the survey questions, including scientific literature (discussing warehouse operations in retailing, warehouse automation and technology, and smart warehousing and technologies) and gray literature, e.g. business journals and tech blogs. We also scanned the market to understand more about automation technology and smart warehousing that either already exist or are being developed. As we initially looked for responses from both very small e-tailers (with large growth) and larger traditional and omnichannel (i.e. integrated store and online) retailers, we defined scales using a logarithmic approach to illustrate the large difference between potential answers regarding company data and contingency factors.

3.2 Data analysis

With an exploratory aim and too few respondents to conduct advanced statistical analysis, we described patterns in the participants' perceptions of current and future practice. We were inspired by multiple case study analyses (see, e.g. Miles and Huberman, 1994), with the aim of developing propositions for future research by pattern-matching data from open-ended and closed-ended questions. The same set of questions was used for both current and future states, and to detect significant differences in any context, we used a two-tailed *t*-test for equality of means.

To support the formulation of theoretical propositions about different pathways toward smart warehousing, we analyzed the data based on different contextual factors. First, we clustered the data based on channel strategy (with today's share of retailers stated): e-tailing (may include showrooms) (26%); partly integrated multichannel (both physical stores and online sales, but separated or only partly integrated channels) (50%); omnichannel (high degree of integration of store and online channels) (16%); and store focus, without (or locally store-driven) online sales (8%). Interestingly, our data indicate a strong trend (in five years) toward implementation of an omnichannel strategy among the panel retailers. Retailers selling only offline decreased (which is not a surprise), while store-driven online sales increased. Another observation is that e-tailers continued to focus on online sales and, with one exception, did not plan to open physical stores. The other contextual factors that we focused on in our analysis included turnover, assortment range, and sizes of goods.

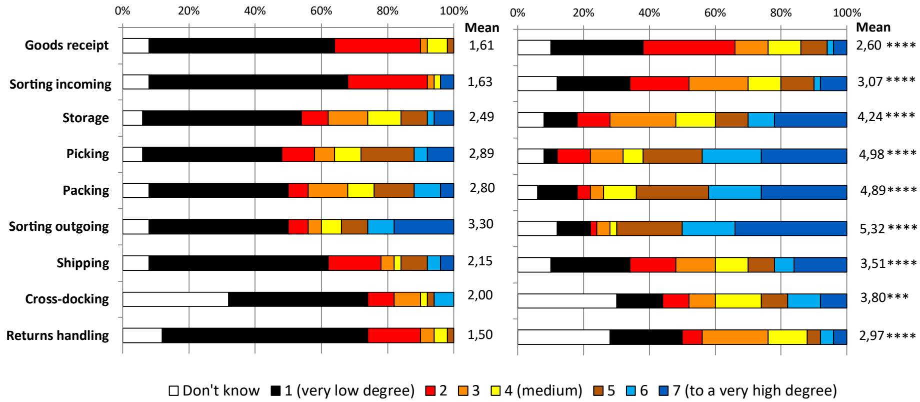
4. Findings and analysis

To understand how Swedish retailers intend to transform from manual to smart warehouse management, we examined current trends and future intentions on several aspects. We present these findings in the following sub-sections and use them to develop 16 theoretical propositions.

4.1 Overall degree of automated warehouse operations

The study indicated an increased willingness to invest in automation, with retailers making large investments (>SEK 100 million annually), more than doubling such expenditures (8–22%), while those investing SEK 31–100 million annually increased such expenditures from 12 to 22%. Retailers not investing at all in automation decreased from 32 to 8%, indicating a statistically significant (see *t*-tests in Appendix) and a strong increase in the overall degree of automation (in the warehouse with the most recent investment). On a scale from 1 (very low degree) to 7 (very high degree), the mean values increased from 2.07 (five years ago) via 3.15 (at present) to 5.13 (in five years). The retailers represented four clusters. The first group of retailers made large investments in recent years, but currently focuses on fine-tuning automation technology (e.g. by supplementing it with other technology). The second cluster has not yet automated to a large extent but intend to invest significantly in automated systems in the coming years. A third group represents retailers who already have made significant investments and continue to invest heavily in warehouse automation in their logistics networks. The fourth cluster, which is decreasing in number, represents retailers that have not and do not intend to automate their warehouses.

The degree of automation was analyzed on a deeper level, related to different warehouse operations (Figure 1). The operations that have been automated to a greater extent represented outbound flows. Above all, "sorting outgoing goods" (average 3.30) stood out, while picking (2.89) and packing (2.80) also were higher, indicating that the most labor-intensive processes were automated first to justify return on investment. The focus on sorting also reflected the increased extent, variety, and complexity of sorting at the operational



Note(s): Asterisks indicate significance mean difference with T-test: ^$p < 0.1$, *$p < 0.05$, **$p < 0.001$, ***$p < 0.0001$, ****$p < 0.00001$

Figure 1.
Degree of automation per process, today and in five years ($n = 50$)

material-handling node level (Kembro *et al.*, 2022). However, on the scale from 1 to 7, values below 4 still indicated a low degree of automation. The operations that currently are automated to a very low degree (thereby still requiring a greater share of manual work) are goods receipt (1.61), sorting of incoming goods (1.63), and handling returns (1.50). These flows included a wide variety of goods and requirements for quality control before storage. It is also important to determine the storage zone and balance incoming flows to avoid bottlenecks. Previous research (e.g. Kembro and Norrman, 2019) has indicated that retailers often position their most experienced staff in goods receipt.

Five years from now, a significant increase (see *t*-tests in Appendix) in automation is expected, with several operations expected to average above 4.00 (storage 4.24, picking 4.98, packing 4.89, and outgoing sorting 5.32), indicating a clear trend toward a relatively high degree of automation (i.e. not only an increase, but also an increase to a relatively high level). Despite current low levels, the trend toward a higher degree of automation for incoming goods is interesting. Insights from a previous study (Kembro and Norrman, 2019) indicate that automation of inbound processes requires greater work and coordination with suppliers, e.g. standardizing boxes/labels and balancing flows handled in warehouses (to avoid bottlenecks). It also seems that retailers want to try to make return handling more efficient, with some retailers stating that "automation of return flows is one of our top-three focus areas for technology in warehousing."

Analyses of individual retailers and the number of warehouse operations that one has stated as highly automated (response alternatives 6–7 on a scale of 1–7) in five years provide additional insights (Table 2). Twenty percent of the retailers answered that they will have automated five or more operations to a very high degree. Of these, many will have automated most of the warehouse operations to a high degree, and some even plan to use a fully automated warehouse. Altogether, 44% indicated that they will automate one to four operations significantly. Simultaneously, many retailers (38%) have not specified any of their operations as being highly automated, indicating that a high demand for manual work will remain in warehouses, but this differs between different retailers.

Thus, we put forth the following proposition:

P1. The more labor-intensive the processes, the higher the priority for retailers to automate. This implies that retailers begin by automating outbound picking, packing, and sorting (and related storage), followed by shipping and cross-docking to focus ultimately on inbound receipt, sorting, and handling returns.

4.2 Contextual factors' influence

To understand differences between the retailers, we first analyzed the data based on channel strategy. This analysis revealed that today's omnichannel retailers automated early (most indicated values 4–7 already five years ago), while e-tailers and retailers with partially integrated multichannels caught up by increasing the degree of automation sharply for the past five years. Retailers with a store focus remain at a low level. On a more detailed level, future omnichannel retailers, to some extent, will lead automation of incoming goods (receipt of goods, sorting of incoming goods, storage). E-tailers, to some extent, have less "cross-docking" compared with other retailers (which is logical considering that incoming pallets and cartons must be broken down for picking for e-customers). Instead, to a greater extent, they have invested in "sorting outgoing goods." The greatest uncertainty (answer alternative "do not know") applies to cross-docking and return handling, which, in itself, is an interesting observation.

Second, we analyzed the retailers' turnover. Most of the retailers in the panel (94%) currently have a turnover larger than 100 MSEK (~10 MEuro), of which 36 (72%) sell more than one billion SEK (100 MEuro). Two of the retailers are global giants and sell over 100 billion SEK (~10 billion Euro). Thus, relatively large retailers (rather than medium-size and small companies) dominate the panel. In five years, both the smaller and larger retailers plan quick growth. The analysis indicates that retailers with low turnover tend not to automate, which is in line with the large capital/investments required for automation. We noted a correlation between high turnover and high degree of automation (Figure 2). An interesting observation is that medium-size companies presently have a relatively low degree of automation, but the tendency is that they are taking a big leap in five years.

Third, we analyzed assortment range, which generally continues to increase. Partially integrated multichannel retailers have driven this development (of which most aim to be highly integrated omnichannel retailers within five years). Altogether, 68% of these retailers will have an assortment range larger than 30,000 articles. The analysis indicates that retailers with a relatively small assortment tend to maintain a low degree of automation throughout their warehouses, while those with a larger assortment range (which are dominant in the study) increase their degree of automation the most (Figure 3).

Fourth, we analyzed sizes of goods (Figure 4). Presently, this mainly entails handling very small (0–1 liter) and small (1.1–50 liter) goods with automation. In five years, the trend is toward a significant increase in all sizes of goods (with the smallest for bulky, i.e. goods that do not fit on EUR pallets), with high averages for very small/small goods (5.60/5.39). Automated handling of medium-size goods (51–200 liters) also has been increasing (from 1.94 to 3.38). For large goods (>200 liters, which can fit on EUR pallets), a significant increase was found, but still at a generally low level. Among the answers were several "Do not knows,"

Number of highly automated processes	Number of retailers	
9	1	Total 10 retailers
8	0	
7	1	
6	4	
5	4	
4	5	Total 21 retailers
3	7	
2	5	
1	4	
0	19	

Table 2.
Number of highly automated processes per company five years ahead

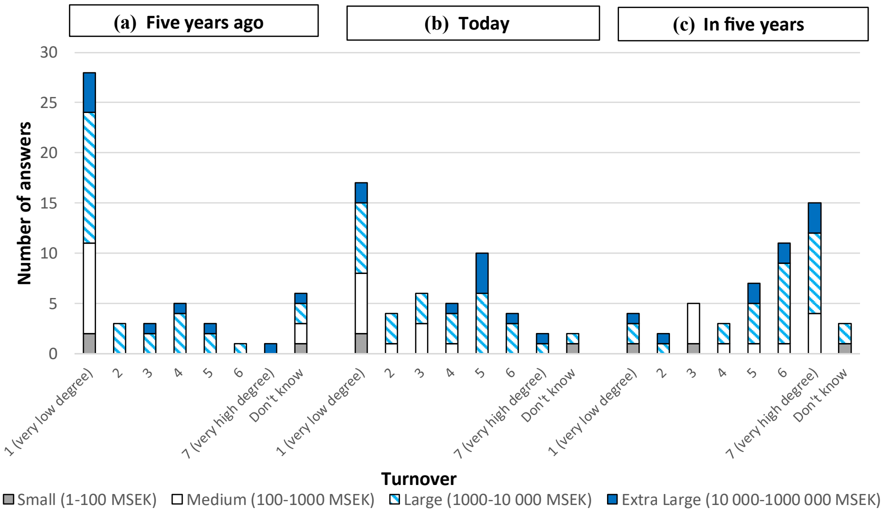


Figure 2. Overall degree of warehouse automation over time, related to turnover

which, in this case, also represent "not applicable," a question that is not relevant to the retailer if it does not handle goods of this size in its warehouses.

Thus, we put forth the following propositions:

P2a. Omnichannel retailers increased automated handling of large and complex order and goods flows early, but as other retailers catch up on their investments, channel strategy will have less explanatory value on the overall degree of automation.

P2b. The larger the turnover and assortment range, and the smaller the sizes of the goods, the more retailers invest in automation technology to improve material handling throughout the warehouse.

4.3 Choice of automation technology for material handling

Another interesting aspect is the choice of automation technology for material handling (Figure 5). We observed generally rare use (Answer Option 1) of most examined automation technologies, but some stood out and are significantly more common than the others: stationary automated sorting systems (3.50); stationary automated storage and retrieval (AS/RS) (2.93); compact/grid-based storage (3.12); and automated packaging systems (2.88). Interestingly, for these technologies, the situation is *dipolar*, i.e. retailers did not use them at all or rarely. This is explained through our analysis: Some automation technologies tend to be chosen for a certain context (e.g. product characteristics), while others are used more generally among retailers. For storage and picking, companies mainly choose an automation technology depending on goods/flow characteristics: Omnichannel retailers with a mix of goods and order characteristics (e.g. both store replenishment and online) typically choose stationary AS/RS storage, while e-tailers typically choose compact/grid-based storage (e.g. AutoStore) to handle large assortments of relatively small goods (e.g. clothes) that individual online customers order. Retailers that handle piece-pick-intense online orders (i.e. large volumes of small goods) opt for A-frame automatic dispensers. Simultaneously, there tends to be a more general approach in terms of automation of packaging, weighing, dimensioning, sorting, and palletizing of outgoing goods (though mainly retailers with store networks use automatic palletizing).

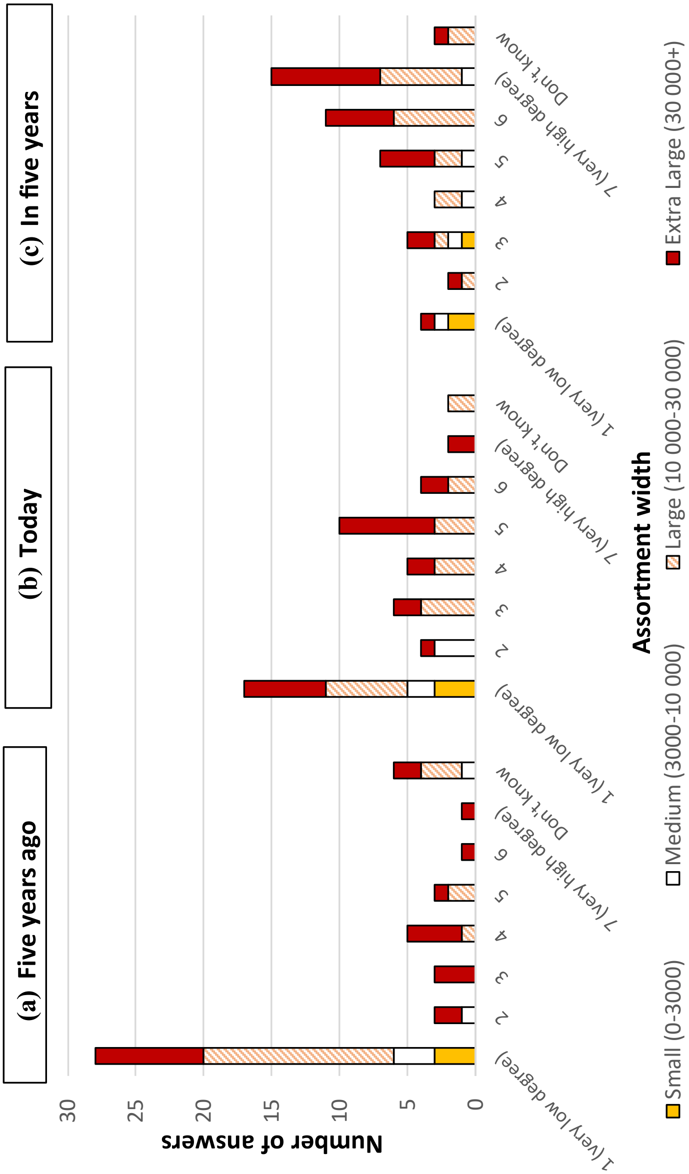
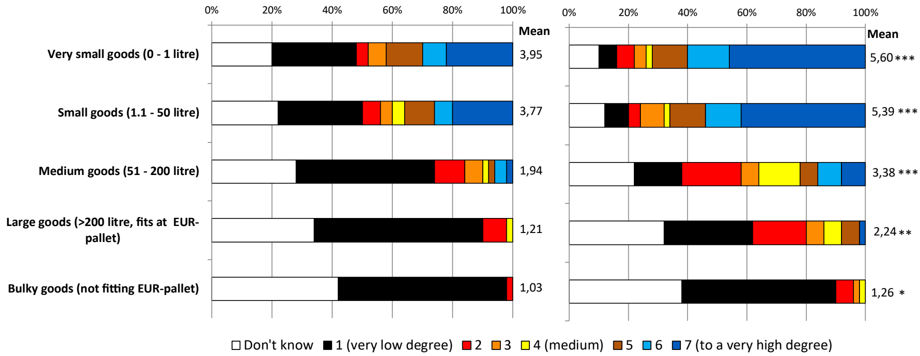


Figure 3.
Overall degree of warehouse automation over time, related to assortment range



Note(s): Asterisks indicate significance mean difference with T-test: ^$p < 0.1$, *$p < 0.05$, **$p < 0.001$, ***$p < 0.0001$, ****$p < 0.00001$

Figure 4. Automation of different sizes of goods, today and in five years

In five years, use of most of these automation technologies will increase, a pattern in line with the current situation observed. We detected significant increases (*t*-test; see Appendix) in stationary automated sorting (5.06), automated packaging (5.06), compact/grid-based storage (4.56), cubing (4.91), robotic palletizing (4.41), stationary automated storage and retrieval (3.72), A-frame systems (2.58), robotized piece-picking (2.25), automated guided vehicles (2.34), and self-driving flexible forklifts (2.00). Several technologies reached over 4.00 (average), and most are *dipolar*, i.e. while some retailers are strong advocates (blue), others will not implement such technology at all (black/red). This implies that retailers will opt for different technologies as they automate material handling in their warehouses. However, the future is not as dipolar as the current situation (the color scale is more gradual). One possible explanation is that when retailers' warehouses (e.g. turnover and assortment ranges) grow, they must handle a larger mix of orders, flows, and goods, with more varied characteristics. Thus, retailers introduce multiple zones and may benefit from using a mix of different technologies (e.g. one technology designed to handle smaller goods in one zone and another technology tailored for larger goods in another zone).

Thus, we put forth the following propositions:

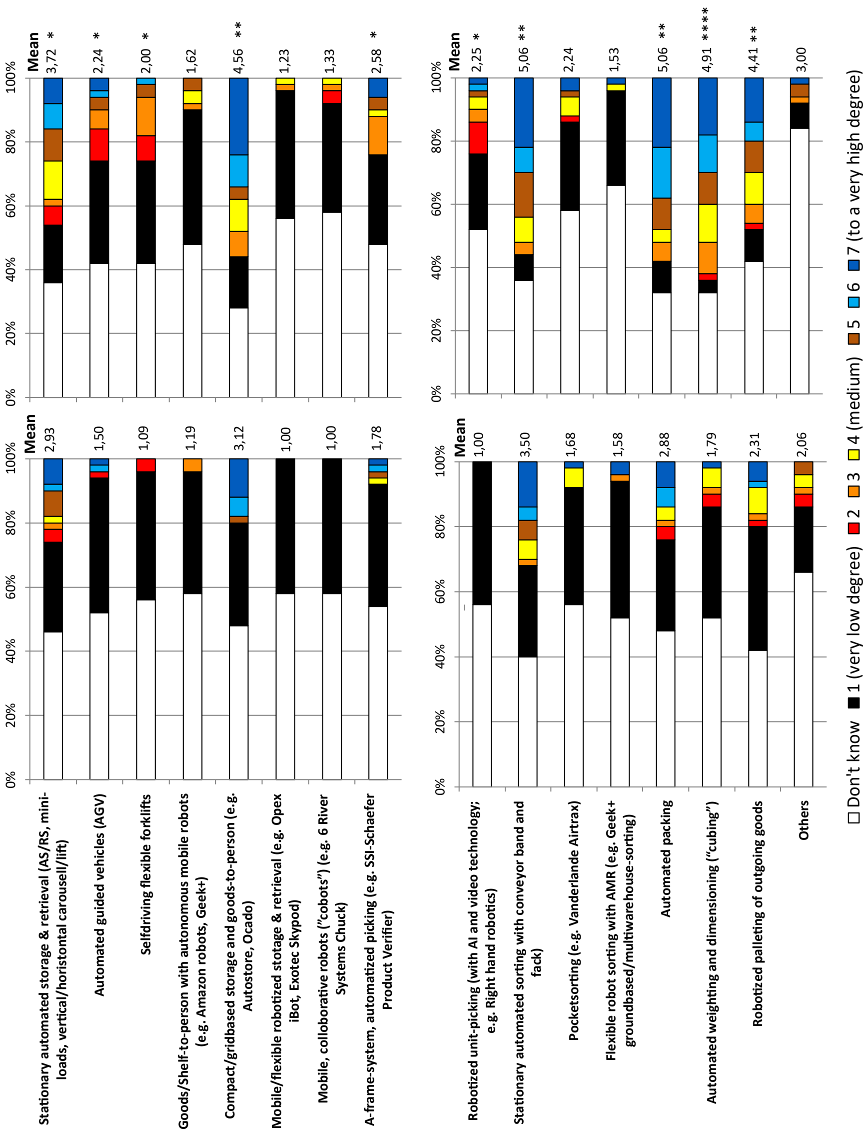
P3a. The less a warehouse activity is influenced by contextual factors – which mainly applies to inbound and outbound due to more standardized processes and handling units – the more standardized automation technologies are used to improve material handling.

P3b. The more a warehouse's activity is influenced by contextual factors – which mainly applies to storage and picking adjusted to, for example, SKU and order characteristics – the more tailored the automation technologies used to improve material handling.

P4a. The larger the assortment of relatively small goods, the more retailers automate by using compact/grid-based storage and goods-to-person technology to improve space utilization and increase efficiency of storage and retrieval activities.

P4b. The higher the volume of small goods for individual customers, the more retailers automate by using A-frame technology to reduce costs and lead time for piece-picking activities.

P4c. The higher the volume of mixed goods and integrated channels, the more retailers automate by using stationary automated storage and retrieval technology to increase space utilization, and the greater the efficacy and efficiency in handling large throughputs of more varied order and product flows.



Note(s): Asterisks indicate significance mean difference with T-test: ^$p < 0.1$, *$p < 0.05$, **$p < 0.001$, ***$p < 0.0001$, ****$p < 0.00001$

Figure 5.
Choice of automation technology for material handling, today and in five years

An interesting observation is that many retailers choose static, rather than flexible, automation technologies mainly for storage, picking, and sorting. This may mean less leeway to change and adapt automation technologies in the future – particularly considering that retailers are making very large investments now and that the future budget for major changes may be limited. Thus, this trend could mean that automation/warehousing, to a greater extent, will dictate conditions in the future (e.g. setting boundaries or creating opportunities) for changes in product assortment, logistics networks, and overall logistics strategy. If retailers invest in scalable and flexible solutions, it may be easier to grow with acquisitions, add more varied store formats, or create more flexible offerings and a wider variety of products. From a historical perspective, large investments in (static) automation technologies were made in the early 2000s, influencing later strategic decisions related to, for example, the designing of networks and warehouses to handle increasing numbers of online orders.

There might be many different reasons why retailers choose static, rather than (new) flexible automation technologies. One potential explanation is that the new generation's flexible solutions have not reached the level of technological maturity required for wider implementation. In this case, only "innovators" and a few "early adopters" currently are jumping on the bandwagon Similarly, there may be a lack of sufficient and clear business cases that document the performance of the new generation's flexible solutions. There also may be a lack of reputable suppliers who offer (market, develop, and maintain) these new flexible technology solutions. Current well-known providers of more static automation technologies (which are increasing in use) might have built up strong credibility, developed contact networks, and succeeded in presenting and selling more static solutions convincingly. Finally, investments in automation often are based on plans that have been developed for many years. Thus, several of the retailers' plans were launched before the new generation of automation technologies became available. To sum up, retailers waiting for automation can access a new generation of more flexible automation technologies, but it remains to be seen how these technologies stand up to proven automation systems. Thus, we put forth the following propositions:

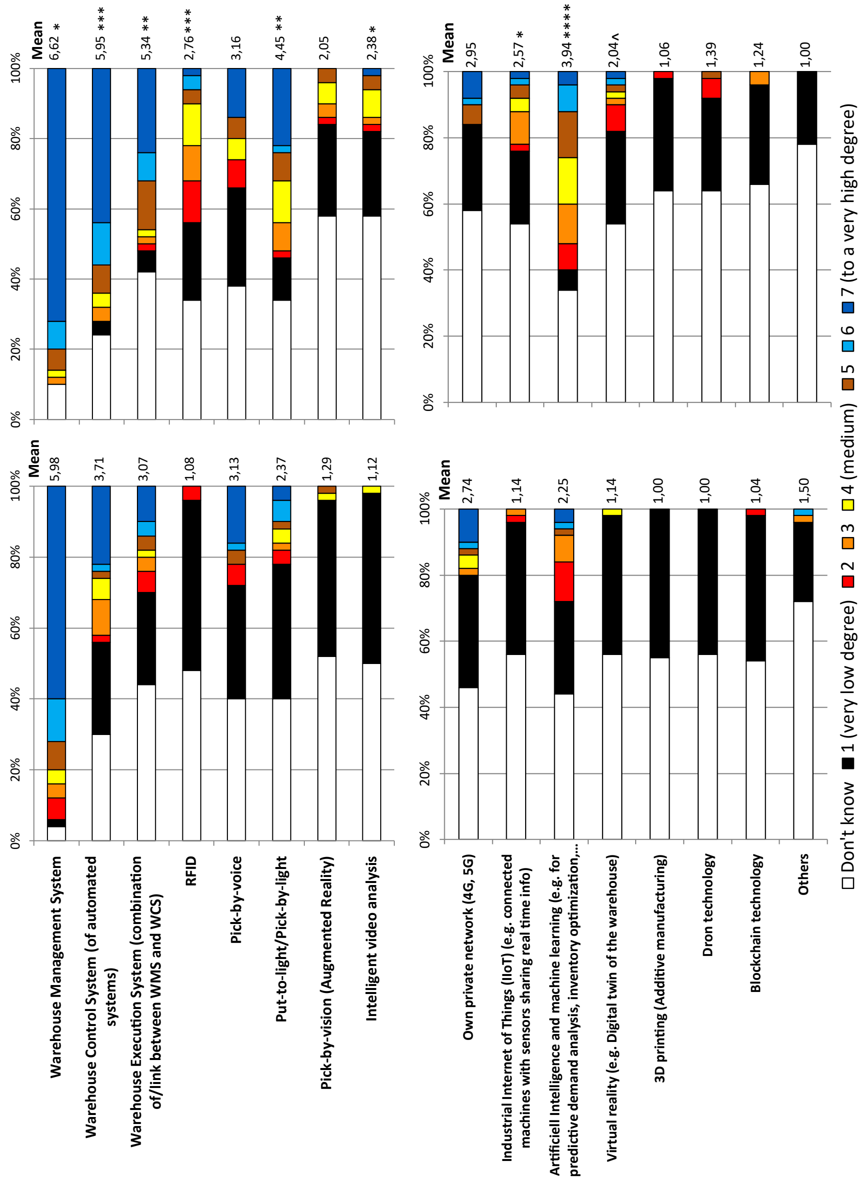
P5a. Investments in static automation technology for storage, picking, and sorting reduce a retailer's ability to adapt warehouse operations to future contextual changes, e.g. reduced customer order lead times and wider variety of product offerings.

P5b. Today's large investments in static automation technology for storage, picking, and sorting imply that warehouse operations to a greater extent may dictate conditions for changes in product assortment, logistics networks, and overall logistics strategy decisions.

4.4 Complementary technologies in warehouses

The survey also examined other technologies that complement automated material handling (Figure 6), e.g. those related to digitalization and connectivity. Today, WMS is used frequently (average 5.98) and is viewed, more or less, as standard for controlling and managing daily operations in warehouses. Corresponding with WMS, WCS (3.71) and WES (3.07) are used to control and coordinate a variety of processes and automation. In addition to these, pick-by-voice (3.13) and pick-by-light/put-to-light (2.37) are used to some extent.

Digitalization and connectivity technologies, e.g. private networks (4G, 5G) and AI, are used to a small extent (2.74 and 2.25, respectively). However, some individual retailers have invested to a large extent and may be viewed as pioneers. Relatively speaking, more e-tailers than omnichannel retailers submitted high values (6, 7) for WMS, WCS, WCE, private networks, and AI. Today, other technologies are not used at all in principle, including RFID



Note(s): Asterisks indicate significance mean difference with T-test: ^$p < 0.1$, *$p < 0.05$, **$p < 0.001$, ***$p < 0.0001$, ****$p < 0.00001$

Figure 6.
Other complementary technology used in warehouses, today and in five years

technology (1.08), pick-by-vision (1.29), and IVA (1.12), nor are other hyped technologies used, e.g. the IoT, digital twins, drone technology, or blockchain.

The trend in five years indicates that WMS (average 6.62), WCS (5.95), and WES (5.34) will become the backbone of warehouse management, with large significant increases in WCS and WES. Strong future trends also indicate significant increases for several technologies that humans use to strengthen workers' abilities, e.g. to pick faster or reduce picking errors (so-called "human augmentation"), including put-to-light/pick-by-light (4.45), pick-by-voice (3.16), and pick-by-vision (2.05). The increasing use of these technologies indicates that there still will be human workers in the future who conduct material-handling activities (particularly picking) in warehouses. The sharp rise in use of put-to-light/pick-by-light partly points to the importance of faster labor with lower error rates.

Technologies that support data management, connectivity, and real-time analysis are also on the rise. Despite generally lower use among companies, the trend indicates significant increases in intended use of primarily AI (3.94), IoT (2.57), RFID (2.76), and IVA (2.38), with small increases in private networks (2.95). Many of the e-tailers indicated plans for future implementations. However, a large proportion of the retailers answered "Do not know," which can be interpreted to mean that new technologies involve a certain amount of uncertainty regarding function and usefulness. Another interpretation might be that they are not well known at all among respondents today. Thus, we put forth the following propositions:

P6a. WMS, WCS, and WES represent the backbone of warehouse management, whereas hyped technologies – e.g. RFID, IoT, drone technology, and blockchain – will play a limited role in warehousing in the years to come.

P6b. The bigger the focus on online customers, the more retailers invest in technologies that support data management, connectivity, and real-time analysis.

5. The pathway toward smart warehousing

Building on our findings and analysis, we sought to understand to what degree smart warehousing was a tendency or trend among the panel's retailers. With support from the literature, we used survey data to operationalize two dimensions: (1) degree of automation and (2) degree of digitalization and connectivity of information platforms. Degree of automation focuses on automation of material handling, i.e. the handling of physical goods. Examples include stationary automated storage, compact/grid-based storage, A-frame systems, automated sorting systems, and automated weighing and dimensioning. Degree of digitalization and connectivity of information platforms focuses on technologies for handling, analysis, and coordination of information and includes, for example, WMS, WCS, WES, AI, IoT, and private networks.

For each dimension, we summarized the number of technologies (per dimension) for each retailer, in which a high degree of implementation was indicated (Values 5, 6, and 7). We then plotted this value for each retailer in Figure 7, indicating each company's current position (yellow square) and its intentions in five years (red circle). Automation of material handling is illustrated on the *Y*-axis, with degree of digitalization and connectivity of information platforms on the *X*-axis. As previously described, several retailers increased automation of material handling (moving upward along the *Y*-axis). Simultaneously, many retailers are investing in information platforms and increased digitalization (moving to the right). As the gray arrows illustrate in Figure 7, the overall trend is that the technology frontier moves diagonally upward to the right, implying that retailers to varying degrees are investing in both automation technologies and information platforms, representing a general tendency toward an intentional technological shift in retailers' warehouses over the next five years.

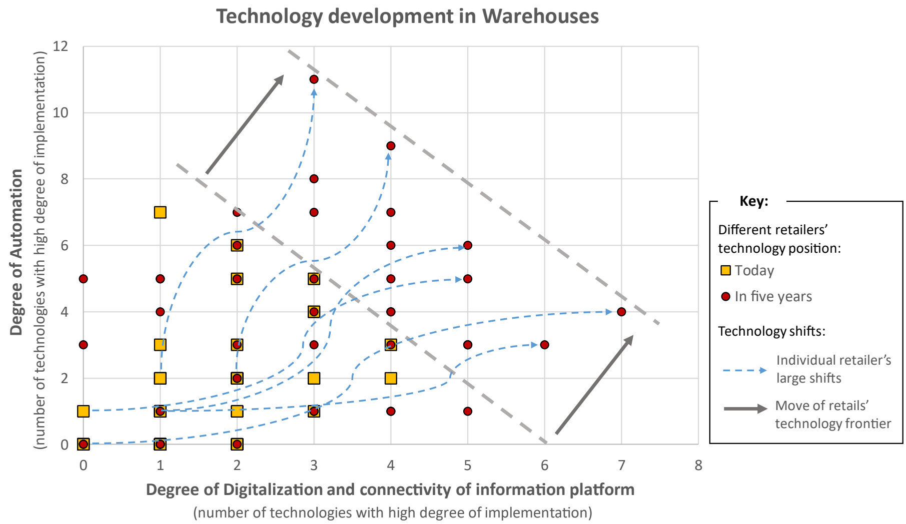


Figure 7.
Technology shifts in retailers' warehouses over the next five years; several retailers may hide behind the same point in the chart

We conducted additional analyses of the individual retailers' movements. Interestingly, the retailers that perceive themselves as having smart warehouses in five years are not the retailers that are most automated or digitalized today. Instead, several retailers are planning major technological upgrades over the next five years, i.e. moving from having limited technology in warehousing to being at the forefront of development toward smart warehousing. We illustrated this technology shift with four retailers' movements (the blue dotted arrows in Figure 7).

Our analysis further indicates that retailers follow different paths toward smart warehousing. On one hand, some retailers follow an automation-focused path toward smart warehousing, i.e. while investing in a wide range of technologies to implement smart warehousing, these retailers emphasize technologies that automate material handling of their physical goods flows. This may arise from the need to manage more varied warehouse operations (Kembro and Norrman, 2020). Examples include handling online customers vs store replenishment; a variation in flows, including handling returns and cross-docking; and large variations in SKU sizes (e.g. pieces, cartons, and pallets). The more varied the operations, the wider the range of automation technology needed for material handling. Another driver is increased sorting complexity (due to, e.g. multiple destinations, delivery modes, and transporters), creating a need for additional automation technology (Kembro *et al.*, 2022). The historical footprint is also relevant, in which retailers that automated certain material flows early (e.g. store replenishment) add automation technologies dedicated to meeting continuously changing online customers' requirements (Eriksson *et al.*, 2022).

On the other hand, our data indicate that some retailers, particularly e-tailers, will follow a more digitalization-focused path toward smart warehousing. While these retailers invest in automated material handling, they emphasize information platforms and technology that enable real-time data analysis (e.g. AI). These retailers have less variation in operations and, therefore, require a narrower range of automation technologies for material handling. For example, an e-tailer may have a high automation degree, but can handle warehouse operations with only one main form of automation technology (e.g. AutoStore). This enables a greater focus on other complementary technologies for digitalization and connectivity of information platforms. An important driver is online sales, in which e-tailers generally are more focused on virtual contact with customers, requiring a range of integrated IT systems. Another driver is the need to connect multiple material-handling nodes (e.g. DC, OFC, retail stores) in the logistics network (Kembro and Norrman, 2019).

Thus, we put forth the following propositions:

P7a. The advancement of the smart warehousing frontline is driven not by retailers with a current high degree of automated material handling, but rather by pioneering retailers that make a major technological shift from limited use of technology.

P7b. Retailers with different channel strategies take different implementation routes toward smart warehousing, in which more-integrated omnichannel retailers follow an automation-focused path, whereas less-integrated retailers and e-tailers follow a more digitalization-focused path.

5.1 Conceptualizing smart warehousing

At this stage, it is also relevant to define *smart warehouse* (which is currently missing in the literature). Based on extant literature (Section 2) and on an analysis of retailers' current and intended technological implementation, we conceptualize future smart warehouses as: **Automated**, i.e. robots will handle a large part of physical material handling; **Autonomous**, in which robots make their own decisions regarding task distribution (e.g. order management) and movements in the warehouse – a combination of autonomous automation also can be called autonomization; **Digital**, i.e. integrated information platforms handle warehouse management (e.g. inventory levels, sequencing of order picks), including functionality for analysis of large amounts of data (AI/machine learning), e.g. for improved forecasting; and **Connected**, in which moving resources and products are monitored, controlled, and coordinated in real time. It also enables real-time analysis (e.g. via IVA) of in-store activity to allow for fast decision-making and further development of processes.

We summarize these insights in Figure 8, which outlines both the two dimensions of smart warehousing, as well as the different stages and pathways toward this goal.

5.2 Connecting multiple smart warehouses in extended logistics networks

Moving beyond the single smart warehouse, retailers will use multiple material-handling nodes in their future logistics networks (Hübner *et al.*, 2022; Kembro *et al.*, 2022). Our findings indicate that retailers will expand from zero or one to between two and five large distribution warehouses. Our study also found that retailers are adding more and varied material-handling nodes (e.g. DC, OFC, MFC) in their decentralized logistics networks. These are complemented by transformed physical stores, which are becoming the center of retail operations (Hübner *et al.*, 2022).

Apart from market expansion, the main reason for expanding the number of material-handling nodes is the extremely short lead times from customer order to final delivery. Global giants, e.g. Alibaba and Amazon largely have driven this development, with their increasingly competitive promises to customers (Kembro *et al.*, 2022). In our study, 52% of multichannel retailers (of which most aim to be highly integrated omnichannel retailers within five years) intend to offer standard lead times under 24 h. A similar pattern is visible for e-tailers. No matter how fast a central warehouse fulfills an order, the transportation times to final destination (e.g. home delivery, C&C) may result in lead times that exceed customer expectations. This development will require well-coordinated logistics networks (e.g. use of drop-shipment and small-scale warehouses, e.g. OFCs or MFCs in and around cities, i.e. closer to end customers). It also will drive the need for effective and efficient material handling across network nodes, which can be implemented, e.g. by investing in new automation technology, as well as advanced and integrated information systems. As Kembro and

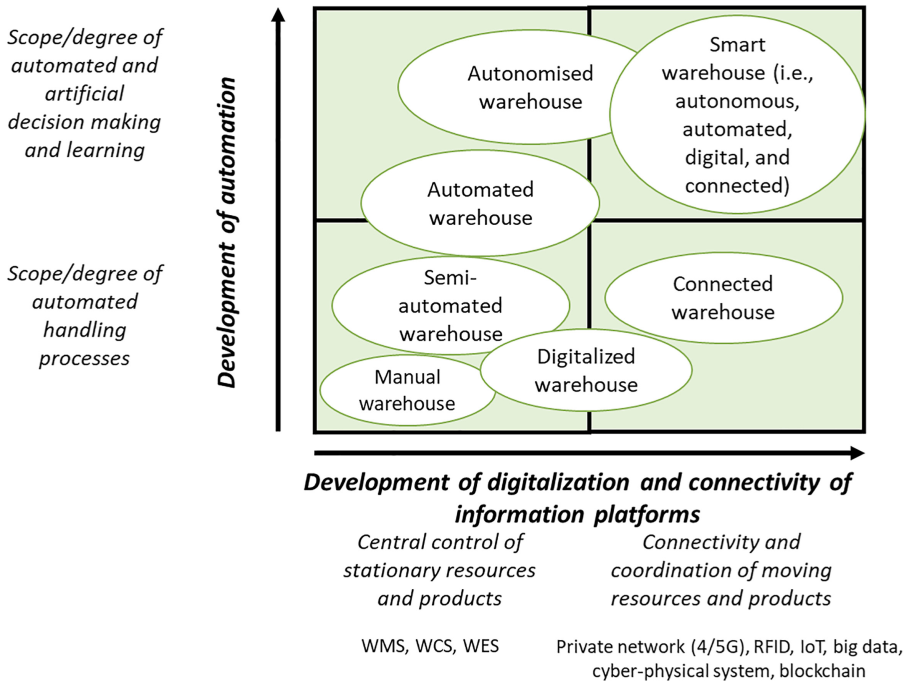


Figure 8.
Conceptualization of smart warehousing

Norrman discussed (2019), future warehouses and stores, to a greater extent, will be interconnected, among other ways, through the use of a so-called DOM system. For example, inventory levels are coordinated between different material-handling nodes, and an online order can be routed to/managed in different nodes depending on several defined parameters/goals (e.g. reducing lead times or lowering handling costs).

Thus, we position the smart warehouse as part of a larger logistics network (Figure 9). The dashed arrows in the *X*- and *Y*-direction indicate a further extension externally to the warehouse, i.e. the retailers also automate, digitalize, autonomize, and connect different types of material-handling nodes (e.g. OFC, MFC). The interconnection takes place using different systems – e.g. IoT, DOM, ERP, and TMS – enabling coordination of order and goods flows both within and between different material-handling nodes. It also can include functionality for more advanced forecasting of purchase patterns and delivery/ordering patterns to ensure that the right goods are in the right place at the right time. Thus, we put forth the following propositions:

P8a. With increasingly competitive lead-time promises to customers, retailers use more and varied (smaller, localized) material-handling nodes that need to be interconnected in smart warehouse networks.

P8b. With requirements on effective and efficient warehousing across logistics networks, retailers increasingly use automated material-handling technology in different types of decentralized material-handling nodes, e.g. micro-fulfillment centers.

6. Conclusions and future research

This study aimed to conceptualize the term *smart warehousing* and explain pathways on how to implement it. By empirically studying this novel phenomenon, our research influences the

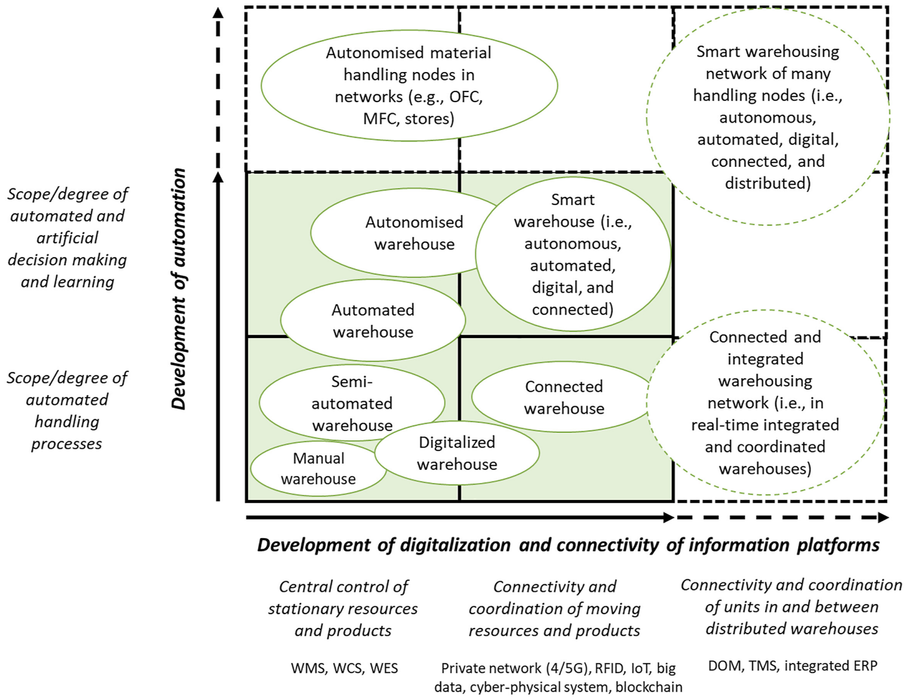


Figure 9.
Multiple, connected smart warehouses in expanding, decentralized logistics networks

definition of its problem domain and offers multiple contributions of the "theoretical pre-science" type (Corley and Gioia, 2011).

Contributing to recent and limited literature on smart warehousing (Azadeh *et al.*, 2019; Mahroof, 2019; Chung, 2021; Zhang *et al.*, 2021), we put forth 16 propositions related to automation and complementary technology, as well as pathways toward smart warehousing. Our analysis indicates that the future smart warehouse will be automated, autonomous, digital, and connected, but that retailers will follow different paths along this journey. To support our analysis, we operationalized smart warehousing into two dimensions: degree of automation and degree of digitalization and connectivity of information platforms. This is an important contribution to the literature in different fields (e.g. logistics, operations research, and information systems) that mention smart warehousing without defining it. Our operationalization also could influence future conversion of smart warehousing, enabling analysis of patterns on a more holistic level and focusing not just on specific applications of certain technologies that characterize much of current research.

Interestingly, our study revealed that many of the retailers that aim to create smart warehouses in five years are not the retailers with the most developed technology today. In this transition, retailers followed different technological pathways driven by contextual trends, e.g. the growth of sales, wider product assortment, shorter lead-time offerings, and channel strategy. By demonstrating how the continuously evolving retail landscape influences back-end logistics, we contribute to the literature on retail logistics and warehousing (e.g. Galipoglu *et al.*, 2018; Kembro *et al.*, 2018), as well as related automation technology and information platforms (Kembro and Norrman, 2019). Specifically, we explain why retailers calibrate their timing, technology, and focus to suit certain operations. The study found that retailers first automate labor-intensive, outbound warehousing operations, with an emphasis on small or very small goods. Next, many automate larger-size goods and expand their focus to include inbound operations. An important observation is that automation of outgoing flows is more non-contextual (i.e. similar across retailers), while storage and picking technologies seem more tailored to contextual factors (e.g. characteristics of goods). We also conclude that although new automation technology is available for a wider range of retail segments and sizes, it still requires a large investment. This may explain why retailers with larger turnovers and assortment ranges invest more in automation.

Our study proposes this and provides explanations as to why some retailers focus on advanced automation technology while others tend to pioneer digitalization and connectivity. Retailers generally have a solid understanding of information systems for automated material handling, but have limited knowledge about emerging smart warehousing technologies related to digitalization and connectivity. In five years, WMS, WCS, and WES will be the backbone of warehouse operations, complemented with technologies that support data management and real-time analysis, including AI, IoT, RFID, and IVA. This technological development also is important for connecting logistics networks with multiple, different, and decentralized material-handling nodes (e.g. automated MFCs) to meet growing demand for very short lead times from placed order to delivery.

This study provides *practically useful* guidance for managers by outlining what is trending now and five years down the road. In many companies and countries, the transformation toward smart warehousing has only just begun. Empirical insights from pioneering practice can help other retailers understand critical issues earlier, as well as how to address them. Our findings provide insights into technologies expected to grow in use and criticality to support both material handling in single warehouses and increasingly complex and decentralized networks. Managers also can use our 16 propositions to reflect on what the near future holds and use them as input for scenario analysis.

Pre-science studies' observations naturally elicit speculation that needs more research. We noted that, related to automation, retailers' current tendency to invest in static automation solutions could limit their future strategic options. Future research could investigate whether these kinds of technological investments follow existing strategy – or whether they instead are driving or delimiting future strategies (e.g. to be able to grow, we need to automate vs our current automation technology, which restricts/supports our scaling up). Explanations as to why some retailers seem to lead the digitalization and connectivity journey should be studied: Are fewer capital investments (compared with automation) required? Do they have fewer nodes and simpler flows on which to focus? Have they reached a higher maturity level regarding information technology?

The conceptualization and operationalization of smart warehousing can be developed further through additional empirical evidence collected in other markets. To build theory, in-depth case study research could be employed to better understand different contingency factors' influence. Of special interest would be research on implementation and transformation (using theoretical lenses, e.g. dynamic capabilities or technology adoption models), economic assessment of investment and performance, and an examination of barriers and opportunities related to the interaction between human and smart technologies in future warehouses. The literature presented mixed perspectives on humans' role in future warehousing. Some warehouse operations remain difficult to automate and may need to be carried out manually (Azadeh *et al.*, 2019). While some researchers trumpet their unmanned warehouses as a defining characteristic or goal for smart warehouses (Aamer and Sahara, 2021; Jiang *et al.*, 2021), others see robots and AI eventually replacing humans (Jabber *et al.*, 2018). Some have argued that humans will not be replaced, but rather supported (Winkelhaus and Grosse, 2020), with the intent to better connect people, objects, and physical systems (Lee *et al.*, 2018). Thus, future research could study which factors explain to what extent future warehouses will be manual, automated, or smart.

Like most research designs, this study has limitations. The sample of retailers (50) that answered the survey was relatively small, not random, and only included retailers from one country. However, we argue that the sample is sufficient for developing propositions regarding the researched phenomenon (Forza, 2002) because Sweden is among the leaders in online sales, and among the top-10 industrial digital transformation countries in 2020 (Top 10 industrial digital transformation countries in 2020 | InfotechLead). Furthermore, the most important product segments are covered, including leading retailers within each segment. To pinpoint theoretical and managerial implications further, our research needs to be complemented by and tested through more research. Specifically, the 16 propositions can be tested as hypotheses in future research with more empirical evidence by expanding testing to other markets, both in larger countries at similar stages of transformation toward omnichannels (e.g. the US, UK, and Germany) and in countries that are developed in terms of online sales. To understand smart warehousing technologies, logistics service providers and industrial companies also should be examined. Due to their deeper backgrounds with Industry 4.0 and their connection to smart production, industrial companies might make investments and implement smart warehousing differently than retailers.

In conclusion, the pace of development toward smart warehousing will increase in the coming years. Various systems and technologies will be developed and integrated within and across various material-handling nodes, providing many opportunities for researchers to examine and analyze new challenges and solutions, creating new knowledge in warehousing and retail logistics. Only the future can tell us how smart warehouses evolve and why.

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Appendix

Question tested	Sub question tested	Two-tailed *t*-test for equality of means [today vs in five years]	Finding
Q22 What is the overall degree of automation in your warehouse?	–	0.00002167248	Strongly significant
Q22 What is the overall degree of automation in your warehouse?	–	0.00000000011	Strongly significant
Q23/Q24 To what degree are different warehouse operations automated?	Goods receiving	0.00002043576	Strongly significant
Q23/Q24 To what degree are different warehouse operations automated?	Sorting incoming goods	0.00000005748	Strongly significant
Q23/Q24 To what degree are different warehouse operations automated?	Put-away	0.00000013637	Strongly significant
Q23/Q24 To what degree are different warehouse operations automated?	Picking	0.00000001797	Strongly significant
Q23/Q24 To what degree are different warehouse operations automated?	Packing	0.00000000078	Strongly significant
Q23/Q24 To what degree are different warehouse operations automated?	Sorting outgoing goods	0.00000140333	Strongly significant
Q23/Q24 To what degree are different warehouse operations automated?	Shipping	0.00003426058	Strongly significant
Q23/Q24 To what degree are different warehouse operations automated?	Cross-docking	0.00008288327	Strongly significant
Q23/Q24 To what degree are different warehouse operations automated?	Returns handling	0.00000797048	Strongly significant
Q28/29 What type of automation technology do you use for materials handling in your warehouse?	Stationary automated storate and retrieval (e.g. AS/RS, mini-load, carousels)	0.037955985	Significant 0.95
Q28/29 What type of automation technology do you use for materials handling in your warehouse?	Automated guided vehicles (AGV)	0.017130652	Significant 0.97
Q28/29 What type of automation technology do you use for materials handling in your warehouse?	Autonomous forklifts	0.014625798	Significant 0.97
Q28/29 What type of automation technology do you use for materials handling in your warehouse?	Goods/shelf-to-person, “autonomous mobile robots” (e.g. Amazon robots, Geek+)	0.333170136	Not significant

(*continued*)

Table A1.
T-tests to detect significant differences between current and future states

Question tested	Sub question tested	Two-tailed *t*-test for equality of means [today vs in five years]	Finding
Q28/29 What type of automation technology do you use for materials handling in your warehouse?	Compact/grid based storage and goods-to-person (e.g. Autostore, Ocado)	0.000417379	Strongly significant
Q28/29 What type of automation technology do you use for materials handling in your warehouse?	Mobile/flexible robotized storage and retrieval (e.g. Opex iBot, Exotec Skypod)	0.335561278	Not significant
Q28/29 What type of automation technology do you use for materials handling in your warehouse?	Mobile, collaborative robots ("cobots") (e.g. 6 River Systems Chuck)	0.335561278	Not significant
Q28/29 What type of automation technology do you use for materials handling in your warehouse?	A-frame-system, automated picking (t.ex. SSI-Schaefer Product Verifier)	0.02228574	Significant 0.97
Q28/29 What type of automation technology do you use for materials handling in your warehouse?	Robotic piece-picking, using AI och video technology (e.g. Right hand robotics)	0.02660758	Significant 0.97
Q28/29 What type of automation technology do you use for materials handling in your warehouse?	Stationary, automated sorting system (with conveyors and trays)	0.00072573	Strongly significant
Q28/29 What type of automation technology do you use for materials handling in your warehouse?	Pocket sorter (e.g. Vanderlande Airtrax)	0.574774459	Not significant
Q28/29 What type of automation technology do you use for materials handling in your warehouse?	Flexible robot sorter using autonomous mobile robots (e.g. Geek+)	0.912280179	Not significant
Q28/29 What type of automation technology do you use for materials handling in your warehouse?	Automated packaging system	0.000379296	Strongly significant
Q28/29 What type of automation technology do you use for materials handling in your warehouse?	Automated weighing and dimensioning ("cubing")	0.00000016138	Strongly significant
Q28/29 What type of automation technology do you use for materials handling in your warehouse?	Robotic palletization of outgoing goods	0.000356349	Significant 0.999
Q32/33 What type of other technology do you use to increase performance of different warehouse operations?	Warehouse Management System	0.008350201	Significant 0.99

(*continued*)

Table A1.

Question tested	Sub question tested	Two-tailed t-test for equality of means [today vs in five years]	Finding
Q32/33 What type of other technology do you use to increase performance of different warehouse operations?	Warehouse Control System (for controlling automation)	0.00002477367	Strongly significant
Q32/33 What type of other technology do you use to increase performance of different warehouse operations?	Warehouse Execution System (combination of/link between WMS och WCS)	0.000324865	Significant 0.999
Q32/33 What type of other technology do you use to increase performance of different warehouse operations?	Radio Frequency Identification (RFID)	0.00004673371	Strongly significant
Q32/33 What type of other technology do you use to increase performance of different warehouse operations?	Pick-by-voice	0.37915436664	Not significant
Q32/33 What type of other technology do you use to increase performance of different warehouse operations?	Put-to-light/Pick-by-light	0.00027328449	Strongly significant
Q32/33 What type of other technology do you use to increase performance of different warehouse operations?	Pick-by-vision (Augmented Reality)	0.41022972212	Not significant
Q32/33 What type of other technology do you use to increase performance of different warehouse operations?	Intelligent video analysis	0.02420688701	Significant 0.985
Q32/33 What type of other technology do you use to increase performance of different warehouse operations?	Private Networks (4G, 5G)	0.48198685749	Not significant
Q32/33 What type of other technology do you use to increase performance of different warehouse operations?	Industrial Internet of Things (IIoT) (e.g. connected machines with sensors sharing information in real time)	0.00569091060	Significant 0.99
Q32/33 What type of other technology do you use to increase performance of different warehouse operations?	Artificial Intelligence and machine learning (e.g. för predictive demand planning, inventory control, route optimization)	0.00000388704	Strongly significant

Table A1. *(continued)*

Question tested	Sub question tested	Two-tailed t-test for equality of means [today vs in five years]	Finding
Q32/33 What type of other technology do you use to increase performance of different warehouse operations?	Virtual reality (e.g. digital twin of warehouse)	0.08269790631	Weak significance 0.91
Q32/33 What type of other technology do you use to increase performance of different warehouse operations?	3D printing (Additive manufacturing)	0.33219498465	Not significant
Q32/33 What type of other technology do you use to increase performance of different warehouse operations?	Drone technology	0.16387561366	Not significant
Q32/33 What type of other technology do you use to increase performance of different warehouse operations?	Blockchain technology	0.33556127787	Not significant

Table A1.

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