

Adapting warehouse operations and design to omni-channel logistics

890 A literature review and research agenda

Joakim Hans Kembro, Andreas Norrman and Ebba Eriksson
*Department of Industrial Management and Logistics, Faculty of Engineering,
Lund University, Lund, Sweden*

Received 3 February 2017
Revised 7 September 2017
14 March 2018
16 June 2018
20 June 2018
Accepted 20 June 2018

Abstract

Purpose – The purpose of this paper is to increase the understanding of how warehouse operations and design are affected by the move toward integrated omni-channels.

Design/methodology/approach – A structured literature review is conducted to identify and categorize themes in multi- and omni-channel logistics, and to discuss how aspects related to these themes impact and pose contingencies for warehouse operations and design.

Findings – The review revealed a lack of focus on warehouse operations and design in multi- and omni-channels. Instead, most articles published in scientific journals discuss changes in consumer demand and implications for the network level, concerning aspects such as the organization and management of material and information flows, inventory management, resources, actors and relationships. Ten themes in omni-channel logistics were identified and grouped into two categories: the value proposition and channel management; and the physical distribution network design. The themes and related aspects have implications for warehousing, and by combining these with general warehousing knowledge, the authors derive a comprehensive and structured agenda is derived to guide future research on omni-channel warehousing.

Research limitations/implications – This paper outlines a research agenda, including detailed research questions, for advancing the theory on warehouse operations and design in omni-channels.

Practical implications – The agenda can inspire practitioners in their work to understand the upcoming challenges and address relevant issues in omni-channel warehousing, taking into consideration its interdependence with value proposition, channel management and network decisions.

Originality/value – This is the first comprehensive review focusing on and synthesizing available literature on omni-channel warehousing. This topic has until now received limited coverage but is of increasing importance to scholars in the field.

Keywords Logistics, Literature review, Retail, Research agenda, Omni-channel, Channel integration, Material handling, Warehouse

Paper type Literature review

Introduction

Retailers increasingly integrate their physical stores and online channels into a seamless world of shopping, a concept often referred to as omni-channel retailing. In omni-channels, inventories and order fulfillment are conflated, and customers can place their orders in one channel (e.g. on a smartphone), pick up or receive through another channel (e.g. home delivery), and return products in a third channel (e.g. physical store) (Brynjolfsson *et al.*, 2013; Piotrowicz and Cuthbertson, 2014; Saghir *et al.*, 2017). Omni-channel retailing represents a competitive and continuously changing landscape (Ishfaq *et al.*, 2016), and it has become



more important and more difficult to design effective and efficient distribution systems (Agatz *et al.*, 2008; Beck and Rygl, 2015). Essential considerations for distribution systems (also referred to as omni-channel logistics) include, for example, how and where to keep stock and fulfill orders for store replenishment and e-commerce, and how and where to handle the increasing return flows (Bernon *et al.*, 2016; Hübner, Wollenburg and Holzapfel, 2016).

A critical aspect of distribution systems is represented by the warehouse operations carried out at the various material-handling nodes (Faber *et al.*, 2013; Hübner, Kuhn and Wollenburg, 2016). One major challenge is, for example, to effectively combine the handling and shipment of small consumer online orders with large store replenishment orders, orders and shipments that previously were handled in separate channels (Hübner *et al.*, 2015). As argued by Rouwenhorst *et al.* (2000, p. 515), “the efficiency and effectiveness in any distribution network is largely determined by the operations of the node in such network, i.e. the warehouses.” Having previously been considered as a burden because of high capital and operating expenses (De Koster *et al.*, 2007; Bartholdi and Hackman, 2016), warehouse operations are now increasingly regarded as a strategic component of supply chains and omni-channel retailing particularly (Hübner, Holzapfel and Kuhn, 2016), and the topic of warehousing is attracting increased attention (Kembro *et al.*, 2017).

Despite the growing strategic importance of warehouse operations, there is a lack of a structured and comprehensive overview of the context of omni-channel retailing. A number of reviews have looked at multi-channel and omni-channel logistics, primarily from the overall network perspective (see, e.g. Agatz *et al.*, 2008; Hübner, Holzapfel and Kuhn, 2016; Melacini *et al.*, 2018). Meanwhile, there are several literature reviews conducted on the topic of warehouse operations and design (see, e.g. De Koster *et al.*, 2007; Gu *et al.*, 2007, 2010; Davarzani and Norrman, 2015). However, none of these have focused on the link between omni-channels and the requirements, challenges and opportunities that arise for warehousing. In addition, there seem to be parallel discussions going on across several disciplines, including: management (Lee *et al.*, 2013; Gallino and Moreno, 2014); information technology (Lewis *et al.*, 2014; Piotrowicz and Cuthbertson, 2014); retailing (Xing and Grant, 2006; Verhoef *et al.*, 2015); marketing (Neslin and Shankar, 2009; Vinhas *et al.*, 2010); operations management (Faber *et al.*, 2013; Hübner *et al.*, 2015); operations research (Agatz *et al.*, 2008; Rodriguez and Aydin, 2015); and logistics and supply chain management (Kull *et al.*, 2013; Hübner, Kuhn and Wollenburg, 2016). It is time to bring knowledge from these streams together and provide a structured and comprehensive overview of omni-channel logistics with a focus on the implications for warehouse operations and design. Such a review would also contribute to filling the recently highlighted lack of research investigating back-end omni-channel logistics (Galipoglu *et al.*, 2018; Marchet *et al.*, 2018).

The purpose of this study is to increase our understanding of how warehouse operations and design are affected by the change toward integrated omni-channels. To address this, we conduct a literature review following a structured approach (cf. Durach *et al.*, 2017) to identify and categorize themes in omni-channel logistics and discuss how aspects related to these themes impact and pose contingencies for warehouse operations and design. To provide a foundation for the literature review and a resulting research agenda for omni-channel warehousing, the next section includes an overview of extant literature on warehouse operations and design. We use the term warehouse as a representation of various material-handling nodes that are used in omni-channels. Such nodes include, for example, distribution centers, direct fulfillment centers (designed to handle e-commerce orders and ship directly to consumer) and forward fulfillment centers (FFCs) (using retail stores as logistic hubs located closer to the consumer). We also use the term network as a representation of a distribution system consisting of transportation links connecting multiple nodes such as material-handling centers, suppliers and retail stores.

Warehouse operations and design

Warehouses can, according to Bartholdi and Hackman (2016, p. 3), be described as “the points in the supply chain where [the] product pauses, however briefly, and is touched.” The rationale for using a warehouse is, for example, to match supply and demand, to consolidate a range of products and to reduce transportation costs and lead times (Faber *et al.*, 2013). Figure 1 presents an overview of warehouse operations and design and highlights the importance of tailoring the operations and design to a number of contextual factors in order to reduce cost and improve service to customers.

Most warehouses have operations for receiving, put-away, storage, picking, sorting, packing and shipping (see, e.g. Van den Berg and Zijm, 1999; Petersen and Aase, 2004). Along with increased e-commerce, many distribution warehouses also have extensive return operations (Bernon *et al.*, 2016). First, when products arrive at the warehouse, they are checked for quality and registered before being put-away in the assigned storage location (Bartholdi and Hackman, 2016). Storage includes a reserve area and a picking zone (Frazelle, 2002). The latter includes a limited quantity of each product, also referred to as a stock-keeping item (SKU), that can be easily retrieved (Rouwenhorst *et al.*, 2000). SKUs are either dedicated or randomly assigned to a location. A common approach is to combine dedicated and random storage (class-based storage), which implies that SKUs are dedicated to a certain zone, but within each zone, the SKUs are randomly placed. This approach draws on benefits of both dedicated and random storage, enabling reduced travel while avoiding congestion (Gu *et al.*, 2007). According to Frazelle (2002), utilizing 80 percent of the total storage space is appropriate for flexibility and planning, and beyond 86 percent, effectiveness, efficiency and safety decline exponentially for every percentage-point of increase.

Picking represents most of the operations cost and has by far been the most-researched topic in warehousing (see, e.g. Le-Duc and De Koster, 2005; Bottani *et al.*, 2012). Picking efficiency

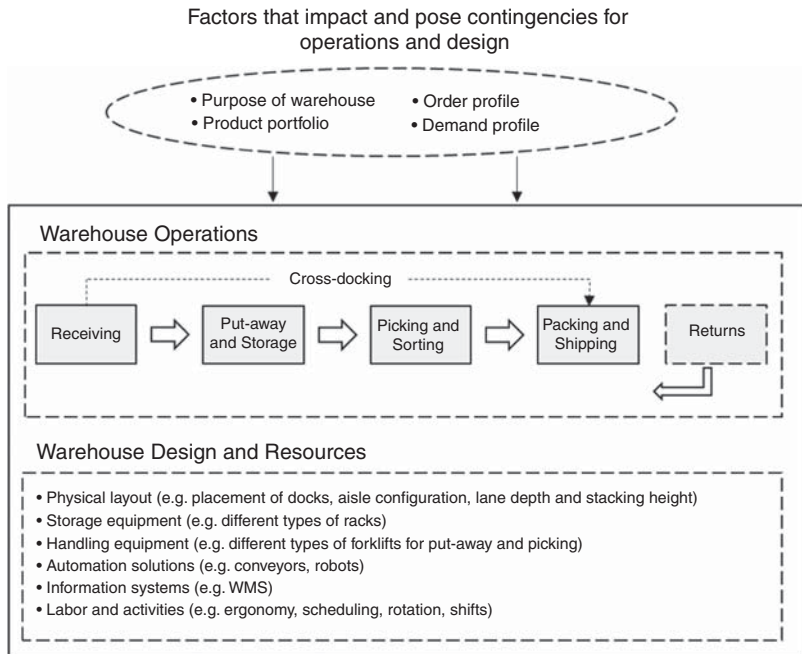


Figure 1.
Overview of
warehouse operations
and design

can be improved by putting the fastest moving products in the most convenient locations (Gu *et al.*, 2007) and by selecting the appropriate picking methods. The four common picking methods include single, batch, zone and wave (see, e.g. Hassan, 2002; Bartholdi and Hackman, 2016). Eventually, orders are packed and shipped (Gu *et al.*, 2007) while, 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 thereafter registered for departure and put at the allocated gate and time window (Bartholdi and Hackman, 2016).

To make warehouse operations effective and efficient, multiple design aspects and resources must be considered, including: physical layout, e.g. placement of docks, aisle configuration, lane depth and stacking height (Huertas *et al.*, 2007); storage and handling equipment, e.g. different types of racks and different types of forklifts for put-away and picking (Rouwenhorst *et al.*, 2000); automation solutions, e.g. conveyors and robots (Baker and Halim, 2007); information systems, e.g. the warehouse management system (WMS) (Faber *et al.*, 2002); and labor management, e.g. scheduling, rotation and shifts (De Leeuw and Wiers, 2015). Design goals that have been discussed in the literature include improved capacity and resource utilization (both space, equipment and labor), increased throughput and reduced material-handling time by, for example, eliminating double-handling and limiting congestion, and increased flexibility in operations and design (see, e.g. Cormier and Gunn, 1992; Petersen and Aase, 2004; Le-Duc and De Koster, 2005; Huertas *et al.*, 2007). These goals can be complex to balance considering that many design components are interrelated. Focusing only on separate parts may therefore lead to sub-optimization (Baker and Canessa, 2009). In addition, the design process may involve several (re)iterations and trade-offs (Rouwenhorst *et al.*, 2000), and it can be difficult and costly to make significant layout changes at a later stage (Huertas *et al.*, 2007).

The contingency approach (Donaldson, 2001) of tailoring operations and design to the particular context is receiving increased attention in the warehousing theory. Lower performance would thus be expected if there were a misfit between warehouse operations and design and a number of contingency factors. Factors that have an impact on the operations and design include the purpose of the warehouse, product portfolio, order profile and demand profile (Frazelle, 2002; Gu *et al.*, 2010; Bartholdi and Hackman, 2016). For instance, a production warehouse and a distribution warehouse have different needs in terms of required operations (Van den Berg and Zijm, 1999), the SKU characteristics define the need of storage and handling equipment (Rouwenhorst *et al.*, 2000), and the order characteristics impact the choice of picking method (Bartholdi and Hackman, 2016). Meanwhile, understanding the characteristics and size of current and forecasted demand, including seasonality and growth of overall demand and variety within the product portfolio, is critical to assign appropriate capacities for storage and labor (Rouwenhorst *et al.*, 2000; Frazelle, 2002; Gu *et al.*, 2010).

Next, a structured literature review is conducted to identify omni-channel themes and related aspects that are subsequently used to discuss the implications for warehouse operations and design. We will thereafter revert to Figure 1 and present a structured agenda with research questions addressing how warehouse operations and design need to be adapted to omni-channels.

Methodology for the literature review

To identify publications related to omni-channel logistics, we followed six steps highlighted in Figure 2 based on common guidelines for conducting a structured literature review (see, e.g. Durach *et al.*, 2017).

First, a pilot review of the research field was conducted to identify the gap and define the goal of the structured literature review, and to identify relevant terminology. A workshop with senior logistics managers was arranged to discuss the focus of the project. This workshop

confirmed the importance and lack of a warehouse-operations framework in omni-channel retailing, and emphasized that the network, strategy and management of omni-channels impact and pose contingencies for warehouse operations and design in various material-handling nodes. The workshop thus directed the review toward understanding the various themes and contextual factors that must be considered for omni-channel warehousing.

Second, criteria were established for identifying relevant literature. Considering the focus on logistics systems in multi- and omni-channels, studies focusing only on one channel, either pure-store channel or online channel, were excluded. Selected literature should focus on the logistics network and/or the warehouse. Studies focusing solely on transportation and last-mile distribution, and publications exclusively investigating the customer perceptions or perspectives of retail, sales or marketing, were excluded. A broad range of empirical, analytical and conceptual studies across a variety of published material was considered, for example, scientific journal papers, book chapters and industry reports. No limitations were made in time, outlets or research methods.

Third, to minimize the risk of excluding relevant literature, we employed two electronic, complementary and commonly used databases (see, e.g. Leuschner *et al.*, 2014; Durach *et al.*, 2017): Business Source Complete (via EBSCOhost) and the Web of Science Core Collection. Based on the pilot review of literature, the following keywords were identified and combined using Boolean operators [OR, AND]: [omni*channel; multi*channel; dual*channel; cross*channel; channel multiplicity; e-tailing; bricks-and-clicks; clicks-and-mortar] and [warehousing; warehouse operation; material* handling; material flow; physical flow; goods flow; distribution center; distribution network; distribution system; logistics; supply chain].

Fourth, by searching in document titles, we identified 343 publications (Figure 2). Removing duplicates and applying the inclusion/exclusion criteria resulted in a subset of 101 documents. Two of the authors then carefully read the full-text version of each publication and thereafter jointly decided if the papers should be included. A total of 44 studies were excluded based on the following rationale: 19 investigated only one channel, 15 focused on the perspective of the customer, sales, pricing and/or marketing rather than logistics, and 1 focused solely on last-mile distribution. In addition, we excluded one editorial, six work-in-progress papers and two journal publications that discussed definitions rather than themes related to omni-channel logistics. To reduce the risk that our review excluded relevant literature, we thereafter compared our list of primary studies with the authors, articles and reference lists included in a recent special issue on omni-channel logistics (Saghiri *et al.*, 2018). This validation resulted in adding seven publications, resulting in a final synthesis sample (cf. Durach *et al.*, 2017) of 64 publications, including: 51 journal articles, 11 popular-science publications, 1 dissertation and 1 book. The identified literature does not solely focus on omni-channel retailing, but rather includes perspectives of how the implementation of multiple channels potentially impacts different aspects of back-end fulfilment.

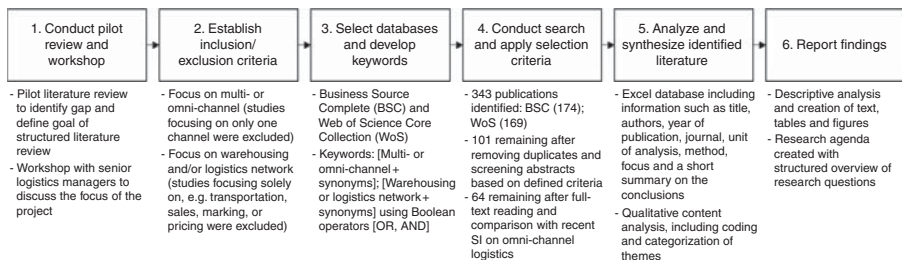


Figure 2.
Overview of the six literature-review steps

The fifth step included an analysis and synthesis of the identified literature. We first analyzed publication trends such as outlets, publications per year, applied unit of analyses and research methods employed. Next, two of the authors independently conducted a qualitative content analysis (Combs *et al.*, 2011) to identify research themes. The coding categories were derived directly from the text where identified themes were given unique codes. The two researchers then jointly analyzed the codes and, guided by the literature, grouped related codes together into common themes. Examples of codes that were merged include: competencies and capabilities (see e.g. Grant, 1991); and performance metrics and incentive systems. A third researcher assessed the generated codes and facilitated discussions to reach a consensus (Gioia *et al.*, 2013). The research group discussed various ways that the themes relate to each other and how they could be categorized in a structured overview. This categorization is a first attempt to structure the omni-channel logistics context, and we acknowledge that other categorizations could have been possible and put forward. Our classification must therefore be validated in future research. The next step of the analysis focused on how aspects related to the different themes impact and pose contingencies for warehouse operations and design.

The final step reports these findings in text, tables and figures. A descriptive analysis was conducted, including the mapping of the identified publications based on, for example, research method applied, publication outlets over years and number of papers per theme. The analysis of themes and related aspects, and their impact on warehouse operations and design, was used to develop a research agenda for researchers, consisting of a structured and comprehensive overview of research questions focusing on omni-channel warehousing. The final agenda, which is presented in the implications section, builds on Figure 1 such that the research questions are structured according to warehouse operations on one axis, and warehouse design aspects on the other. Finally, the analysis was also used to present managerial implications.

Overview of extant literature: publications per journal, year and method

Research on logistics systems in multi- and omni-channels is published in a large number of outlets and disciplines such as logistics, supply chain management, operations management, general management, operations research, marketing and retailing. The top-two outlets in terms of publication count include the *International Journal of Physical Distribution and Logistics Management* (total 13) and the *European Journal of Operations Research* (6). The relatively low number of journal publications per year (average 3.4, 2007–2017) confirms the lack of focus on omni-channel logistics as noted by, for example, Galipoglu *et al.* (2018). Most journal articles focus on the network level, concerning aspects such as the organization and management of material and information flows, inventory management, resources, actors and relationships. Similar to conclusions drawn from a literature review conducted a decade ago (Agatz *et al.*, 2008), our review revealed a lack of focus on warehouse operations and design in multi- and omni-channels (see Table I). Only seven scientific publications, mainly authored by one research group, were identified as focusing on warehousing to some extent (cf. Hübner *et al.*, 2015; Hübner, Holzapfel and Kuhn, 2016; Hübner, Wollenburg and Holzapfel, 2016; Hübner, Kuhn and Wollenburg, 2016; Wollenburg *et al.*, 2018). These studies have explored the general challenges for warehousing when integrating e-commerce with an existing store channel, focusing mainly on three aspects: integration of inventory, picking activities and capacity considerations.

The predominant research methods include mathematical modeling and simulation (total 24). Qualitative methods that have been applied include interview studies (five) and case studies (three). The multi-method and mixed-method approaches have been used in two papers. Surprisingly, although mathematical modeling and simulation are dominant methods in

Table I.
Methods applied in
scientific journals

Method/perspective	Value proposition and channel management + physical network design	Warehouse operations and design ^a
Model/simulation	24	
Literature review	6	1
Survey	6	1
Interview study	5	4
Conceptual	4	
Case	3	1
Mixed-method (qualitative + quantitative)	1	
Multi-method (qualitative + quantitative)	1	
Secondary data	1	
Total	51	7

Notes: ^aAll 51 scientific journal articles address the network level. Of these, seven also address warehouse operations and design

warehousing research (see e.g. Davarzani and Norrman, 2015), we did not find such research focused on omni-channel warehousing. Reasons might be that researchers have either not explicitly mentioned the omni-channel strategy, or that specific challenges related to this transformation have not yet been modeled.

Popular-science journals were also considered in the literature review, and for these outlets, warehousing is more often in focus; we found six popular-science papers that specifically discuss different aspects of warehousing related to omni-channel retailing (Andel, 2014; Michel, 2015; Bond, 2016a, b; Kembro, 2016; McMahon, 2016). These publications indicate a recent surge in interest among practitioners in omni-channel warehousing.

Themes in omni-channel logistics

We identified ten themes in omni-channel logistics and grouped these into two categories, namely, aspects and decisions related to meeting the consumers' requirements and expectations as well as the organization and management of resources, actors and relationships in the omni-channel (referred to as value proposition and channel management); and aspects and decisions related to design and planning of the physical flow of goods from supplier to customer through the network of nodes and links (referred to as physical distribution network design). An overview of the categories, themes, descriptions and references is shown in Table II. Next, we describe the themes and thereafter discuss how aspects related to these themes impact and pose contingencies for warehouse operations and design.

Value proposition and channel management

Differences in demand profiles and increased assortment. The store-order size often differs significantly from the size of orders placed online by a single customer. Hübner, Wollenburg and Holzapfel (2016) describe an example where the average items per store order were 34 times higher than online orders placed by end-customers. This difference is a central challenge in the transformation to omni-channel logistics when trying to integrate store- and online orders and create time- and cost-efficient warehousing operations (Hübner *et al.*, 2015). The particular impact and challenges for the picking operation are recurring themes (e.g. Agatz *et al.*, 2008; Hübner, Kuhn and Wollenburg, 2016), whereas the impact on other aspects such as inventory and automation is focused on only in a few publications (e.g. Hübner, Wollenburg, and Holzapfel, 2016). The literature highlights the connection between demand profile, product characteristics and store replenishment operations, and the impact these aspects may have on the ability to integrate e-commerce with store replenishment (Ishfaq *et al.*, 2016; Hübner, Holzapfel and

Theme	References
<i>Value proposition and channel management</i>	
Differences in demand profiles and increased assortment	Agatz <i>et al.</i> (2008); Bernon <i>et al.</i> (2016); Boldt and Patel (2015); Cao (2014); De Koster <i>et al.</i> (2002a); de Koster (2002b); Hobkirk (2015); Hübner <i>et al.</i> (2015); Hübner, Holzapfel and Kuhn (2016); Hübner, Wollenburg and Holzapfel (2016); Hübner, Kuhn and Wollenburg (2016); Ishfaq <i>et al.</i> (2016); Michel (2015); Napolitano (2013); Wollenburg <i>et al.</i> (2018)
Development of channel management strategies	Bernon <i>et al.</i> (2016); Cao (2014); De Koster <i>et al.</i> (2002a); Galipoglu <i>et al.</i> (2018); Gulati and Garino (2000); Hobkirk (2015); Hübner, Holzapfel and Kuhn (2016); Hübner, Wollenburg and Holzapfel (2016); Hübner, Kuhn and Wollenburg (2016); Ishfaq <i>et al.</i> (2016); Lang and Bressolles (2013); Larke <i>et al.</i> (2018); Lee <i>et al.</i> (2013); Marchet <i>et al.</i> (2018); Rabinovich <i>et al.</i> (2007); Wollenburg <i>et al.</i> (2018)
New services requiring new types of competencies and capabilities	Bernon <i>et al.</i> (2016); Ishfaq <i>et al.</i> (2016); Oh <i>et al.</i> (2012); Wallace <i>et al.</i> (2009)
The role of logistics service providers	Bernon <i>et al.</i> (2016); Murfield <i>et al.</i> (2017); Napolitano (2013); Rabinovich <i>et al.</i> (2007)
Performance metrics and incentive systems for risk and gain sharing	Boyaci (2005); Cai <i>et al.</i> (2012); Chiang and Feng (2010); Lu and Liu (2015); Mangiaracina <i>et al.</i> (2015); Neslin and Shankar (2009); Rabinovich and Bailey (2004); Rodriguez and Aydin (2015); Vinhas <i>et al.</i> (2010); Webb (2002); Xing and Grant (2006); Xing <i>et al.</i> (2010); Zhang (2009)
<i>Physical distribution network design</i>	
Increasingly complex distribution and returns process	Acimovic and Graves (2014); Alptekinoğlu and Tang (2005); Baird and Kilcourse (2011); Bernon <i>et al.</i> (2016); De Koster <i>et al.</i> (2002a); de Koster (2002b); Hübner, Holzapfel and Kuhn (2016); Hübner, Wollenburg and Holzapfel (2016); Hübner, Kuhn and Wollenburg (2016); Ishfaq <i>et al.</i> (2016); Lang and Bressolles (2013); Larke <i>et al.</i> (2018); Mahar <i>et al.</i> (2014); Marchet <i>et al.</i> (2018); Melacini <i>et al.</i> (2018); Melacini and Tappia (2018); Wollenburg <i>et al.</i> (2018)
The retail store's potential role as material-handling node	Aksen and Altinkemer (2008); Alptekinoğlu and Tang (2005); Baird and Kilcourse (2011); Cao (2014); Hübner, Kuhn and Wollenburg (2016); Ishfaq <i>et al.</i> (2016); Larke <i>et al.</i> (2018); Mahar <i>et al.</i> (2009); Marchet <i>et al.</i> (2018); Piotrowicz and Cuthbertson (2014); Wollenburg <i>et al.</i> (2018)
Inventory management in increasingly complex networks	Agatz <i>et al.</i> (2008); Alptekinoğlu and Tang (2005); Bendoly (2004); Bendoly <i>et al.</i> (2007); Boyaci (2005); Bretthauer <i>et al.</i> (2010); Hübner, Holzapfel and Kuhn (2016); Kull <i>et al.</i> (2013); Lang and Bressolles (2013); Mahar <i>et al.</i> (2009, 2012); Melacini <i>et al.</i> (2018); Xu <i>et al.</i> (2017); Yao <i>et al.</i> (2009)
Capacity planning and allocation	Agatz <i>et al.</i> (2008); Hübner <i>et al.</i> (2015); Rao <i>et al.</i> (2009); Xie <i>et al.</i> (2014)
Integrated information system for distributed orders and handling	Alshawi (2001); Bond (2016a, b); Cao (2014); Gallino and Moreno (2014); Hellberg (2016); Hübner, Wollenburg and Holzapfel (2016); Larke <i>et al.</i> (2018); Mahar and Wright (2009); Napolitano (2013); Oh <i>et al.</i> (2012)

Table II.
Overview of categories, themes and references identified in the structured literature review

Kuhn, 2016). Another important consideration is the increasing product assortment made available through e-commerce and online marketplaces (Wollenburg *et al.*, 2018). This expansion may entail a higher complexity in warehousing, for example, precipitating an increased need for storage space as well as an increase in the numbers and types of storage locations visited during order picking (de Koster, 2002b; Hübner, Wollenburg and Holzapfel, 2016).

Development of channel management strategies. To meet the challenges related to demand profiles and expanding assortments, many retailers consider integrating different

channel activities. Such a change is, however, far from trivial considering the complex, dynamic and continuously changing environment of omni-channels and consumer behavior (Rabinovich *et al.*, 2007; Hübner, Holzapfel and Kuhn *et al.*, 2016). Ishfaq *et al.* (2016, p. 559) find that: “the omni-channel retail logistics landscape is continuously evolving. These transitions are caused by complex dynamics which arise from actions of large online retailers, other omni-channel retailers and demanding customers.” Omni-channel retailers aim to create a seamless front-end experience for their customers, but there is still a lack of research on how companies address the increasing complexity in back-end fulfilment and to what extent they choose to integrate or separate their different channels (Wollenburg *et al.*, 2018). One stream of research suggests that companies follow maturity models where, for example, they move from having separated inventories toward having integrated inventories for both store replenishment and e-customers (Cao, 2014; Hübner, Wollenburg, and Holzapfel, 2016). Another research stream suggests that a range of factors, such as assortment, demand profile, current distribution network, customer expectations, and market and organizational characteristics, impact the appropriateness of integrating back-end fulfilment (e.g. Lang and Bressolles, 2013; Larke *et al.*, 2018; Wollenburg *et al.*, 2018). Researchers have recently combined the two streams, suggesting that companies consider contextual factors and follow maturity paths. Ishfaq *et al.* (2016, p. 559) discuss further: “Handling the underlying complexities of omni-channel retail may require firms to follow different paths to a steady-state omni-channel physical distribution process. Further research is needed to fully understand these dynamics and to identify potential maturation paths followed by omni-channel retailers in pursuit of an optimal omni-channel distribution strategy.” Similarly, Marchet *et al.* (2018) recently conducted a study showing that companies adopt their channel-management strategies to both contextual factors and omni-channel maturity.

New services requiring new types of competencies and capabilities. In the dynamic and rapidly changing omni-channel environment, retailers will likely be required to add new services in order to meet the demands from customers. Examples of such services include new packaging solutions, new tools for channel tracking and new solutions for customer accessibility to return points (e.g. Wallace *et al.*, 2009). Bernon *et al.* (2016, p. 599) describe further that, “an increasingly important dimension for retailers will be customer accessibility to return entry points and the capability retailers have to develop their own solutions or engage with specialist service providers [...] will become a point of differentiation.” Recent studies suggest that the ability to reallocate resources and develop new services will be highly rewarding (Oh *et al.*, 2012; Ishfaq *et al.*, 2016), and that it will be critical for retailers to understand the new set of capabilities and competencies that are required for these new services, e.g. store personnel’s ability to manage more complex information systems. Research on this theme is, however, limited.

The role of logistics service providers (LSPs). LSPs could play an important role in developing unique capabilities and new omni-channel solutions. Engaging with specialist service providers to develop new omni-channel solutions may, in fact, become a point of differentiation for retailers (Bernon *et al.*, 2016). However, the few existing studies focusing on omni-channel warehousing indicate that retailers initially prefer to consolidate and take care of integrated order fulfilment and distribution in-house (Hübner, Wollenburg, and Holzapfel, 2016). Later, as volumes increase, the size and complexity of the operation at some point outgrow the existing network and facilities. Outsourcing could then be considered an option for both short- or long-term solutions, where LSPs could offer economies of scale or a temporary surge of capacity to deal with rapid growth or seasonality (Napolitano, 2013). Outsourcing decisions should ultimately be based on the analysis of potential savings and whether the required logistics functions fit with the core competencies of the retailer, and, as Rabinovich *et al.* (2007) note, if asset specificity is reduced, firms are expected to increase

their use of LSPs. In a recent study, Murfield *et al.* (2017, p. 285) conclude that timeliness of deliveries is the single most important aspect of logistics service: “Logistics service providers need to emphasize speed and reliability of their delivery processes for omni-channel consumers. If managers do not account for these distinct omni-channel service requirements, then retailers risk alienating this growing and important customer segment.”

Performance metrics and incentive systems for risk and gain sharing. The increased level of integration in back-end fulfilment and the involvement of LSPs could lead to a number of challenging questions in the management and coordination of multi- and omni-channels. For instance: in what channel was the sale generated; how is the appropriate channel “credited”; and how should the costs and gains be shared between omni-channel members (Neslin and Shankar, 2009; Chiang and Feng, 2010; Cai *et al.*, 2012). Similarly, Vinhas *et al.* (2010, p. 229) argue that retailers must update their performance metrics and compensation systems in order to promote value creation and avoid outdated channel structures. Retailers will also need to adopt an integrated approach to performance management to avoid channel conflict, which could reduce the performance of the entire omni-channel (Webb, 2002). Another related and important aspect is the control and measurement of sustainability. Omni-channels have made it possible for retailers to reach additional customers and increase their sales, resulting in increasing material flows. At the same time, retailers offer generous return policies, which has triggered a growing number of returns that drives increases in logistics handling costs but maybe not always give extra revenue or profit. Exactly how these increased flows affect sustainability aspects is uncertain, and the topic has not received much attention in the literature. Mangiaracina *et al.* (2015, p. 584) conclude: “there continues to be a general lack of quantitative models for measuring the environmental impact of B2C e-commerce and dividing it among the supply chain players.”

Physical distribution network design

Increasingly complex distribution and returns process. The literature describes an increasingly complex distribution and returns process, which needs to be able to serve diverse requirements from multi- and omni-channels. Retailers “orchestrate various dispatching locations and enable the shipment to various points, whereas for a single-channel retailer the physical flow of goods is more or less linear” (Hübner, Holzapfel and Kuhn, 2016, p. 290). The decision of where an order should be picked and shipped from (e.g. manufacturer, distribution center, retail store) is complex, involving aspects such as lead times, transportation costs, handling costs, fixed operating costs, holding costs and backorder costs (Lang and Bressolles, 2013; Hübner, Kuhn and Wollenburg, 2016; Ishfaq *et al.*, 2016). Research has predominantly focused on the cost evaluation of omni-channel distribution networks, and only recently started to incorporate environmental impacts into the decision (Melacini and Tappia, 2018). The complexity of the network design is further increased because of liberal return policies and increasing return flows (Bernon *et al.*, 2016). In addition, there are multiple return options, such as return to store, send via post to distribution center and return directly to supplier. While generous return policies and multiple return points are convenient for the customer, they pose major challenges for retailers and raise the question of how to design the optimal network with high accessibility and low logistics cost (Hübner, Holzapfel and Kuhn, 2016). Recent research shows that companies adopt different approaches to handling returns. Marchet *et al.* (2018), for example, observe that many Italian retailers do not allow in-store returns, whereas Larke *et al.* (2018) find that Japan’s largest and most profitable retail chain enables customers to return products in all of their retail stores. Meanwhile, Mahar *et al.* (2014, p. 619) use mathematical modeling, showing that not all physical retail stores should be available to accept returns: “not all retail stores should be offering in-store pickups and/or returns [...] optimizing the set of pick up and return locations may reduce system cost over baseline marketing policies where these services are set up at all or none of a retailer’s stores.”

The retail store's potential role as material-handling node. Along with the development of omni-channels, stores take on a new and bigger role in the network, acting, for example, as pick-up and support points in the handling of returned products (Ishfaq *et al.*, 2016). Research also highlights the potential benefits of using selected stores as FFCs (Mahar *et al.*, 2009). This means a store could create additional value for retailers by simultaneously being responsible for displays, marketing, customer service, direct sales, pick-ups, returns and order fulfillment for e-customers (Cao, 2014). Interestingly, researchers have found that grocery retailers currently utilize stores more frequently for order picking, partly because of the low online order volume and the difference in order characteristics between online orders and store replenishment (Marchet *et al.*, 2018; Wollenburg *et al.*, 2018). It is important to consider this new role when designing the actual retail stores. It may be that some of the responsibilities of the store are in conflict with each other. As an example, designing a layout for displaying products with the purpose of increasing sales is significantly different from designing a layout that supports efficient order fulfillment (Hübner, Kuhn and Wollenburg, 2016). The new role of the physical store may also impact the design of the omni-channel network, where aspects such as product availability, returns, delivery options, reverse flows and inventory management across channels must be considered. Piotrowicz and Cuthbertson (2014, p. 10) conclude: "the future role of the physical store is not clear, and it may end up being determined by the product category and customer segment. The traditional store could change its role to a 'hub,' the focal point which would integrate all sales channels."

Inventory management in increasingly complex networks. Optimizing inventory levels in an omni-channel distribution network with several different types of material-handling nodes is a complex undertaking (Bretthauer *et al.*, 2010; Melacini *et al.*, 2018). There are standard models that provide a foundation for determining inventory levels in omni-channels. These models however need extensions and new approaches to deal with the complexity of omni-channels. Agatz *et al.* (2008, p. 352) argue: "Many standard operations research models provide a basis for addressing supply chain planning issues in e-fulfillment and multi-channel distribution. Yet, specific issues warrant modeling extensions and novel approaches." Important aspects concern the mixing of online/offline inventories and determining re-order points at the various nodes. Xu *et al.* (2017) underline the need for more complicated models including multi-item and multi-level models, to account for multiple points for order fulfillment, pick-up and returns where, "minimizing inventory cost is just one cost component and may not lead to a selection of online fulfillment locations that minimizes total cost (holding, backorder, transportation, handling, and fixed operating costs) for the firm" (Bretthauer *et al.*, 2010, p. 129). This complexity is further increased by the potential for drop-shipments made directly from manufactures to consumers, and the fact that stores are increasingly used as FFC, with possible transshipments between stores (Hübner, Holzapfel and Kuhn, 2016).

Capacity planning and allocation. One of the major challenges not only to inventory management, but also to capacity planning and allocation, concerns demand fluctuations. High uncertainty in both long- and short-term demand makes capacity planning and allocation complex (Agatz *et al.*, 2008; Xie *et al.*, 2014). Despite its importance, there is little research focusing on the challenges of increasing or decreasing different capacities in the short- vs long-term perspective in an omni-channel environment. The literature has mostly focused on workforce planning, largely neglecting infrastructure and physical capacity issues such as storage area and equipment (Agatz *et al.*, 2008; Hübner *et al.*, 2015). Rao *et al.* (2009, p. 121) discuss: "while it is likely that multi-channel retailers can piggyback on their existing infrastructure, where is the tipping point?" One measure addressing capacity issues that has received some attention in the literature is the postponement of orders across channels. This approach is used to shift e-commerce and store replenishment orders forward and backward in time primarily in order to balance the workforce in the network (Hübner *et al.*, 2015).

Integrated information system for distributed orders and handling. The literature suggests that the growing complexity of omni-channel distribution networks calls for the implementation of an integrated information system (Oh *et al.*, 2012). Larke *et al.* (2018, p. 468) conclude that: “For [omni-channel retailers] to work to its full potential, IT thus becomes critical as the driver behind the whole system. In particular, development of an integrated customer database across touchpoints, and efficient information exchange with suppliers across categories, becomes a prerequisite.” An integrated system could make it possible to coordinate inventory information and increase the visibility of inventory across all material-handling nodes in the network (Hübner, Wollenburg and Holzapfel, 2016). It also makes it possible to facilitate the decision-making process of how and where orders should be fulfilled in order to improve service levels while decreasing total costs, including costs for holding, backordering and transportation (Mahar and Wright, 2009). Related features include the possibility to reserve inventory and prioritize orders, track customer orders and facilitate communication with customers as well as manage return flows (Gallino and Moreno, 2014). An integrated system for handling these features is often referred to as a distributed order management (DOM) system (Napolitano, 2013). The DOM system can be regarded as an enabler of “a true [omni-channel] logistics solution resulting in a seamless [omni-channel] experience for retailer and customer” (Hübner, Wollenburg and Holzapfel, 2016, p. 578), and offers “a promising opportunity for retail firms to enhance their relationship with their customers and firm performance” (Oh *et al.*, 2012, p. 368).

Implications for omni-channel warehousing

This section derives implications for warehouse operations and design, summarized in a research agenda for omni-channel warehousing (Figure 3). The structure of the agenda builds on Figure 1, such that the research questions are structured according to warehouse operations and design aspects. The identified themes and the change that each of them represents have a varying array of implications for warehouse operations and design. One theme can have implications for several different aspects of warehouse operations and design, and decisions regarding one aspect (e.g. level of integration in DC) may create new conditions for another (e.g. inventory management across the network). Meanwhile, multiple themes can have implications for the same operations or design aspect. This complexity of how themes and implications interact (with multiple many-to-many relationships) makes it difficult to describe a single impact that one theme may have on one aspect of warehouse operations and design. It is also worth pointing out that some of the highlighted themes and issues can be handled by already-existing technology, and new technologies are currently being implemented and tested in pilot schemes. From a research perspective, it would be beneficial to study these implementations as well as how the technologies can be used on a larger scale.

It is critical to understand the particular role of a warehouse in an omni-channel, considering that material-handling nodes can take on many different roles and should therefore be uniquely designed (Ishfaq *et al.*, 2016; Wollenburg *et al.*, 2018). A major challenge for warehousing is the increasing number and types of warehouses and stores in a given network and the growing mix of channels (Gu *et al.*, 2010; Marchet *et al.*, 2018). In addition to integrating e-commerce and store replenishment, large branded retailers have started selling their goods through giant marketplaces like amazon.com. This development may imply different scenarios of increased drop-shipment where, for example, the retailers deliver consumer packages directly to another e-tailer’s customers, and omni-channel warehouses will ultimately be required to handle and coordinate a wide range of incoming and outgoing flows (Bartholdi and Hackman, 2016; Hübner, Holzapfel and Kuhn, 2016). These changes will have implications for warehouse operations and design. In order to

	Receiving (Suppliers)	Receiving (Returns)	Pu-away and Storage	Picking and Sorting	Packing and Shipping	General
Layout	<ul style="list-style-type: none"> • What challenges do OC retailers encounter in designing the receiving layout when integrating multiple flows in one warehouse? • How should the receiving layout be designed to manage increased cross-dock flows? 	<ul style="list-style-type: none"> • How do increased return flows impact layout considerations for the receiving area? • What factors impact the decision to separate or integrate receiving layout for customer returns and incoming goods from suppliers? 	<ul style="list-style-type: none"> • How do OC retailers manage increased complexity (larger assortment and mixed order size) in the design of storage space? • What factors impact the decision to integrate or separate the storage layout for store- and online orders? 	<ul style="list-style-type: none"> • How do OC retailers design integrated picking areas with different order profiles (mixed order size)? • To what extent is sorting required in OC warehousing and what are the layout requirements? 	<ul style="list-style-type: none"> • What factors impact the appropriateness to integrate or separate physical shipping areas for different types of packing and consolidation activities? 	<ul style="list-style-type: none"> • How should the overall warehouse layout be designed to enable flexibility to handle extreme demand peaks (such as Black Friday)? • How should the layout of a retail store acting as an FCC be designed to successfully cater to a range of activities (e.g. sales, marketing, order picking, act as pick-up point, returns handling)?
Equipment	<ul style="list-style-type: none"> • What are the challenges and opportunities in the choice of handling equipment to manage increased complexity of multiple incoming flows in the receiving operation? 	<ul style="list-style-type: none"> • How do the expected increase in returns impact the requirements on staff competences? • How should OC retailers approach the integration or separation of returns related to customer returns and incoming goods from suppliers (e.g. utilizing time windows)? 	<ul style="list-style-type: none"> • How can the next-generation equipment be used to manage increased complexity (larger assortments and variety) and make the pu-away and storage more effective and efficient? 	<ul style="list-style-type: none"> • What mix of equipment is required to manage increased complexity in picking (e.g. larger assortment and mixed order size) and what factors should be considered? 	<ul style="list-style-type: none"> • How does increased complexity (mixed order size and new customer requirements such as labeling) impact the choice of packing and shipping equipment? 	<ul style="list-style-type: none"> • How should investments, risks, costs, and gains related to new storage and handling equipment necessary for OC channel consists of independent decisionmakers (e.g. franchisee)?
Labour and Activities	<ul style="list-style-type: none"> • How should the receiving operation and activities be designed to support combinations of flows that move either into storage or directly to packing and shipping? • To what extent do OC retailers pool and balance workforce and capacity for different flows in the receiving operation? 	<ul style="list-style-type: none"> • How do OC retailers decide which SKU level to store (i.e. single units or case packs) when integrating inventories for store and e-commerce? • How is the overall inventory optimized strategy and increased use of drop-shippments affecting the inventory strategy and stock levels in various MH nodes? • Who should perform MH operations: store staff, layaway and storage in stores, logistics or sales people? 	<ul style="list-style-type: none"> • How do OC retailers decide the extent to which picking activities for store- and online orders should be integrated or separated? • How should the picking and sorting operation and activities requirements on shorter lead times from customer order to delivery? • How should OC retailers operate when there is a limitation in inventory or capacity? 	<ul style="list-style-type: none"> • How should packing activities for consolidation of multiple flows/orders/packages be designed to support delivery of single shipments to customers? • How do changing requirements on e.g. labeling and gift wrapping affect the design of packing activities? • How should the packing and shipping operations be designed to meet requirements on shorter lead times from customer order to delivery? 	<ul style="list-style-type: none"> • How do OC retailers overcome the decreasing warehouse capacity in a short- and long-term perspective? • For what type of flows is it possible to use cross-docking and what factors impact the decision? 	<ul style="list-style-type: none"> • What warehouse operations and activities are required in various MH nodes and what KPIs should be used given their different roles, operations and activities? • What warehouse operations and activities do OC retailers outsource and why? • How do OC retailers overcome the decreasing warehouse capacity in a short- and long-term perspective? • For what type of flows is it possible to use cross-docking and what factors impact the decision?
Automation	<ul style="list-style-type: none"> • How can automation be used to increase effectiveness and efficiency of the receiving operation and what factors should be considered? 	<ul style="list-style-type: none"> • To what extent is it possible and valuable to automate the receiving of customer returns and what factors should be considered? 	<ul style="list-style-type: none"> • To what extent is it possible and valuable to automate the pu-away and storage and what factors should be considered? 	<ul style="list-style-type: none"> • How can automation be used to improve picking and sorting, e.g. to meet big and rapid changes in demand, or to handle a variety of order types and flows? 	<ul style="list-style-type: none"> • How do varying packaging characteristics and requirements from store and e-commerce impact the appropriate type and level of automation? 	<ul style="list-style-type: none"> • What new competences and capabilities are required in a MH node to handle an increased use of complex automation solutions and other technology? • What are the challenges and opportunities for human-robot interaction?
IT Systems	<ul style="list-style-type: none"> • How can OC retailers improve registration of received goods through IT systems? (e.g. pre-arrival notices)? • What are the requirements on IT systems to enable effective and efficient cross-dock flows? 	<ul style="list-style-type: none"> • How can OC retailers improve system registration of customer returns to enable last re-integration of goods to inventory? 	<ul style="list-style-type: none"> • What factors should be accounted for in a WMS to determine optimal layout, storage- and online demand profile (e.g. campaigns, product category and size)? 	<ul style="list-style-type: none"> • What functionality in IT systems are required to support effective and efficient picking and sorting (e.g. temporary storage and replenishment)? 	<ul style="list-style-type: none"> • How can IT systems support sorting, consolidation, and coordination of multiple flows from store and online orders (considering a wide range of final destinations and shipping times)? 	<ul style="list-style-type: none"> • What new competences and capabilities are required in MH nodes to handle an increased use of complex IT solutions? • What are the challenges and opportunities with integrating WMS with other network IT systems to best support OC logistics?

Notes: Omni-channel, OC; material handling, MH; key performance indicator, KPI

handle incoming goods from multiple suppliers as well as increased consumer returns, retailers need to consider time windows for arrival of goods and the possibilities for the pooling and balancing of warehouse space and workforce (Petersen and Aase, 2004; De Leeuw and Wiers, 2015). Other requirements for receiving include larger areas and dedicated staff with new skills and competencies to handle registering and sorting of goods for quick input into the warehouse (Hübner, Holzapfel and Kuhn, 2016).

The integration of multiple flows in the same warehouse will also have implications for packing and shipping. Integrating storage for the online and store channels may require mixing picking and sorting methods (e.g. single vs batch picking), which are adapted to the characteristics of each channel. Store deliveries and e-commerce also come with different packing requirements, such as specialized areas, equipment and staff expertise, and there may be unique features such as labeling and gift-wrapping that need to be integrated within the existing operation. Furthermore, the multiple flows (e.g. cross-docking, mixed order sizes and zone picking for different goods sizes) need to be coordinated to avoid scattered deliveries to stores and e-customers (Larke *et al.*, 2018). These requirements will increase the demands on the sorting of goods, so a dedicated sorting area may become necessary to cope with increased throughput. Customer requirements for home delivery and shorter time windows (Hübner, Kuhn and Wollenburg, 2016) may also increase the complexity of sorting activities considering the variety of final destinations and shipping times. These complex and time-consuming sorting activities increase the need for sophisticated WMSs and functionalities (Faber *et al.*, 2002), and may require retailers to consider automation alternatives such as conveyer belts (de Koster *et al.*, 2007). Meanwhile, there might be a need to implement “WMS light” in smaller material-handling nodes (e.g. FFC) with the possibility to install and close such installations with short notice. Various systems will also need to be integrated with each other to enable the sharing of inventory and order information across the omni-channel (Oh *et al.*, 2012; Napolitano, 2013). This transformation comes with the need for big investments in information technology, which calls for increased attention from senior management to warehousing issues. It also leads to the questions of who will carry the costs and how to share risks and benefits. This will be an especially sensitive issue in retail chains characterized by more decentralized ownership/decision makers such as franchise takers or independent dealers cooperatively owning a joint brand (Cai *et al.*, 2012; Wollenburg *et al.*, 2018).

Another implication and big challenge for warehousing is that the time from order to delivery has increased in importance for omni-channels (Marchet *et al.*, 2018). Customers expect shorter lead times, which puts pressure on reducing throughput times in warehouses, that is, the total time required from order placement to it being picked, sorted, packed and shipped (Hübner *et al.*, 2015). To cater for reduced lead times, omni-channel warehouses may experience an increase in cross-dock flows where the put-away, storage and picking operations are cut out and goods instead move directly from receiving to packing and shipping (Bartholdi and Hackman, 2016). Another implication of reduced lead times is an increased level of automation of various warehouse operations to improve the speed of material handling (Hübner, Kuhn and Wollenburg, 2016). There is also a wide range of new technologies such as video technology and augmented reality that have been developed and tested to make material handling more effective and efficient (Kembro, 2016; Kembro *et al.*, 2017).

In parallel with shorter lead times, the trend of urbanization has led to omni-channel warehouses often being located close to cities where accessing land is difficult and expensive. Considering also the rapid growth in demand, primarily driven by e-commerce, retailers seek ways to maximize capacity utilization in their existing premises. In the short term, a big challenge will be the ability to retain sufficient, qualified workforce (Michel, 2015). In the long term, one of the main challenges will be insufficient warehouse

space where retailers must consider leveling strategies to balance demand and capacity over time. Hübner *et al.* (2015, p. 98) conclude: “potential capacity management levers are highly dependent on the structural characteristics of the warehouse.” A critical aspect of capacity is the integration of inventory and storage, avoiding having multiple, separated stock positions for e-commerce and store replenishment in the same warehouse (Marchet *et al.*, 2018). The literature highlights the benefits of integrating capacities related to using the same warehouse space, similar processes, joint safety stock and shared personnel for handling store replenishment and e-commerce, for example. Particularly, integrated inventory systems make it possible for the retailers to keep less inventory and create an opportunity to achieve a higher overall service level due to inventory pooling (Hübner, Holzapfel and Kuhn, 2016, Hübner, Wollenburg and Holzapfel, 2016). Integrated inventory systems will however lead to more complex inventory management, and joint inventory for multiple channels might lead to different requirements on service levels that must be aggregated into an overall inventory policy (Agatz *et al.*, 2008; Hübner *et al.*, 2015).

A related aspect is that warehouses must cope with yearly, weekly and daily demand fluctuations where capacity peaks for stores and e-commerce often are similar over the year but can differ over the week. While retailers may operate with fixed delivery patterns for stores, the online order volumes are often harder to forecast (Hübner *et al.*, 2015). Demand fluctuations and uncertainty put pressure on warehouses to be able to quickly increase or decrease capacity, for example, by distributing or shifting labor resources over the week and across operations (Agatz *et al.*, 2008). An example is the demand peaks and variations connected to marketing campaigns such as Black Friday and Cyber Monday, where new bottlenecks emerge as orders and deliveries are significantly higher than the average volumes. Flexibility in terms of capacity, which is typically difficult to achieve in streamlined warehouse operations, has thus become significantly more important for the success of omni-channels. The importance of flexibility has also increased for storage and picking equipment to manage a large mix of SKUs, due to the wider assortment and more rapid rate of new product launches, and the need to handle a variety of order sizes catering to both physical retail stores and e-commerce (Hübner, Holzapfel and Kuhn, 2016). Another aspect of flexibility is the importance of dealing with prioritized orders (between store and online) and real-time changes and allocations in picking (Hübner *et al.*, 2015). Considering this escalated need for multi-faceted flexibility, companies evaluate if and what warehouse operations should be carried out in-house vs the pros and cons of outsourcing to an LSP (Napolitano, 2013; Bernon *et al.*, 2016).

Along with the increased focus on shorter lead times and increased flexibility, competition pushes retailers to cut logistics and warehousing costs (Hübner, Kuhn and Wollenburg, 2016). One of the main focuses will be on improving picking operations, considering their large share (often around 50 percent) of total warehouse costs (Bartholdi and Hackman, 2016). However, while integrated picking operations for store and online orders have several advantages, such as economies of scale and flexibility in short-term capacity allocation, this approach implies a more complex picking system, which requires “assimilated infrastructures, resources and know-how for picking orders of both channels to handle outlet volume and single parcel volume” (Hübner *et al.*, 2015, p. 90). Therefore, it is difficult to make integrated picking operations cost efficient (Hübner, Kuhn and Wollenburg, 2016), and the decision to integrate picking of store and online orders must consider a range of factors such as the characteristics of the product assortment to be picked, the similarity between order sizes in different channels, the range of applied picking methods and equipment as well as store size and replenishment frequency (Faber *et al.*, 2013; Hübner, Holzapfel and Kuhn, 2016; Marchet *et al.*, 2018; Wollenburg *et al.*, 2018). In general, the more differences there are between the two channels, the more

difficult it is to integrate the picking activities. Hübner, Holzapfel and Kuhn (2016, p. 275) add: integrated DC locations for both channels increase the complexity of warehouse operations,” where integrating flows could result in too much complexity for handling the range of products and orders. Thus, retailers need to measure and evaluate if the gains from integrating inventories and pooling capacities outweigh the increased complexity in picking, or if it would be better to separate part of the flows into different warehouses. Marchet *et al.* (2018) highlight this issue by identifying four clusters of companies that either separate, or, to varying degrees, integrate inventory and picking activities at the warehouse level.

In summary, omni-channels have multiple implications for warehouse operations and design, and research increasingly stresses the importance of tailoring warehouses to the particular context. Nonetheless, there is a lack of research on how to design warehouse operations in terms of layout and the activities needed in an omni-channel warehouse. Agatz *et al.* (2008) present general models that could be applicable for designing picking operations, but do not adapt them to the omni-channel context. Hübner *et al.* (2015) initiate a discussion regarding design options, mentioning picking zones and scheduling. We extend the extant knowledge, based on our discussion of implications, to develop a comprehensive and structured research agenda with the purpose of guiding future research on omni-channel warehousing (see Figure 3).

Managerial implications

This study offers practical implications by pointing out different themes in omni-channel logistics and implications for warehouse operations and design. The identified themes and related aspects pose challenges for managers in retail every day, but to different degrees, as some retailers are leaders and other laggards. Managers must understand how omni-channel strategies impact their companies' value proposition and future demand (e.g. variation and lead time), the potential changes of future network structure and the roles of different material-handling nodes. As more nodes (e.g. stores) in the omni-channel network seem to get involved and partake in material-handling responsibilities for e-commerce orders (such as click-and-collect), there will be implications for where and how warehousing theory should be applied.

Neither research nor practice seems to provide “one right answer” of how to adapt or improve warehouse operations and design in omni-channels, and in practice, many different modus operandi are currently being tested and evaluated. The themes and set of research questions presented in this paper could help practitioners as a checklist of important topics to consider when deciding between alternatives for warehouse operations and design in the transformation to omni-channel logistics. With limited resources, managers must prioritize which activities to focus on, and analyze which design element and pioneering practice (e.g. IT and handling equipment) could, and should, be applied to improve current performance. For this purpose, we suggest a simple four-step process: first, understand the changing omni-channel context and the transformation of value proposition, network design, and the need of new types of material-handling nodes. Second, assess the current performance of different warehouse operations at different nodes (e.g. related to cost, lead time and flexibility) compared to competitors' and best practice. Third, analyze how warehouse operations and design aspects should be configured for each material-handling node to improve performance. Also consider if and which nodes, flows and warehouse operations that should be outsourced vs managed in-house, and how an external partner such as an LSP could contribute to developing omni-channel logistics and warehousing. Fourth, prepare implementation by analyzing warehousing investments, costs and benefits for different actors and logistics nodes, and suggest a risk and reward-sharing mechanism that distributes risks and rewards in a fair way.

Conclusions

Although warehousing is critical for omni-channel logistics, the available warehousing literature is sparse while other omni-channel retail and logistics literature is advancing. An increased focus on omni-channel warehousing is required and, as such, this paper presents a research agenda, which could be useful to guide scholars in the field and in their research endeavors. The agenda can also guide practitioners when exploring warehousing options for implementing omni-channel logistics.

The purpose of this study is to identify themes related to the transition toward omni-channel logistics and to derive the implications for omni-channel warehousing. Within warehousing, there has been a series of general literature reviews developing research agendas (see, e.g. De Koster *et al.*, 2007; Gu *et al.*, 2010; Davarzani and Norrman, 2015), however, without any orientation toward retailers' current challenges with new channel strategies. Compared to Swaminathan and Tayur (2003) and Agatz *et al.* (2008), our study is performed a decade later, and covers new literature with a focus on the current challenges and implications for omni-channel warehouses. Furthermore, Agatz *et al.*'s (2008) literature review focused on distribution network design and inventory management, with only limited attention to warehousing. Their observations regarding warehousing were mainly that different transaction sizes between e-fulfillment and multi-channel orders create issues for the degree of automation, warehouse layout and return handling. Recently, Hübner, Holzapfel and Kuhn (2016) included a literature overview in their explorative interview study on omni-channel distribution, but the main focus was not on specific warehousing issues but rather on network design, inventory management, last-mile fulfilment and return processes. Similarly, Melacini *et al.* (2018) do not focus on warehouse operations and design but instead review literature and develop themes related to distribution network design, inventory and capacity management, and delivery planning and execution.

We connect knowledge from various fields, such as logistics and supply chain management, operations research, information technology, retailing and marketing, to identify and categorize ten themes relevant to the transition toward omni-channel logistics. We build on these themes to discuss implications for warehouse operations and design, and present an extensive and structured set of research questions that address issues for different warehouse operations and design aspects in relation to their interdependence with value propositions, channel management and physical distribution network design. The provided framework also contributes to practice as a checklist of important topics to consider when deciding between design alternatives in omni-channel warehousing. The interdependencies between channels strategy, network design and warehouse operations could be particularly worthwhile to consider because a decision in one of the areas might have long-term implications for the others. As more nodes (e.g. stores) in the omni-channel network seem to get involved and partake in material-handling responsibilities for e-commerce orders (such as click-and-collect), there will be implications for where and how warehousing theory should be applied. If a store turns into a node for picking, packing and delivering e-commerce orders, these activities must be done in an effective and efficient way.

There is a need for future research to apply a wide range of methods to develop knowledge on the growing phenomenon of omni-channel warehousing: first, empirical case studies could be used to better understand and analyze the pioneering practices already implemented, as retailers certainly are testing and developing new solutions and technologies within their omni-channels. Such studies would also make it possible to observe and better understand current issues and problems; second, explorative and descriptive survey studies can also contribute to knowledge development in this early stage (see, e.g. Hübner, Holzapfel and Kuhn, 2016) by researching development trends. With a growing number of companies transforming their multi-channels to omni-channels, the number of respondents will soon also be adequate for conducting, third, survey studies that

test different hypotheses regarding, for example, the relationships between different contextual factors, warehouse operations, design alternatives, and performance; fourth, operations-research modeling and simulation has clearly dominated previous research, both in general warehousing (see, e.g. Davarzani and Norrman, 2015), and in omni-channel strategy and network design (Table I), but we found surprisingly limited use of such research methods for omni-channel-warehousing-related issues. Hence, there is room for more omni-channel-dedicated models to address many of the content-related issues discussed above. Our belief is that the requirements of the omni-channel strategy will challenge many of the current warehousing practices and drive innovation, and hence turn warehousing back into an important field of logistics research, in which scholars can learn and build theory from pioneering practice.

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Corresponding author

Joakim Hans Kembro can be contacted at: joakim.kembro@tlog.lth.se

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