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The distribution network of Amazon and the footprint of freight digitalization

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ABSTRACT

The emergence of e-commerce as a dominant retail paradigm is associated with a rapid shift in the commercial footprint towards distributional-based consumption. Through the analysis of the geographical expansion, market coverage, and functional specialization of Amazon's distribution network, the research underlines that digitalization has a pronounced physicality. E-commerce is favoring a transition from the conventional retail freight landscape towards a new physicality of freight distributions involving purpose-designed facilities, modes, and channels. The case of Amazon underlines a consistent locational behavior to achieve a distributional hierarchy of facilities granting logistical access to consumer markets. The distributional hierarchy is organized in three stages, which are procurement and fulfillment, distribution, and last-mile.

1. Introduction: The digitalization of retail

The geography of retail was conventionally influenced by demographic factors such as density, lifestyle, and income, with retail activities seeking locations maximizing their customer base and sales (Dawson, 2013). From the 1960s, suburbanization and increasing mobility allowed for economies of scale to take shape as larger stores overtook smaller rivals and established new distribution structures based on mass retailing. This evolution is well documented (Holmes, 2011) and eventually led to the setting of extensive megastore networks where (suburban) locational advantages were supported by efficient freight distribution capabilities. The real estate footprint of retail increased substantially during the 1980s and 1990s, particularly in North America, where anchoring megastores to shopping mall development projects became the norm.

Economies of scale, new locations, and changes in sourcing and distribution strategies drive disruptions in the retail sector. The setting of chain stores such as Walmart and Target leaned on offering a wide range of products and services in each store, finding locations expanding customer access, and highly efficient procurement and distribution strategies (Lecavalier, 2016). The command of logistics played an essential role in the competitiveness of ‘big box’ retail stores, notably since imports from foreign suppliers allowed for declining prices of a wide range of retail goods. It is not uncommon that 90% of the inventory carried by a contemporary store is of foreign origin.

In the early 2000s, a new retail paradigm emerged around the massive diffusion of information technologies and e-commerce (WEF, WTO, 2018). Retailers have offered their customers the opportunity to purchase goods by catalog since the late 19th century, a direct marketing activity focusing on niche markets such as smaller towns and rural areas (Ross, 1990; Cronon, 1991). E-commerce enabled new forms of distribution, leaning on the fast delivery of packages and new forms of retailing, relying on a virtual storefront (Hortacsu and Syverson, 2015). Instantaneity and ubiquity for accessing retail goods became a standard (Ramcharran, 2013). The virtual store allowed for a physical separation of the interactional component of retail, where commonly, the customer was responsible for carrying back purchases.

Retail digitalization required the digitalization of exchanges, actors, settings, and offerings (Hagberg et al., 2016). Regarding the digitalization of settings, home deliveries rely on physical distribution systems and the growth of conventional courier and parcel services. The itemization of orders that results from e-commerce purchases cannot be consolidated because of the stochastic character of the demand. Unlike a retail store answering the aggregate demand of a small market area (e.g., a neighborhood), e-commerce answers individual itemized demands of a large market area (potentially a whole nation). This is also associated with differences in last-mile distribution since instead of truckloads (either full truckloads; FTLs or less than truckloads; LTLs) brought to a store, parcels are delivered to an individual delivery point.

E-commerce is a distributional form of consumption contingent
upon the efficiency and capabilities of its freight distribution system. It is the joint application of retailing and distribution strategies that are not just only focusing on the procurement (inbound) aspects of logistics, but increasingly on the final distribution of home deliveries. Supporting the logistics of e-commerce required a new footprint. Facilities have been set to fulfilling a specific role such as processing and packaging unique orders, sorting large volumes of parcels by geographical destinations, and decomposing shipments for final delivery routes.

In the 2010s, large e-commerce firms have emerged around the world, each the outcome of technological changes and the unique characteristics of their regional markets in terms of regulation and consumer preferences. Jindong and Alibaba are giants servicing the thriving Chinese market, building as they grew their own distribution capabilities, which were not available. Rakuten and B2W Digital are respectively, the largest e-commerce firms in Japan and Latin America (Brazil). In Europe, the largest e-commerce firms either come from an adaptation of retailers to online sales (e.g. Otto, Sainsbury, Tesco) or from new firms with a digital focus (e.g. Zalando) able to latch on already effective parcel delivery services. Still, Amazon epitomized this emerging logistics of e-commerce and remained the largest e-commerce firm in the world with a strong focus in North America and Europe, where it ranked first in online sales. In 2018, it accounted for 38% of all online retail sales in the United States and 4% of total retail sales (Bloomberg, 2019). In its initial phase of growth, Amazon was able to use the distributional capabilities of postal services and third-party logistics service providers.

This paper provides an overview of a rapid retail footprint shift that took place since 2010 through the analysis of the geographical expansion, market coverage, and functional specialization of Amazon's distribution network. It underlines that digitalization has a pronounced physicality and that e-commerce resulted in a partial shift from the conventional commercial freight landscape of retail towards a new physicality of freight distributions involving purpose-designed facilities, modes, and channels.

2. The Freight landscape of E-commerce

Understand contemporary retailing requires two distinct but complementary geographies, the geography of retail stores, and the geography of warehousing. Research in the spatial diffusion of retail underlined that the expansion of a network of retail stores often took place through proximity effects. The main observed effects are contiguous expansion (Graff and Ashton, 1994), maintaining and expanding a density of stores allowing to lower distribution costs (Holmes, 2011; Joseph and Kuby, 2016) and expanding through waves of regional market saturation to build up store density and expand from that base (Joseph and Kuby, 2015).

Research covering the geography of warehousing has investigated their locational behavior, particularly their shift to suburban locations (Bowen, 2008; Cidell, 2010), a process that is commonly referred to as ‘logistics sprawl’ (Dablanc et al., 2014). The growth of international trade, more stringent supply chain requirements, operational warehousing characteristics (single floor high racks), and accessibility to road, maritime, and air air networks are factors commonly used to explain their locational behavior. While retail stores were seeking market density, the distribution centers supporting them relied on low densities in peripheral areas with high transport network accessibility.

The emergence of e-commerce is creating a new freight landscape that concerns its demand structure, the locational characteristics of its distribution facilities, the modes and terminals used, and crucially, its last-mile that commonly takes place in urban areas (Rodrigue et al., 2017). Instead of the distribution center being the support structure of networks of retail stores, with e-commerce, it becomes the anchor, at times rendering the retail store obsolete and at others relegating them to a showroom and a pickup point. Seminal work concerning the distribution network of Amazon underlined the importance of economies of density in the development of fulfillment centers (Houde et al., 2017). Expanding the network of distribution centers reduce shipping costs and increase profitability. E-commerce is also focusing on the last mile through the setting of city logistics strategies (Browne et al., 2019). Fast deliveries of restaurant orders and groceries are also a key driver in demand for city logistics (Dablanc, 2019).

The growth in home deliveries is one of the most tangible impacts of e-commerce as consumers are substituting a share of their consumption to purchases made online (Gossling, 2018). Initially, this demand was mainly discretionary, but the adoption of e-commerce as a consumption paradigm is increasingly involving essential goods such as household items and groceries. Although several aspects of e-commerce are perceived as virtual retailing, e-commerce can better be understood from a freight distribution perspective since the distribution and delivery aspects are essential. A successful e-commerce transaction and its value for the consumer rely on the capability to deliver the order within a specified timeframe. Thus, distributional consumption is a fundamental characteristic of e-commerce.

Because of its operational characteristics, the freight landscape of e-commerce is having four fundamental impacts on freight distribution (Fig. 1).

While a conventional retail consumption pattern involves consumers going to stores and carry back home their purchases (by foot, car or public transit), with e-commerce, most of these purchases are delivered through parcel services (business to consumer deliveries) (1). The scale of last-mile logistics is being transformed by the growing role of parcel deliveries and strategies to ensure that these parcels reach their consignees within a specified timeframe. The number of shopping trips has declined accordingly, but subject to several factors such as income, mobility, and locational setting (Shi et al., 2019). The assumption is that growth in the reliability of deliveries creates a synergetic effect through the generation of additional demand.

The transition towards online purchases is reducing the demand for commercial retail activities (2), implying a downward pressure on the
conventional retail footprint (Zhang et al., 2016). Many large chain retailers are substantially reducing their footprints, more than often involuntarily through store closures and even bankruptcies. Paradoxically, since home deliveries are distribution-based activities, the growth of e-commerce involves an increase of the warehousing footprint. This transition may also change real estate (and rent) values for commercial areas since the location dynamics of distribution centers tend to favor suburban or exurban locations, which are experiencing a corresponding valuation.

Stores can also be designed to cater more effectively to the operational characteristics of e-commerce, acting partially as showrooms, warehouses, and pickup locations (known as Omni-channel retailing; Verhoef et al., 2015). Changes in the footprint of e-commerce allow e-retailers to sell items at lower costs since, on a per sales basis, the cost of operating distribution centers in peripheral areas is lower than the cost of operating stores in central (high rent) areas. Therefore, the lower cost of its footprint is improving the competitiveness of e-commerce in regard to conventional retailing.

E-commerce required the development of entirely new types of distribution facilities (3), at its core, the e-fulfillment center designed to service large volumes of heterogeneous orders shipped as parcels. More than any other type of distribution center, the high throughput requirements of logistical facilities have pressured the need for automation. These facilities are located to maximize market access and to minimize the lead time (Hounde et al., 2017) and are discussed extensively in the next section.

E-commerce is reaching a throughput level giving its main actors significant leverage as users of logistical and transportation services (4). Many are developing capabilities as third-party and fourth-party logistics service providers, following vertical integration strategies through the acquisition of freight distribution segments. The primary forms this expansion take for large e-commerce platforms like Amazon include carrier services, such as truck parcel deliveries, and freight services such as distribution and warehousing facilities (Lieb and Leib, 2016). These services have the potential to compete with those of already established 3PLs. The setting of urban logistics facilities and freight stations (pick up points) are also part of vertical integration. The development of non-vessel operating common carrier services is an additional strategy undertaken by major online retailers relying on containerized shipping (international sourcing) and able to generate substantial container volumes. Last, like standard retailers, online retailers are establishing partnerships with manufacturers to provide customized goods commonly sold under their brand.

3. E-commerce logistics facilities

One of the foremost physical expression of retail digitalization is the emergence of custom logistics facilities. Like ‘big box’ retailers beforehand (high throughput distribution centers and cross-docking facilities), the setting of specialized freight facilities is a unique outcome of the physical and operational requirements of e-commerce. Each of these facilities fulfills a specific role along the distribution channels with its unique geography of warehousing.

3.1. Functional specialization

A geography of freight distribution has emerged on the principle of functional specialization of distribution facilities to grant market access. Fig. 2 proposes a typology of the role and function of these facilities that can be divided into seven major types. The naming and the function of the facilities have reached a consensus among the industry (MWPVL, 2020).

An inbound cross-dock (IXD) facility (1) prefers locations near major intermodal terminals such as ports and rail yards for de-stuffing international containers carrying imported goods. They can also handle deliveries from domestic suppliers. They perform a similar role than the import distribution centers established by major retailers from the 1990s to accommodate the growing quantities of foreign goods supplying retail (LeCavalier, 2016). IXD facilities are configured with bay doors on both sides and are functionally like transloading facilities but service exclusively e-fulfillment centers. On one side of the facility, inbound cargo loads (mainly containers) are unloaded and stored. Within the facility, the inventory is stored until needed, implying that the IXD is a crucial buffer in large scale e-commerce supply chains. On the other side of the facility, full truckloads are assembled according to demand and sent to specific e-fulfillment facilities. IXDs are the point of entry for the fulfillment process in e-commerce by synchronizing inbound procurement logistics with the distributional capabilities of e-fulfillment centers.

E-fulfillment centers (EFC) (2) are extensive facilities assembling individual online orders (footprint of half a million to one million square feet). Due to the high number of items held in inventory, EFCs usually have high racks storage. While a 24-ft clearance used to be the norm, 36 ft is now considered to be the standard EFC height, with newer designs exceeding 40 ft (Wall Street Journal, 2015). In recent years, several EFCs have become partially or fully automated, allowing them to quickly retrieve orders from storage and place them into backs for parcels assembly.

With enough scale, an online retailer elects for the specialization of its EFCs, which falls into two categories. The first is the range of items handled, implying there are e-fulfillment centers specialized for apparel, electronics, jewelry, groceries, and perishables. The second specialization is by item size where EFCs are mainly allocated to handle small sortable (items fit in a small box; < 10 kg), large sortable (items fit in a large box; < 25 kg) and large non-sortable (items too large for a box; e.g., furniture, tv, printers). The main reason behind this specialization is that different item sizes require different warehouse handling equipment. Small sortable warehouses can easily be automated with conveyor belts, while this is more complex for large non-sortable items stored on pallets.

Air hubs (not shown in Fig. 2) are facilities adjacent (co-located) to airports designed to transfer parcels to and from air cargo services with regional fulfillment and sorting centers. These services are usually organized as a hub-and-spoke network linking metropolitan areas to an intermediate hub. Major third-party logistics service providers such as FedEx, UPS, or DHL are generally providing these air cargo services through gigantic hub/sortation facilities in Louisville and Memphis. Amazon Air, which began operations in 2016, is developing an air network as the online retailer generates enough volumes to justify investing in dedicated air cargo services.

Parcel hubs and sortation centers (3) arrange shipments by their regional/local destinations and tend to be large-sized facilities (half a million square feet). They are designed to sort parcels bound to an area into smaller batches, such as a postal code, which includes sorting packages coming from different e-fulfillment centers. From the sortation center, parcels can be sent to local post offices or parcel delivery stations for last-mile delivery or to subcontracting delivery companies. Due to their high throughput sortation function, these facilities rely on the cross-docking model where inbound flows arrive on one side and outbound flows on the other. Further, depending on the strategy of the online retailer, they can also act as e-fulfillment centers (parcel hubs), particularly for goods that are in high and regular demand. Like e-fulfillment centers, low land cost is an essential locational attribute, but the facility is located to maximize accessibility to a regional/metropolitan distribution system.

Parcel delivery stations (4) are medium-sized cross-docking facilities mostly to sort parcels bound for specific local delivery routes. Since deliveries are primarily within an urban setting, parcels are usually loaded into delivery vans or other specialized urban delivery vehicles (electric vans and even cargo bicycles). These facilities are usually in the immediate periphery of a metropolitan area, but some are in central locations if deliveries are done by adapted vehicles. Due to their high
throughput, parcel delivery stations can be accommodated by lower clearance buildings at brownfield locations.

Pickup locations and local freight stations (5) are used when deliveries are not made directly to the final address. These small-scale facilities, located at accessible high-density locations, are serviced with urban adapted vehicles. In most cases, a store-like facility is used, but an emerging trend has been the usage of freight stations composed of locker banks where customers can pick up their parcels by using a code (e.g., credit card, QR code).

Fast delivery hubs (6) are designed to service the growing requirements for fast deliveries of high demand items, usually within a lead time of 48 h. To do so, these small to medium-sized facilities are located within large metropolitan areas carrying an inventory of a limited number of high demand items. The inventory is therefore pre-positioned ahead of the expected demand and made available immediately for delivery upon order. Since the availability of green sites in central areas is limited, older facilities are often converted into fast delivery hubs. While storage and retrieval can be less efficient, fewer items and market proximity compensate for this drawback. A distinct category of fast delivery hubs concerns groceries delivered using a separate distribution channel.

3.2. Distribution channels

Amazon is associated with the development of distribution channels forming an e-commerce supply chain hierarchy composed of three main stages (Fig. 3).

The first stage involves procurement with the primary purpose of stocking e-fulfillment centers with the required inventory. The sourcing strategies are similar to those established in prior decades by large big-box retailers where imports from low-cost manufacturers have been prevalent. Still, the extensive range of goods sold by Amazon, in addition to products offered under its own brand, underlines multiple suppliers, origins, and transportation modes used for deliveries. The positioning of the inventory for fulfillment indicates that the primary concerns are regional demand patterns and minimizing delivery time through the advantage of proximity.

The second stage is the distribution of parcel delivery stations towards facilities near the final delivery point. The matter is to establish a distribution structure that offers capacity, flexibility, and time performance through the selection of the most suitable distribution channels. The focus is on where the order is going to be fulfilled and the routing of the delivery.

The third stage is known as the last mile that brings parcels to their final destination, mainly through delivery routes from specialized facilities. The purpose is developing city logistics strategies that cope with the constraints of urban freight distribution such as congestion, the lack of parking space, and the atomization of deliveries (a small number or a unique parcel to a single address).

The introduction of sortation centers has led to a blurring of the distribution channels since parcels routed through Amazon's distribution system can be sent to a sectional center facility (SCF) for last-mile delivery (Fig. 3). An SCF is a processing and distribution center of the United States Postal Service (USPS) that serves a designated geographical area defined by one or more three-digit ZIP Code prefixes. It routes mail between local post offices and network distribution centers (NDCs), which form the backbone of the parcel network. A parcel delivered to an address by USPS may have initially gone through Amazon distribution channels, reached a sortation center, and sent to a local post office.

In standard e-commerce supply chains, e-fulfillment facilities are usually owned by the online retailer with parcels allocated to third-party logistics providers. They operate a network of parcel hubs, sortation centers, and parcel delivery centers servicing several market areas. However, consolidation (vertical integration) trends are emerging as large online retailers are opening their sortation centers. Some are also getting involved in the transportation segment of their distribution with urban delivery vehicles and trailers to move cargo between e-fulfillment and sortation centers. A new distribution system controlled by Amazon has emerged to support its stringent logistics requirements.

4. Data

Empirically analyzing the footprint of e-commerce required performing an inventory of Amazon’s facilities in the United States through a geocoded dataset.¹ This dataset contained for each facility its four-letter facility code, function, address, the year it came online, its square

¹ MWPVL International maintains list of facilities used by Amazon, which is used with permission. This dataset is the most comprehensive available, but the full range of facilities such as Prime Now Hubs may be incomplete. https://mwpvl.com/html/amazon_com.html.
footage, status (open, closed or planned), and the facility code of a co-located facility (if present). The database does not include local freight stations (locker boxes). Each address was geocoded into latitudes and longitudes, trying to correspond to the middle of the roof of the facility, with the resulting dataset containing 578 operational facilities classified into seven functions (Fig. 4).

Freight facilities are either directly owned or leased by Amazon. Still, the online retailer prefers renting as it was estimated that Amazon owns less than 5% of the footprint it operates. The main reason behind its reliance on leasing is the flexibility it confers in terms of market penetration while requiring less capital investments to operate the same footprint. This has allowed Amazon to expand faster and adjust to regional shifts in market demand. A drawback is that it must rely on the existing commercial real estate market, which can limit available options on the market or to what commercial builders are willing to provide. However, commercial warehousing real estate is standardized, allowing to adapt operations to the existing footprint. As e-commerce matures, it can be expected that online retailers such as Amazon will own a more significant share of their distribution facilities.

As of 2019, Amazon accounted for a total footprint of 171.1 million square feet in the United States, the equivalent of 15.9 km². The majority of the footprint is accounted for by 187 e-fulfillment centers (71.4%), which are the core support for e-commerce. The second most crucial footprint concerns 250 delivery stations (13.9%), which are the last step (last mile) in the e-commerce distribution chain. The average size per facility type reveals apparent differences mainly based on a trade-off between economies of scale, market areas, land use density, lead time, and land cost. The principle of facility co-location is also prevalent, with 68 (11.7%) of the facilities co-located (sharing the same physical facility but as distinct units).

The growth of Amazon's footprint is impressive, exponential (Fig. 5), and the structure and composition of this growth suggest four phases. The first phase represents the emergence of Amazon as a niche online retailer in 1995, mostly focusing on books, movies, computer games, and music (1). These products were at the time distributed in a physical form packaged into parcels, but since then, all these products are almost exclusively distributed digitally. Its footprint was limited to a few e-fulfillment centers on the East and West coasts.

From the mid-2000s, as its initial product specialization became digital products to the most part, Amazon transitioned into new product
categories such as consumer electronics, toys, cosmetics, and fashion items, directly competing with retail (2). Its footprint of e-fulfillment centers was expanded, particularly after 2006, when fulfillment by Amazon was initiated. Under this program, Amazon allows retailers to use its e-fulfillment facilities to store, package, and ship their inventory for a fee. The outcome was the shift of inventories to Amazon facilities, as the volumes handled by its e-fulfillment centers are used to support the widespread development of e-commerce. This placed Amazon in the paradoxical situation of complementing the e-commerce development of firms it was often competing with directly. Because of its switch to consumer products, Amazon's inventory increasingly relied on the imports of foreign goods arriving in containers, which required the setting of the first inbound cross-docking facility in 2007.

In the 2010s, with its business model well defined, Amazon undertook an aggressive horizontal integration by opening a large number of e-fulfillment centers across the United States (3). The ubiquity of digital devices and data networks allowed e-commerce to transition from a niche market segment into the mainstream consumer market. The growth in volumes also incited Amazon to begin offering Sunday deliveries with an arrangement with USPS in Dawson, 2013 with correspondence to the setting of the first sortation centers. By 2014, the delivery structure of Amazon was under stress. Its main American carriers, UPS and FedEx, are not dedicated to Amazon, which is only one of their customers. Demand surges, particularly during the holiday season (November and December), were not fully accommodated, leading to delays. As a consequence, Amazon started a process of vertical integration by expanding in ground transportation services to handle the additional demand and operational requirements of its distribution system (4). By 2020, it was estimated that Amazon was operating a fleet of more than 20,000 tractor-trailers (Thomas Industry Update, 2019).

5. The geography of Amazon's distribution network

Analyzing the geography of Amazon's distribution network in the United States considers the conventional supply chain and distribution perspective that involves the phases of procurement, fulfillment, distribution, and last-mile logistics (see Fig. 3).

5.1. Procurement and fulfillment

Procurement and fulfillment involve all the steps required so that Amazon's e-commerce platform has the capability and capacity to offer goods as a function of stochastic demand. While the e-fulfillment center is one of the most visible structures of e-commerce (Fig. 7), it relies on a share of its procurement on a network of inbound cross-docking facilities (Fig. 6).

Amazon's network of 10 inbound cross-docking facilities (IXD) is positioned in relation to port gateways and corridors. The main goal of IXD facilities is to transload import containers into truckloads bound to e-fulfillment centers. With an average clustering level (Nearest Neighbor Index of 0.60), IXD facilities are observed around the port gateways of Los Angeles / Long Beach and New York. Inland locations correspond to major intermodal terminals in proximity to manufacturing clusters as IXD facilities also receive domestic procurement. The weighted median location is revealing as it corresponds to an area close to the demographic center of the United States. None of IXD facilities are co-located, underlining that their function and operations are not compatible with other facilities.

From a network of IXDs, the inventory is distributed by trucks to Amazon's network of 187 e-fulfillment centers (Fig. 7). Domestic procurement can also go directly to an e-fulfillment center without going through an IXD. These palletized shipments bound to an EFC must use an appointment system to make sure that there is a docking slot and labor available for each FTL or LTL shipment.

The location of e-fulfillment centers (EFC) shows a strong market orientation with an NNI of 0.26 and relatively uniform distribution of facility sizes with a median footprint of 855,000 square feet. This implies that Amazon is using a facility size that it considers being optimal and that growth is accommodated by leasing new facilities of similar size. This is a common practice in the expansion of “big-box” retailers that elect for a standard store size, such as Walmart. The latter has a network of more than 3280 SuperCenters in the United States of an average footprint of 180,000 square feet. Still, there are variations in

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2 The Nearest Neighbor Index (NNI) is expressed as the ratio of the observed mean distance to the expected mean distance. The expected distance is the average distance between neighbors in a random distribution. If the index is less than 1, the pattern exhibits clustering. If the index is greater than 1, the trend is towards dispersion.

3 The weighted median location is the point that minimizes that summation of all distances and where each location is weighted by a factor of importance (square footage in this analysis). It therefore represents the central location of a distribution of locations and is technically the point of maximal accessibility.
Fig. 6. Amazon inbound cross dock facilities network (N = 10), mid 2020.

Fig. 7. Amazon E-fulfillment centers network (N = 187), mid 2020.
the footprint of EDCs reflecting the specialization of their functions with the great majority of the footprint in the 600,000 to 1 M square foot range.

The space requirement of EFCs usually implies their location in a suburban (exurban) setting, near a major highway, and a parcel hub, since orders are shipped through parcel services. Similar to IXDs, EFCs have a weighted median location in close proximity to the demographic center of the United States, underlining Amazon's strategy towards optimal market accessibility. The most common co-location concerns delivery stations as when an EFC is in proximity to a high demand area, there is an opportunity to use a part of the facility as a delivery station.

To accommodate the high throughput generated by online orders, a new generation of automated EFCs have developed random storage operations for sortable items. This matches the stochastic nature of online orders, and the large variety of goods carried. Sortable goods are stored randomly on automated racks with each location recorded, which reduces the average retrieval time since the inventory is at several locations in the distribution center. As online orders usually involve single items that are shipped as individual parcels, random storage matches more closely the volume and frequency of e-commerce orders. This storage strategy, which was developed for the purpose of e-commerce, reduces the warehousing footprint since inventory is stored in unallocated space. The storage capacity has a higher utilization level than if storage space was allocated by item category. Heavier and non-sortable items are stored in separate allocated spaces. An outcome of the diversity of items offered by Amazon is that a large number of e-fulfillment facilities are designed not for the type of items they carry, but if this item is sortable or not (Fig. 8).

The most common EFC (38% of all facilities where item specialization was known) are large non-sortable facilities that need to be close to markets because of the weight and bulk of the shipments. EFCs specializing in small sortable items are the second most common (34%) and have more locational flexibility. Specialized EFCs (12% of all facilities) focus on a specific range of items such as footwear, apparel, jewelry, and high-value electronics. Amazon also maintains two facilities solely specializing in returns where items are either restocked, sold to liquidation companies, or discarded.

5.2. Distribution

A complex hierarchical system supports the distributional needs generated by Amazon's extensive e-commerce activities. The two main networks solely focusing on distribution are air hubs and sortation centers.

Founded in late 2015, Amazon Air operated by early 2020 a fleet of 42 leased aircraft, the majority being 767 s. Amazon Air relies less on the hub-and-spoke structure than major air freight operators since the purpose of its services is to support purchases made on Amazon's digital platform. While it still extensively relies on the air networks of FedEx and UPS, Amazon Air is developing a network complementing the lack of capacity between its EFCs, which implies more direct services (Schwieterman and Walls, 2020). As of mid-2020, 29 airports were serviced, and Amazon operated directly six air hubs (Fig. 9). The development of the Cincinnati hub, expected to act as the primary nexus, is indicative that Amazon Air is seeking to replicate a hub-and-spoke structure that competes more directly with FedEx and UPS.

A significant factor in airport choice is proximity to distribution facilities, focusing on smaller airports at a distance from major metropolitan areas (Bowen, 2012). From these airports, parcels are brought by truck to regional sortation centers or local delivery stations. Thirty-two e-fulfillment centers (17%) and eight sortation centers (17%) are within 10 km from an airport serviced by Amazon Air, underlining a close integration between air distribution and fulfillment capabilities.

Sortation centers play an essential role in accessibility to regional distribution and represent the first layer to city logistics. When an area reaches a specific volume of parcel deliveries, Amazon is likely to implement a sortation center breaking loads bound to specific ZIP codes, transforming LTLs into FTLs. From these centers, parcels are either sent to delivery stations or to post offices for final delivery. As of 2020, 47 sortation centers of a median size of 321,400 square feet were covering the largest metropolitan areas (Fig. 10).

Sortation centers are the facilities having the highest level of dispersion (NNI = 0.74), underlining their reliance on accessibility to a regional parcel distribution market. This is particularly apparent by looking at the uniform spatial distribution of sortation centers along the Boston – Washington corridor, extending into Virginia and North Carolina. Their weighted median center is the same as the pattern observed for IXDs and EFCs. The most prevalent co-location involves delivery stations, Amazon Fresh, and Amazon Pantry facilities, underlining the importance of market proximity and low lead time and the last segments of the e-commerce distribution chain.

5.3. Last mile

Two distribution networks compose the last mile for e-commerce, which allows servicing specific metropolitan markets and neighborhoods. The first involves fast delivery hubs supplying the local market with pre-positioned high demand or perishable goods. They include Amazon Prime Facilities (Fig. 11) as well as Amazon Fresh and Amazon

![Fig. 8. Amazon E-fulfillment centers by item (N = 187).](image)
Pantry (Fig. 12), underlining a specialization in the fast deliveries market segment. The second involves delivery centers where parcels are loaded on vans for home deliveries or delivery points (Fig. 13).

The 53 Prime Hubs are located within large metropolitan areas, usually where there is good access to the local transportation system, which is illustrative of their high concentration level (NNI = 0.50). Prime Hubs are mainly of small size, with a median of 39,500 square feet, allowing for high demand items to be delivered within a 48 h
timeframe. They represent a trade-off between high market accessibility and its reduced delivery lead time with high rent costs. Regarding this, it was estimated that Amazon saves between 0.5% to 1% in shipping costs for every 100 miles of reduced shipping distance (Houde et al., 2017). The footprint is therefore attributed to selected items having a high turnover rate, multiplying the distance reduction saving effect. Prime facilities are mainly co-located with delivery stations, Amazon Fresh and Amazon Pantry facilities, that have in common short lead
times and access to central areas.

Amazon Fresh and Amazon Pantry are both specialized distribution services in selected metropolitan areas, with Amazon Fresh specializing in groceries, including perishables, while Amazon Pantry is specializing in household items and cleaning supplies. Orders in the former are delivered through its own distribution system, often in temperature-controlled totes, while orders in the later are delivered through regular parcel services. The two locational patterns observed concern areas with a high level of discretionary income (e.g., West Coast and New York) or with a large share of elderly population (Florida).

The network of delivery stations proliferated since Dawson, 2013, underlining Amazon’s effort to offer last-mile services through a process of horizontal integration. The delivery station represents the most common facility, occupying a small median footprint of 91,200 square feet in high accessibility areas. A specialization of delivery stations towards heavy and bulky goods requiring special last-mile delivery arrangements is being noted, involving 45 delivery stations (17%) as of 2020. This trend is indicative of Amazon moving into large consumption goods such as televisions and appliances. With a network of delivery stations being implemented, Amazon is substituting the full array of retailing goods and their delivery requirements. Delivery stations are the freight facility subject the most to co-location, accounting for 36% of all observed co-locations (26 locations).

A last-mile delivery network that has not been compiled in this

![Fig. 13. Amazon delivery stations network (N = 250), mid 2020.](image-url)

![Fig. 14. Location of Amazon's E-commerce facilities in the Los Angeles and New York metropolitan areas. Note: Same scale for both maps.](image-url)
research concerns freight stations. In 2011, Amazon began setting locker banks at high accessibility and high traffic neighborhood locations such as grocery stores (e.g., through the Whole Food chain that it owns) and drug stores. Evidence underlines that freight stations are usually located as a sequential chain along main delivery routes, particularly in institutional and high-density areas. Amazon further expanded this business by making them available to property managers so that they can be installed in apartment buildings and office complexes. The geography of this micro-freight distribution system remains to be further explored.

5.4. The regionalism of Amazon: Los Angeles and New York

Los Angeles and New York are major trade gateways and consumption markets (Rodrique et al., 2017). The complexity of the metropolitan areas in terms of density, accessibility, and available real estate implies a freight landscape that Amazon has populated with its hierarchy of facilities (Fig. 14). In both metropolitan areas, two distinct clusters are noted, the fulfillment cluster (A; large facility footprint of more than 600,000 square feet) and a last-mile cluster (B; small facility footprint of less than 150,000 square feet).

For Los Angeles, a large fulfillment cluster (A) composed of two inbound cross-docking facilities (IDX) and 15 e-fulfillment centers (IFC) has emerged in the Inland Empire (San Bernardino, Riverside, Ontario). This area has been the focus of substantial developments in warehousing and distribution activities in the last 25 years as distribution centers left areas nearby Los Angeles due to the lack of land (Dablanc et al., 2014). With three air hubs serviced by Amazon Air, this cluster is Amazon’s largest concentration of air cargo activity in the United States. A new 700,000 square feet air hub is expected to open at the San Bernardino International Airport (SBD) in 2021, improving the cluster’s high level of maritime and air connectivity. For New York, the fulfillment cluster includes one IDX located 75 km from the port’s container terminals and seven EFC along the Interstate 95 corridor between Newark and the suburbs of Philadelphia. The nearest Amazon Air hub is in Allentown, PA (125 km from NYC), which is also in important freight distribution cluster. In both cases, the median distance of the cluster is around 75 km from the CBD.

The last mile clusters (B) are composed of delivery stations, prime hubs, and Amazon pantry/fresh hubs, which are of smaller size and high throughput. These facilities are distributed in a relatively uniform fashion to maximize accessibility for last-mile deliveries in medium to high-density consumption markets. The only Amazon facility in Manhattan is a prime hub providing high demand items, and Long Island is serviced by two adjacent delivery stations with one specializing in heavy deliveries. Both Los Angeles and New York have their sorting centers at the edge of the high-density areas, about 25 km from the central business district. This locational characteristic is following its purpose of a point of interaction, a gateway between distribution and last-mile logistics.

This apparent regionalism has implications for large metropolitan areas. Even if fulfillment centers are located in peripheral areas, they generate a substantial amount of continuous truck traffic, underlining the preference to locate adjacent to major highways and at times with a dedicated ramp. A similar observation applies to delivery stations in central areas that experience the convergence of delivery vans in local streets. The growth of e-commerce and its footprint is in direct relationship with the growth a freight circulation in metropolitan areas, generating externalities and regulatory responses such as delivery restrictions.

6. Conclusion

The transition towards e-commerce has reached a point where what used to be a marginal complementary activity became in direct competition with conventional retail. Accordingly, significant changes in the footprint of the retail sector have taken place, which is shifting from commercially-accessible locations towards transportation-accessible locations. The example of Amazon is illustrative of a retailer using e-commerce to penetrate a wide range of retail segments. To support the requirement of distribution-based consumption, a hierarchy of specialized distribution facilities has emerged, each with its own locational, operational, and physical characteristics. It includes three stages: procurement and fulfillment, distribution, and last-mile deliveries.

A look at the respective footprint of Amazon’s facilities underlined that their function is size-related, from large suburban e-fulfillment centers (of about 850,000 square feet) to small-sized fast delivery hubs and delivery stations usually located in central areas (of about 50,000 to 90,000 square feet). Medium-sized facilities (about 300,000 square feet), namely sortation centers, tend to be located in intermediate locations. The location of each facility represents a trade-off between economics of scale, operational requirements, market areas, land use density, lead time, and land cost.

The weighted median center of most of Amazon’s facilities corresponds to the demographic center of the United States, a behavior that has previously been noted for the air hub selection of FedEx and UPS. This consistent locational attribute underlines the market servicing function of e-commerce as the goal is to achieve a distributional hierarchy of facilities to access consumer markets. The inbound cross-docking facility and the e-fulfillment center are the backbones of the fulfillment process, accounting for the most significant footprint. The sortation center, a medium-sized facility, is the core of the distribution process, allowing to route deliveries within metropolitan areas and for Amazon the option to interface with local post offices. It reconciles the apparent contradictions between the need to service high market density in central areas from low-density peripheral locations. The last-mile layer either focuses on fast delivery facilities such as Amazon Prime, or delivery stations where parcels are assigned on delivery routes.

The co-location of facilities is common and appears to be a location-specific opportunity that involves two separate distribution functions within the same facility (each facility bears a different code and is therefore considered independently within the distribution network). It is used as an ad-hoc opportunity taking advantage of local market accessibility potential, existing volumes, and the footprint available.

The functional specialization of e-fulfillment centers is prevalent, mainly along the lines of if the parcel is sortable or non-sortable. The nature of the item is secondary, while how it can be distributed is primary. If the parcel is sortable, it can be sent through regular parcel delivery services, while a non-storable parcel requires a different distribution channel because of bulk and weight considerations. Concomitantly, an emerging functional specialization of delivery stations between regular parcels and heavy deliveries is rapidly emerging.

The growth of Amazon is reflective of both horizontal and vertical integration underlining an extensive command of logistics, by being able to address customer expectations for faster deliveries while countering intuitively offering an unparalleled diversity of items that retail stores cannot carry. Through horizontal integration, Amazon used logistical facilities to expand market coverage and lower lead time, realizing economies of density on which relied the prior expansion of major retail chains such as Walmart and Target. Through vertical integration, Amazon used logistical facilities to control distribution flows and channels, allowing to control how the parcels are routed within its distribution and last-mile facilities, including final deliveries to the consumer.

The locational behavior of facilities seeks to maximize regional market accessibility. Still, it remains unclear if locations in a local context are optimal in terms of reducing externalities such as congestion. A closer look at the cases of Los Angeles and New York underlined a regionalism articulated around two freight distribution clusters, the fulfillment cluster with an agglomeration of large footprint inbound cross-docking and e-fulfillment centers, and a last-mile cluster serviced by small footprint delivery stations and fast delivery facilities (Amazon
Prime, Amazon Fresh, and Amazon Pantry). In both cases, the sortation center was located at an intermediary location, acting as a gateway between the fulfillment and last-mile clusters.

The rapid growth of e-commerce has opened new research avenues that are being actively explored. Among potential research opportunities are the market penetration and diffusion behavior of e-commerce, including its resilience to disruptions (e.g. COVID-19). This also includes entry strategies in new markets, such as developing economies that have seen the growing popularity of e-commerce but require substantial improvements in the logistical capabilities that e-commerce firms can provide. Case studies about the context-specific aspects of e-commerce (spatial structure, income, demographic composition, regulations) would reveal much about the resulting locational choice adaptations. The impact of the footprint of e-commerce as a generator of externalities is of high relevance. Congestion, energy consumption, carbon emissions, and reverse flows (wastes and returns), could impede further developments as e-commerce receives greater public and regulatory scrutiny. Consequently, several overlapping e-commerce distribution systems are operating in any given market. A closer look at their respective diffusion, competition and complementarity could reveal original adaptations of distribution networks and footprints.

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