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Assessing the spatial footprint of e-commerce logistics differentiating the types of warehouses: The case of Amazon in the United States

Matthieu Schorung (corresponding author)
Sorbonne University
matthieu.schorung@gmail.com

Thibault Lecourt
Avignon University
thibault.lecourt@pelicane.fr

Laetitia Dablanc
Gustave Eiffel University
laetitia.dablanc@univ-eiffel.fr

Abstract: E-commerce is simultaneously creating a new retail landscape through digitalization and new consumption and distribution practices and a new freight landscape in terms of the structuring of demand, the location characteristics of warehouses and distribution centers, and the handling of the last-mile segment in dense urban areas. Amazon represents all these developments in retail and e-commerce, being a dominant player in the e-commerce sector. This research, therefore, focuses on the evolution of Amazon's logistics system, and particularly the geography of Amazon's warehouses, marked by an expansion of the spatial footprint of the warehouses and by a functional specialization of its logistics system. From the analysis of Amazon's logistics system, we understand how strong the spatial footprint of e-commerce is and we can confirm some of the major processes affecting the e-commerce sector. With the empirical spatial analysis, we identify through cartographic representations several spatial logics of Amazon's logistics system: (i) a dual spatial rationale of networking and concentration of logistics warehouses, with the development of clusters of warehouses around major transport infrastructures and the creation of a more or less fine network of warehouses, particularly in urban areas; (ii) a dual spatial rationale that focuses both on the outskirts of metropolitan areas and on dense urban centers; (iii) the emergence of regionalized logistics strategies and differentiated spatial patterns regarding the type of logistics facility.

Keywords: Warehouse, Amazon, logistics sprawl, urban logistics, United States

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1 Introduction

This research examines the evolution of Amazon's supply chain, particularly the geography of its warehouses, which has been characterized by an expansion of its spatial footprint and a functional specialization over time. This research has three objectives: (i) to map these changes in space and time and identify the logics of Amazon's spatial

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footprint, particularly with respect to markets of varying sizes; (ii) to identify spatial patterns according to warehouse type; (iii) to confront our preliminary hypotheses with three case studies corresponding to the top e-commerce markets in the US (New York, Los Angeles, and Chicago).

Since the early 2000s, research on the location of warehouses and its explaining factors has been expanding, following a first wave of rapid expansion of warehousing throughout the United States, particularly in megaregions (Dablanc & Ross, 2012). A pattern of spatial decentralization of warehouses and growth in the number of warehouses on the outskirts of large cities has been identified in the United States and other major urbanized regions of the world (Bowen, 2008; Cidell, 2010; Dablanc & Rakotonarivo, 2010; Giuliano et al., 2013). Urban renewal, land pressure, and land-use competition with other activities have created conditions that are increasingly unfavorable to the development of logistics activities in dense areas (Heitz, 2017), whereas suburban areas offer large plots for logistics activities and access to large consumer markets thanks to good road and highway connections, thereby favoring a deconcentration of logistics facilities outside urban centers.

In fact, the availability of transportation infrastructure provides excellent access on two different scales: first, local access (to delivery areas), and second, regional or inter-regional access (to other cities or countries for logistics facilities with an extended hub role). Local logistics-friendly public policies, such as the establishment of logistics zones in suburban areas, have also influenced the location of warehouses. The absence of spatial planning regulations in suburban areas has encouraged the construction of warehouses (Raimbault, 2014), fueling a process known as “logistics sprawl” (Dablanc & Ross, 2012) in which warehouses become concentrated in sparsely populated suburban areas (Bowen, 2008; Cidell, 2010). The intensity of logistics sprawl differs depending on the type of warehouse (greater for distribution centers and less for parcel processing facilities) and the strategy pursued by logistics actors (Kang, 2020b). Other contributors to logistics sprawl include the evolution of supply chains, the demand for logistics real estate, and the construction of ever-larger facilities (Hesse, 2008).

The primary negative effects of this sprawl (congestion, pollution, artificialization of land) are inconsistent with the goals of sustainable cities, which typically involve urban densification, mixed-use developments, reductions in congestion and CO_2 emissions, and control of land artificialization. As a means of mitigating logistics sprawl, sustainability initiatives have shifted emphasis to last-mile logistics and urban facilities (Buldeo Rai et al., 2022). In addition, private demand for warehouses in densely populated areas has increased. Some logistics-intensive industries, particularly those associated with e-commerce, have begun to seek warehousing space within urban centers. This new demand for real estate coincides with the desire of public authorities to reinvigorate logistics activities in urban cores to curtail logistics sprawl. The current trend in logistics markets is twofold: on the one hand, the development of suburban logistics activities characterized by large, standardized logistics buildings intended for logistics service providers, mass retail, or manufacturing (Heitz et al., 2017); on the other hand, the emergence of a new urban logistics real estate based on buildings that are still largely "made-to-measure" and subject to challenging urban integration (Buldeo Rai et al., 2022).

E-commerce is simultaneously creating a new retail landscape through digitalization and new consumption and distribution practices (virtual access to a wide variety of products, instantaneity, omnicanality)[1] (Hagberg et al., 2016; Ramcharran, 2013) and a new freight landscape with regard to the structuring of demand, the location patterns of warehouses and distribution centers, transportation strategies (modal choices and nodal facilities), and the management of the last-mile segment (Rodrigue, 2020). As the leading e-commerce company in the United States and one of the leading e-commerce companies in many regions of the world, Amazon provides an interesting example of the effects of e-commerce on the supply chain and on the warehousing sector. In his founding paper on Amazon's logistics system, Rodrigue (2020) identifies multiple effects of e-commerce on the distribution of goods: effect on distribution structures (growth of B2C deliveries); effect on the real estate market (reduction in the land footprint associated with retail activity and expansion of the footprint of warehouse facilities); effect on logistics facilities (development of new types of warehouses – e-fulfillment centers, sorting facilities). By achieving significant economies of scale and density, particularly for their distribution centers (Houde et al., 2017), developing their own urban logistics strategies for last-mile deliveries (Browne et al., 2019), and promoting vertical integration (Lieb & Leib, 2016), e-commerce players seek to maximize access to urban markets and minimize delivery times.

Using an empirical spatial analysis, this paper investigates the distribution of Amazon warehouses in the United States. This method enables us to identify, at various geographical scales (national, regional, metropolitan), the spatial patterns underlying this development. Our research focuses on three aspects, completing previous research (Rodrigue, 2020): (i) the specialization of Amazon warehouses; (ii) the development of differentiated regional spatial patterns; (iii) the spatial distribution analysis of warehouses by type and size. The research on the size of warehouses expands upon the research of Kang (2020b), who analyzed the size-dependent disparity of logistics sprawl in US cities.

The structure of the paper is as follows. In the first section, we present the methodology used to analyze the database and create the maps; in the second section, we briefly present Amazon and its supply chain, and we analyze the spatial patterns of Amazon warehouses over time at the scale of the United States prior to examining the functional specialization and diversification of Amazon warehouses. A section is devoted to a regional and metropolitan approach to the Amazon system, using New York, Los Angeles, and Chicago as case studies, to refine the analysis of logistics sprawl patterns using the centrographic method. This is the most used method for assessing spatial shifts, which tests changes in the average distance of warehouses from their barycenter and looks at changes in the activity's spatial distribution (Kang, 2020a). The concluding section presents and discusses the findings and outlines potential avenues for future research.

2 Literature review

Several recent studies have analyzed the location of warehouses in metropolitan areas and the evolution over time of this location. These studies have demonstrated a shift in the location of warehouses and logistics facilities to suburban areas (Allen & Browne,

[1] The term "omnicanality" refers to the fact that all possible contact and sales channels between a company and its customers are used and mobilized. The notion of omnichannel can therefore refer to contacts initiated by customers or prospects, as well as those initiated by the company. Omnichannel retailers integrate online and offline retail channels in a single process. In practice, omnichannel retailers enable consumers to make online purchases and pick them up in-store or return them to the store, order items in-store and receive them at home, and merge online and offline shopping.

2010; Bowen, 2008; Cidell, 2010; Giuliano et al., 2016; Heitz et al., 2017; Kang, 2020a). Logistics warehouse location dynamics are based on several criteria and a complex supply chain cost structure (transportation, accessibility, distribution activities, structure of the regional economy, warehouse equipment, land and real estate, organization of logistics flows and the last-mile segment, etc.) (Dablanc & Rakotonarivo, 2010). This evolution has been characterized as a "logistics sprawl" phenomenon that can be defined as "the tendency for warehouses to move from urban to suburban and exurban areas" (Dablanc & Ross, 2012) that has been identified by research in numerous case studies considered (Cidell, 2010; Dablanc & Rakotonarivo, 2010; Dablanc & Ross, 2012; Dablanc et al., 2014; Dubie et al., 2020; Giuliano & Kang, 2018; Heitz & Dablanc, 2015; Kang, 2020a, 2020b, 2020c; Rivera et al., 2014; Sakai et al., 2017; Sun et al., 2018; Todesco et al., 2016; Woudsma et al., 2016).

Numerous studies have looked at location characteristics of logistics facilities and their factors, especially the opportunity to access larger and cheaper vacant parcels in suburban areas and proximity to highway networks and airports (Allen & Browne, 2010; Dablanc & Ross, 2012); the growth of the logistics industry fueled by globalization and new production and distribution dynamics (Andreoli et al., 2010; Kang, 2020a; Sakai et al., 2020) and the transformation of the logistics real estate sector, increasingly dominated by global firms whose activities are organized around multi-scalar distribution networks (Hesse & Rodrigue, 2004).

Logistics sprawl implies that these spatial changes would lead to longer freight transport distances and related unfavorable externalities (Giuliano & Kang, 2018; Sakai et al., 2019). Nevertheless, the relationship between logistics and changes in freight transport distance is significantly complex (Kang, 2020c; Sakai et al., 2019). Logistics warehouses are not simply moving away from the center, but these spatial changes are part of more profound mutations in the logistics sector (i.e., the globalization of supply chains, the development of integrated global companies, the exceptional development of express courier activities, particularly those linked to e-commerce). Many warehouses have moved away from central areas, but the spatial patterns of these location changes vary with the characteristics of the warehouse (size, type of warehouse, function). Logistics sprawl concerns first large facilities and fulfillment centers (Kang, 2020b, 2020c). Moreover, some negative externalities of freight activities are not directly, or only, related to logistics sprawl but to the consequences of urban sprawl and the growing demand of goods in suburban and exurban areas (Giuliano & Kang, 2018; Sakai et al., 2017). Some new studies analyze the impact of last-mile facilities on logistics sprawl (Fried & Goodchild, 2023).

Most of this research on logistics sprawl focuses on the spatial dynamics of warehouse location without distinguishing the types of warehouses (distribution centers, cross-docking warehouses), the companies (logistics providers, parcel and express operators, e-retailers), or the catchment area of each warehouse (to determine which warehouse serves which area). This is predominantly due to a lack of trustworthy and accessible data. A few studies are beginning to examine this topic (Heitz et al., 2019; Kang, 2020a, 2020b; Schorung & Escarfail, 2023), particularly on the Amazon logistics system in the United States (Rodrigue, 2020; Schorung & Lecourt, 2021) or on carrier terminals such as DB Schenker (Robichet & Nierat, 2021). The research gap is still challenging. Due to the lack of differentiated measures of logistics sprawl, previous studies could not sufficiently address the following research questions. Are all warehouses sprawling outward? Are small warehouses moving close to consumer demand? Is the distribution structure of e-commerce creating specific spatial patterns and relative or differentiated logistics sprawl measures? Our first research question centers around how the Amazon case highlights new trends and spatial patterns regarding logistics facility development, while the second research question queries the differential spatial characteristics related to the size and type of logistics facility. Due to the specific characteristics of e-commerce activities and its consequences on global supply and production chains, the distribution structure of e-commerce is operationally decentralized and uses multiple large fulfillment and sortation centers and small logistics facilities (delivery stations, urban hubs, urban warehouses, or consolidation centers) to reduce delivery times (Onstein et al., 2018). Amazon is a representative example of all these developments (Rodrigue, 2020).

In this research, we use a mixed approach combining relative spatial measures to quantify warehouse distribution considering the type, function, and size and a cartographic work to represent and identify the spatial changes in specific metropolitan areas. The methodology is described in the following section.

3 Data and methodology

The analysis of Amazon's warehouses in the United States was based on an inventory of logistics facilities maintained by MWPVL International, a logistics and supply chain consulting firm.[2] This inventory is regularly updated. It is accessible from the company's dedicated website and, though protected, is authorized for use for purposes of research. This open-access inventory is the most complete, but it is possible that some projects are not referenced or that the information on smaller logistics facilities is incomplete.

This research was carried out in two stages: first from April to July 2021 for the cartographic representation of Amazon warehouses, second from June to August 2022 for updating the database and measuring the barycenters. This database from MWPVL International is constantly updated, so some information (particularly on planned warehouses) may have changed since the completion of this research and the publication of this paper. This database contains information about the location, with for each facility: a specific code (usually 3 letters and 1 number), the location by U.S. state and then by address (precise or approximate, especially in the case of planned facilities), the function and type of warehouse, the surface area (expressed in square feet), the year of opening (estimated opening for projects), the status of the warehouse (open, closed, planned), and the presence, if any, of any other logistics or transportation facility. Other information subject to cartographic processing may feature in the description of warehouse function, for example, whether it has been extended or is totally or partially automated.

After recovering the database, which had to be transcribed in its entirety to Excel spreadsheets by OCR processing because of its size, and since the website of MWPVL International is protected against automatic copying, the task of standardizing the database was undertaken as well as extracting certain characteristics in the description of functions, in particular the automation of certain facilities or the distinction between warehouses that specialize in handling "sortable" and "non-sortable" products. The tables included in the data retrieved from the website were scanned. Each facility address was geocoded from the address provided or the approximate location (in which case we chose either to represent the middle of the facility or to indicate a location in the nearest industrial zone) via OpenStreetMap and Nominatim. This entailed a degree of approximation in the location of some warehouses, and we undertook manual relocation for the outliers using the GIS software QGIS. The maps presented in the following

[2] https://www.mwpvl.com/html/amazon_com.html [accessed on 05/15/2022].

sections were produced using QGIS, supplemented by processing in R software for statistical representations and calculations.

To facilitate visualization and calculation of barycenters on QGIS, a geocoding process is necessary to assign longitude and latitude coordinates to each warehouse. This geocoding task is executed using Python, resulting in geocoded databases that are then imported into QGIS for mapping. The concept of the barycenter is harnessed to depict the centroids of each Amazon warehouse type based on their respective establishment sizes within each studied Metropolitan Statistical Area (MSA) or Combined Statistical Area (CSA).

We chose to compare three cases that share similar characteristics: high population density, implying a high demand for e-commerce (Rodrigue et al., 2017); function of major logistics hub (Bowen, 2008); high concentration of Amazon activities (Rodrigue, 2020). Case studies are useful for identifying causes and characteristics of contemporary phenomena (Meyer, 2001) and for allowing a strict comparison of such causes and characteristics. Following this sampling procedure, in which cases are selected purposefully, our three cases are: New York City (NY), Chicago (IL), and Los Angeles (CA). This case study methodology allows us to avoid the limitations of a monographic approach, which limits reproducibility. Nevertheless, the case study approach leads to a certain, but unavoidable, redundancy. This initial research calls for a more systematic quantitative analysis of a larger sample of cases in the US and elsewhere in the world.

The objective of this methodology is to characterize and contextualize the development of logistics facilities in these three major US cities, using the case of Amazon. This research is based on an inductive method that mobilizes raw and observable data. It involves moving from one or more specific cases to more generic, theoretical conclusions, thus departing from the classic quantitative deductive approach aimed at statistical verification of a pre-established theoretical framework (Blais & Martineau, 2006; Thomas, 2006). Although the cities differ significantly from one another, they share high population density and high rates of e-commerce adoption, two criteria considered critical in the development of the warehousing sector (Dablanc, 2018; Rodrigue et al., 2017). The use of a case study is intended to complement the research gaps in the scientific literature on logistics sprawl and the analysis of warehouse location. This approach avoids the main limit in the database of economic establishments in the United States (*County Business Patterns*, U.S. Census Bureau) relating to the absence of precise data on warehouses (except for the size of the establishment in terms of number of employees and the county and zip code of location). By building and exploiting our database of Amazon logistics warehouses, we have access to unprecedented data (precise location by geographic coordinates, warehouse size, opening date, warehouse logistics function, among others). The following section analyzes Amazon's development strategy and the structure of its logistics model in the United States.

4 Amazon: The sprawling growth of its logistics real estate footprint

As a major player in the e-commerce sector, Amazon embodies many of the development patterns in retail and e-commerce: in 2017, Amazon accounted for 37% of the total online shopping market in the United States (by total sales), rising to 39.6% in 2023. Its share is expected to exceed 40% in 2024. In the United States, Amazon's dominance is clear: 38% of the e-commerce market in 2021, compared with 7.1% for

Walmart (2nd), 4.3% for eBay (3rd), 3.7% for Apple (4th), and 2.2% for Best Buy (5th).[3] In the retail sector, Amazon is the second biggest market player behind Walmart. The Covid-19 pandemic has had the effect of accelerating Amazon's already strong growth, with sales in 2020 rising by 44.1% and by 22% in 2021. This performance is based on an efficient vertical integration and supply chain management, particularly in the last-mile segment.[4] This enabled the company to reduce its click-to-door time in 2020 from an average of 3.4 days to 2.2 days (industry average: 5.1 days).[5] This effectiveness relies on a logistics system organized around an interlocking network of warehouses and logistics facilities of different sizes and types, emerging proprietary 3PL and 4PL services,[6] and emerging proprietary transportation services (air and road freight). At the beginning of 2021, Amazon purchased eleven Boeing 767 aircraft converted to cargo planes. The Amazon cargo fleet operated, as of October 2022, 110 aircraft and has added ten Airbus planes at the end of 2023.[7] For several years, Amazon has been shifting its strategy towards direct ownership and control of most aspects of the supply chain, to reduce its dependence on third-party service providers (UPS, FedEx).

For the United States, the database lists a total of 302.6 million square feet (28.1 million square meters) of logistics facilities and warehouses for 2021 and more than 144.6 million square feet (13.4 million square meters) of planned projects (2021-2024). The Amazon warehouses listed are divided into nine categories (Schorung & Lecourt, 2021):

- Fulfillment and Distribution Centers are large distribution centers that handle consumers' online orders, generally ranging in size from 500,000 to 2 million square feet. Many of these centers are undergoing full or partial automation as well as expansion (either through the reorganization or optimization of existing structures or through extensions). Large distribution centers may also specialize: according to product type (clothing, jewelry, electronics, perishables, all information that may be mentioned in the description of the functions in the database but has not been the subject of a cartographic processing); or according to the nature of the handling and packaging ("small sortable" for small sortable products that can fit in packages weighing less than 10 kilos, "large sortable" for sortable products weighing 10 to 25 kilos; "large non-sortable" for heavy and/or bulky products such as furniture or televisions that cannot be sent in standardized packages).
- Pantry/Fresh Food Fulfillment Centers are the same types of warehouses as the previous category (i.e., fulfillment and distribution centers) but specialized in handling orders for perishable and/or fresh food products as well as cleaning products.

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[3] https://www.emarketer.com/content/amazon-will-surpass-40-of-us-ecommerce-sales-this-year [accessed on 06/12/2024]

[4] https://www.forbes.com/sites/shelleykohan/2021/02/02/amazons-net-profit-soars-84-with-sales-hitting-386-billion/?sh=69d546a41334 [accessed on 06/12/2022]

[5] https://www.forbes.com/sites/shelleykohan/2021/02/02/amazons-net-profit-soars-84-with-sales-hitting-386-billion/?sh=69d546a41334 [accessed on 06/13/2022]

[6] The term 3PL stands for "Third Party Logistics" and refers to the outsourcing of all or part of a company's logistics to an external service provider (for storage management, order preparation, transport of goods and products, etc.). In addition to the warehousing, order-picking, and transport operations usually carried out by a 3PL, the 4PL takes on the responsibility of managing supplies for its customers, in complete autonomy.

[7] https://www.aboutamazon.com/news/transportation/amazon-air-adds-10-airbus-a330-300s-to-its-global-fleet [accessed on 06/11/2022]

- Whole Foods Retail Grocery Delivery Centers constitute a very specific category with a limited number of facilities, catering for the stores of the Whole Foods chain acquired by Amazon in 2017 for $13.7 billion. These supermarkets also act as distribution and delivery centers for the chain and for online orders.
- Prime Hubs are local fulfillment and picking hubs dedicated to express deliveries and Amazon's fast delivery service. These urban hubs serve very fast deliveries, in less than 48 hours, and instant deliveries, in less than two hours. These small and medium-sized warehouses are in dense parts of major metropolitan areas to be as close as possible to urban consumers.
- Inbound Cross-Dock Centers (IXD) are processing centers for maritime containers carrying goods imported into the United States, generally located near major multimodal hubs (ports, logistics parks, rail hubs).
- Regional Sortation Centers are the intermediate regional links between several large fulfillment and distribution centers. They are used to sort packages for a given region from multiple Amazon distribution centers. Packages are sorted by zip code and then redistributed to urban warehouses or last-mile distribution hubs.
- Delivery Stations (Packages) and Delivery Stations (Heavy/Bulky) are small last-mile delivery centers that serve either as distribution locations for delivery drivers picking up packages or as final delivery pick-up points. These small facilities are the most local link in Amazon's logistics system, and there are large numbers of delivery and collection points in urban and suburban areas. The database divides these "stations" into two sub-categories: delivery points for small packages and delivery points for unpackaged bulky or heavy objects.
- Air Gateways are facilities located near or within an airport space that handle the cargo pallets of air cargo services from or to major distribution centers and large pooling centers. These services are organized according to a hub-and-spoke principle (Rodrigue, 2020).

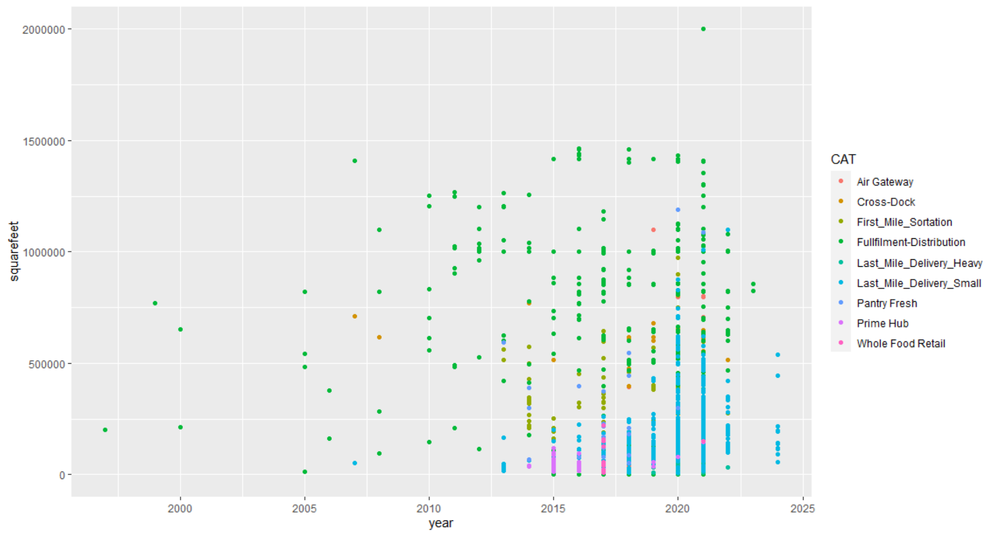
The most represented type of warehouse is the Delivery Stations Packages & Heavy/Bulky, of which the database lists 454 across the country and another 275 planned facilities, reflecting the growth of Amazon business in the United States and particularly its spatial coverage. The second commonest type is the distribution center, of which the database listed 264 facilities and 106 planned facilities as of September 2021. Distribution centers account for the bulk of Amazon's spatial footprint: 184.8 million square feet (17.1 million square meters), or nearly 61% of Amazon's total warehouse space. They also account for 49.4% of total planned space.

4.1 Amazon footprint expansion

The spread of Amazon's logistics system reflects the growth of the company's business. Rodrigue (2020) has identified four phases of growth since the 1990s. From a niche market from 1995 onwards with only a very limited number of medium-sized distribution centers; to a diversification in the types of products sold resulting in a first wave of expansion in Amazon's logistics system from 2005 to 2008 and the opening of the first Inbound Cross-Dock center for imported goods. Since 2010, a new expansion strategy with a large number of distribution centers throughout the country followed by a gradual process of warehouse specialization. Since 2016, three major changes: (i) a change of scale with the opening of a very large number of warehouses, especially large distribution centers; (ii) the move towards increasing warehouse specialization; (iii) a strategy of vertical integration that has reinforced Amazon's control over the entire distribution and transportation chain and reduced its dependency on third-party carriers (UPS, FedEx).

The analysis of the MWPVL International database shows Amazon's deployment strategy over time. The first graph below (Fig. 1(a)) situates the opening of Amazon warehouses in time (from 1997 to the projects planned up to 2024). With this figure, we can identify the multiple phases of expansion, especially the massive increase in the number of warehouses between 2015 and 2020. However, the most interesting lesson from this graph is the reduction over time in the average size of the warehouses opened, especially in the years 2014-2015. Each point represents the creation of a warehouse (all categories combined) classified by date (x-axis) and surface area (y-axis). The concentration of points on the right shows the surge in the number of warehouses from 2013 to 2014 and shows the proliferation of very large warehouses from 2010 onwards. We also provide the curve and the linear regression line, which show the downward trend in the average surface area of warehouses (the curve shows that it rose until 2010, then fell until 2015 and has remained stable since). The straight line and regression curve express this gradual decrease over time after a period of continuous growth from 1997 until 2013, with a short period of large warehouse openings between 2009 and 2013. This represents a shift in Amazon's logistics strategy, with a gradual move towards the coverage of urban spaces, which require smaller urban warehouses (e.g., for fast delivery services) and many small parcel distribution points.

*a



*b

Figure 1. *(a) Opening of Amazon's US warehouses over time by size (sq ft) and the regression curve; ***(b)** Opening of Amazon's US warehouses over time by size (sq ft) and type of warehouse
Sources: MWPVL, 2022

Several observations can be made based on this graph (Fig. 1 (b)). Amazon's logistics development has taken place in a short period of time, a process of exponential development over a timespan of only 7 to 8 years (2014-2021). Amazon's strategy is based on diversification and functional specialization with respect to both the size and the type of warehouse. From 2013 to 2016, the number of warehouses – whether large, medium, or small – increased. Although after 2018 Amazon mainly focused on small warehouses and last-mile logistics facilities, very large distribution and fulfillment centers continued to be established, several dozens of them measuring almost 1.5 million square feet (130,000-140,000 sq m), some are multistorey warehouses. Distribution centers (DC) constitute the backbone of Amazon's logistics system, and their spatial coverage is expanding, including DCs planned for 2022 to 2024. This skeleton connects to a specialized regional framework (Sortation Centers, Inbound Cross-Dock Centers, Air Gateways) and a relatively narrow local framework (Last-Mile Delivery, Prime Hubs).

The functional specialization of Amazon's warehouses is at work with numerous specialized warehouse openings between 2015 and 2020: first-mile sortation centers, last-mile delivery centers, Prime hubs, pantry/fresh centers. This specialization also signals Amazon's strategy of vertical integration to reduce its dependence on third-party operators, as shown by the very rapid opening of air hubs (Air Gateways) and cross-dock terminals.

4.2 Geography of Amazon logistics system

The map below provides a spatial representation of Amazon's logistics system according to the type of warehouse or logistics facility (Fig. 2). This cartographic representation enables us to draw conclusions about Amazon's logistics system. Air Gateways are few. They are generally not located in major airport hubs (except Dallas and Los Angeles). Instead, Amazon appears to set up facilities either at medium-sized airports or at large airports that did not serve previously as a hub for a carrier or express carrier. As of 2021, Amazon's largest hub is located near Cincinnati in the city of Wilmington, while Atlanta (the largest US airport) or Memphis (FedEx major hub) do not host an Amazon hub. The situation in the Northeast region is enlightening on this point. The two Amazon hubs are located outside the major metro areas. IXDs (Inbound Cross-Dock centers) serve as processing centers for maritime containers loaded with goods imported into the United States, generally located near major multimodal hubs (ports, logistics villages, intermodal hubs). Pantry and Fresh Distribution Centers cater to developing markets and, so far, have a modest logistics footprint with few warehouses. These are generally small – with two exceptions in the east – and close to major urban centers so that they can meet demand from urban customers for fresh/perishable and household goods. The map (Fig. 2) shows an intensification of this strategy of diversification and specialization.

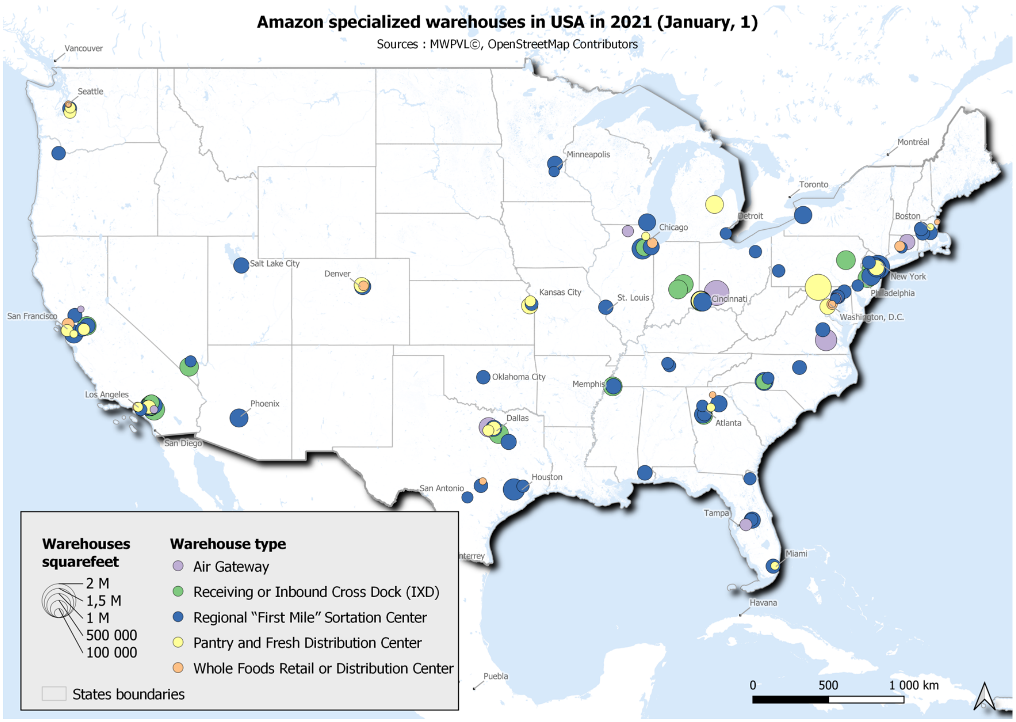


Figure 2. Opening of Amazon warehouses in the United States in 2021 by warehouse type
Sources: MWPVL ©Authors, 2022

Finally, to complete this overview of Amazon's logistics system, we represented the spatial distribution of all fulfillment and distribution centers (Fig. 3). The analysis of the location strategies for distribution centers can also provide insight into the process of functional specialization for warehouses. In the period 2014-2015, Amazon pursued a vertical integration strategy to gain control of several components of the global supply chain, from importing goods, to chartering air assets for distribution over continental distances to last-mile delivery (Rodrigue, 2020).

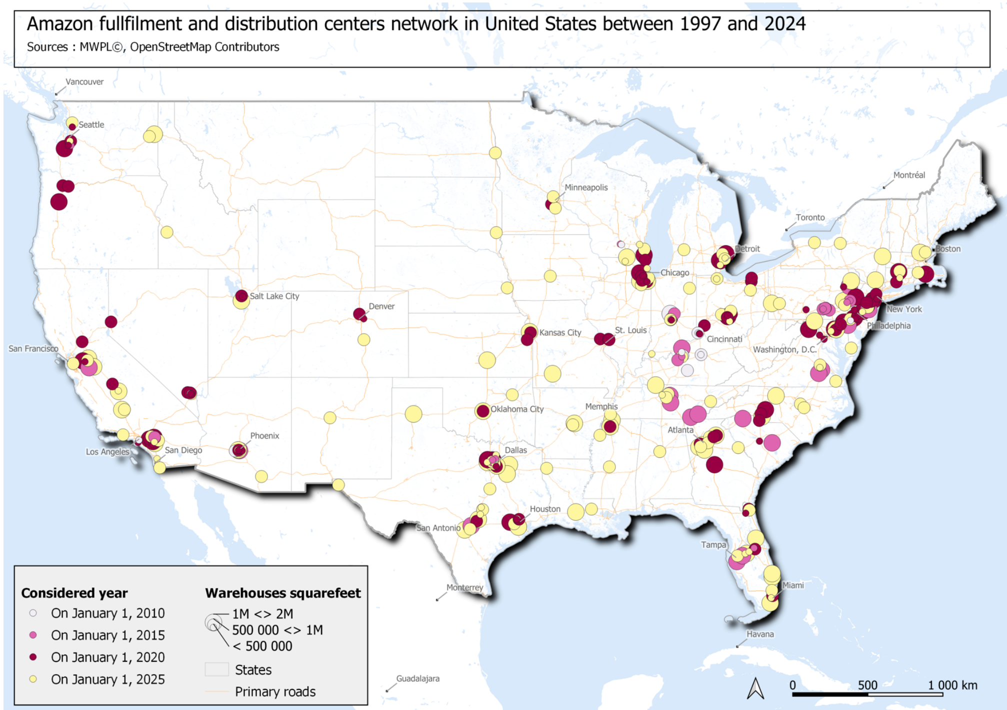


Figure 3. Evolution over time (at four selected time steps) of fulfillment and distribution centers in all categories across the United States
Sources: MWPVL ©Authors, 2022

To do this, we chose four-time steps, including one in the future to include all the listed projects, to visualize the spatial distribution of Amazon warehouses. Three remarks can be made.

First, until 2015, the establishment of large distribution centers was geographically very selective, concentrated in a few major economic regions in the country (California, the Atlanta region, the Northeast region). It is interesting to note that, before 2015, distribution centers were not established in other major regions and metro areas of national importance or else were modest in size (Texas metro areas, Chicago, St. Louis, Miami, Detroit, Boston). This may reflect Amazon's strategy of setting up in a few key areas with a mature or strong e-commerce market and favoring locations near major gateways*,* as illustrated by the situation in the Southeast around Atlanta.

Second, from 2015 to 2020, Amazon's system expands very significantly, reflecting the proliferation of its activities and its dominant position in the e-commerce sector. All major metropolitan areas now have one or more large distribution centers, forming clusters of warehouses in the most urbanized regions (Northeast, Great Lakes region, Atlantic Piedmont, Texas Triangle, California). In addition, fulfillment centers start to arrive in previously neglected inland regions and midsized cities (Salt Lake City, Denver, Las Vegas, Phoenix, Kansas City, Oklahoma City, Portland, Minneapolis, etc.). This global trend signals the horizontal integration strategy implemented by the company in the 2010s to achieve economies of scale and cut costs through the development of a fine network of large distribution centers and specialized warehouses.

Third, the projects listed from 2021 to the end of 2024 reflect a threefold strategy: (i) a continued horizontal integration with a sharp increase in the number of distribution centers in the United States; (ii) a tightening of the network in the best-served megaregions (Great Lakes, Northeast, Texas Triangle, California, Florida, Atlantic Piedmont, Northwest region); (iii) the implementation of an interstitial strategy to fill the "gaps" in less densely populated territories, with projects planned for medium-sized cities and in states or regions without a major metro area (Idaho, North Dakota, South Dakota, New Mexico).

4.3 A network logic favoring urban logistics activities

For several years, Amazon has been offering fast (less than 48 hours) and even same day delivery services for certain types of product – until May 2021, Amazon gave access to a dedicated service (dedicated app and website) for its Prime Now members for less-than-two-hours deliveries.[8] Providing these new services to consumers requires specially designed and dedicated logistics facilities, for the premium Prime Now service. In line with its overall strategy of horizontal and vertical integration, the company is therefore developing small urban warehouses through which it can control the various links in the logistics chain, particularly the last-mile segment (Fig. 4). These urban Prime Now warehouses are very small compared with the other warehouse categories and have a coverage that is still largely limited to the major metropolitan markets where demand for this type of service is highest – there are several small urban warehouses in the Los Angeles, San Francisco, Dallas, and New York City areas.

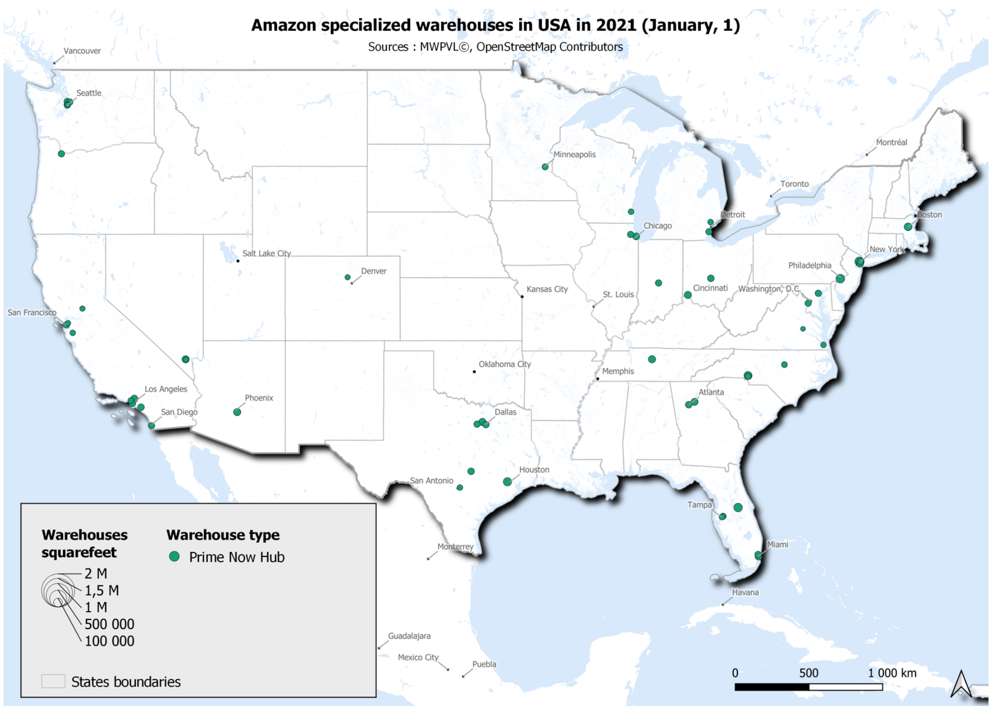


Figure 4. Location of small urban Amazon warehouses dedicated to *Prime Now* service as of January 1, 2021

Sources: MWPVL ©Authors, 2022

[8] https://www.cnbc.com/2021/05/21/amazon-is-shutting-down-its-prime-now-fast-delivery-app.html [accessed on 11/06/2022]

These dedicated urban warehouses are currently concentrated in metropolitan areas at the top of the American urban hierarchy, although some intermediate cities are now included (San Diego, Sacramento, Portland, Tampa, etc.). In 2016, 44.8 million U.S. households signed up for Amazon Prime. That number has exceeded 80 million by 2021 and is expected to reach 90 million by 2025, according to projections by consulting firm Insider Intelligence.[9]

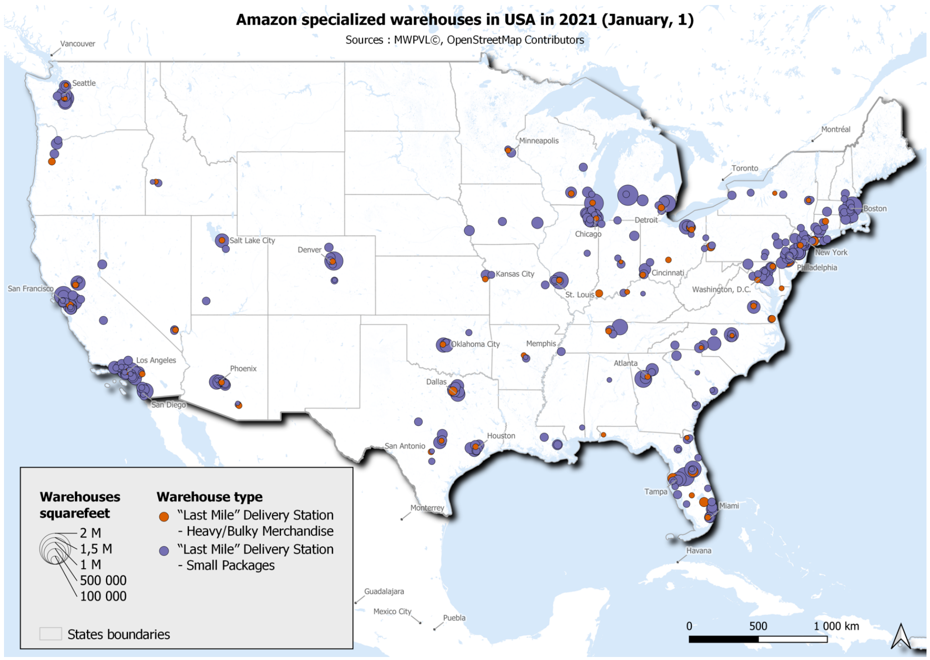


Figure 5. Location of last-mile delivery stations in the United States as of January 1, 2021
Sources: MWPVL ©Authors, 2022

Last-mile delivery stations are the most developed type of logistics facility in Amazon's logistics system.[10] They handle the final stage of delivery to the end customer, and their spatial coverage must be as extensive as possible to facilitate access to distribution and delivery points for carriers, delivery personnel, or consumers. There are two types of delivery points, for different product types: points for small parcels, which are the most numerous, and points for heavy or bulky goods. The map indicating the location of these sites as of January 2021 shows the extent of this spatial coverage (Fig. 5).

A few megaregions contain the bulk of these last-mile delivery points: the Northeast region, the Great Lakes region, Florida, the Piedmont Atlantic, the Texas Triangle, Northern and Southern California, and the Northwest region. In some metropolitan areas, the density of delivery points is very high, reflecting the adjustment of the logistics system to the most dynamic urban markets (New York, Los Angeles, Chicago). All major metropolitan areas and most intermediate metropolitan areas have this type of logistics

[9] https://www.emarketer.com/content/forecast-just-how-big-amazon-prime-how-fast-will-grow [accessed on 12/11/2022]

[10] Automated lockers are not included in the database.

facility, even mid-sized cities. The very strong dissymmetry in numbers between delivery points for small packages and delivery points for heavy/bulky products testifies to the dominance of parcels in Amazon's sales.

5 Findings

5.1 Regionalization of logistics development: inputs from three case studies (New York, Los Angeles, Chicago)

The analysis of the spatial footprint of Amazon's warehouses on a national scale requires a cross-section of scales to understand how Amazon's regional and metropolitan network is organized. We considered a relatively large regional urbanized area (the Northeast region, in particular the region between Washington DC and New York City) and two major metropolitan areas (Los Angeles-Riverside and Chicago). New York, Los Angeles, and Chicago are the top three metropolitan areas for the number of logistics warehouses (493 NAICS code), according to the US Census Bureau. Los Angeles and New York, and secondarily Chicago, especially as a rail hub, are major gateways for international and domestic trade as well as powerful multimodal trade and logistics hubs (Rodrigue et al., 2017).

In the case of the Northeast megalopolis, our analysis focused on the central and southern part, from New York to Washington DC, considering the warehouses in the hinterland in relative proximity to the major maritime, air, and logistics gateways. Based on the map of Amazon's network of logistics operations in the region on January 1, 2021 (Fig. 6), most of the warehouses are in the urban continuum of the Northeast region following a linear pattern and the region's major transportation corridors.

The large distribution centers are mainly located on the outskirts of the major metropolitan areas (Baltimore, Philadelphia, and New York). Moreover, several of the biggest fulfillment centers are in exurban areas, such as the three between Baltimore and Wilmington and the four between Philadelphia and New York at Trenton.

In addition, a second hinterland axis is appearing to play a supporting role with a cluster of several distribution centers in the Harrisburg and Allentown suburbs and a large warehouse to the southwest in Winchester. The mismatch between the size of the logistics location and the size of the surrounding market might suggest that these hinterland warehouses either service logistics facilities for the core consumer markets or are facilities that network with many intermediate-sized inland markets.

Many warehouses are located on the outskirts of the metropolitan area, on the edge of the urban areas, confirming the search for low-cost land available for large warehouses.

The large logistics warehouses that do not fall into the "fulfillment and distribution centers" category – Inbound Cross-Dock Center, Regional Sortation Center, Pantry and Fresh Distribution Center – are located in the region in two ways: either in suburban or exurban areas or in a pericentral position relatively close to urban centers (Trenton, Newark, Baltimore). This pericentral position could confirm the role of these warehouses as intermediate links in Amazon's global logistics chain.

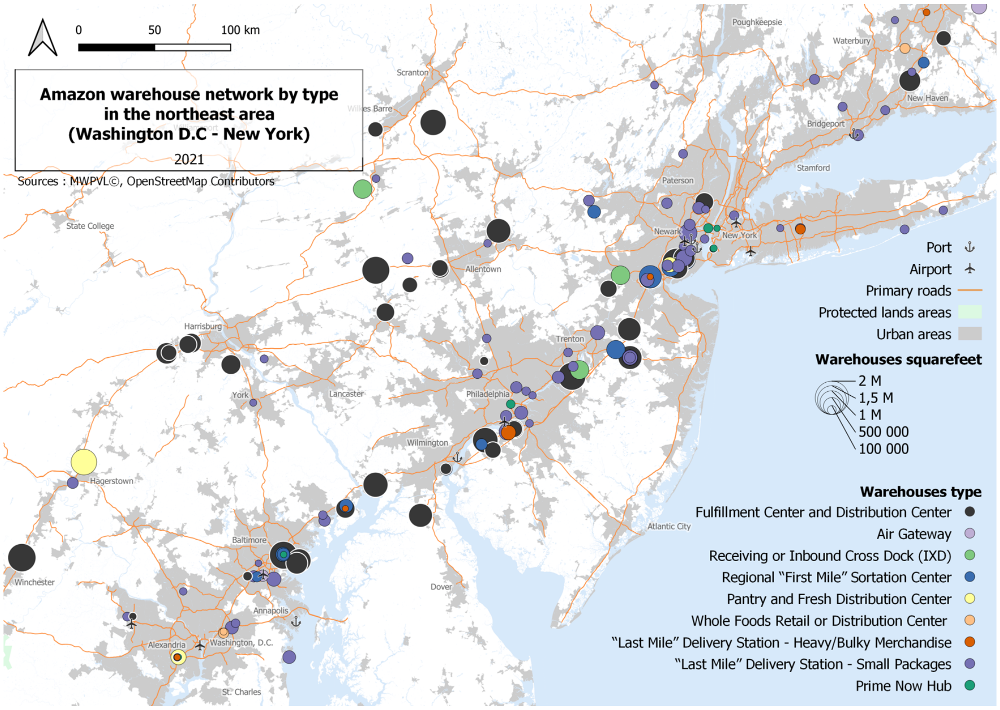


Figure 6. Amazon's logistics network in the Northeast region (Washington D.C.-New York City) in 2021
Sources: MWPVL ©Authors, 2022

Finally, there is a second level in this logistics network, an urban and local network with a multitude of small urban logistics spaces (last-mile delivery stations and Prime hubs). There is a network of urban delivery points that is particularly well developed in the two major cities considered in the study area: Philadelphia and New York. The other two cities (Baltimore, Washington DC) have a less-developed network, reflecting the relatively strong geographical selectivity of e-commerce and urban deliveries. The other urban logistics areas appear to be scattered throughout the region under consideration, with a multitude of points in suburban areas, illustrating the strategy of penetrating suburban consumer markets. The Prime Hub service and its small urban hubs dedicated to these rapid delivery services are marked by selectivity for an even larger geographic area, with a single deployment market in New York City, apart from a small Prime warehouse in Philadelphia.

When we look at the Los Angeles metropolitan area (Fig. 7) (including Long Beach, Irvine, Anaheim, Riverside, and San Bernardino), there is a sharp dualization in Amazon's logistics network, with large warehouses (fulfillment centers, IXDs, and regional sortation centers) in the east around Riverside and San Bernardino (in the "Inland Empire"), and small warehouses and urban logistics facilities in the west, both in the urban center and on the coastline. Beyond these two poles, a few scattered logistics facilities exist in the area's other suburban centers (Irvine to the south and Burbank to the north-west). The Los Angeles-Riverside metropolitan area is one of the main markets for Amazon and one of the cornerstones of its logistics system. The logistics infrastructure is particularly well developed there, with a particularly visible concentration effect in Riverside and especially San Bernardino, which are areas marked by transportation activities (airport, rail terminal, or depot), logistics (exceptional concentration of warehouses), and trade. The area around Ontario International Airport and the Interstate

15 and 10 interchanges, and the area around San Bernardino International Airport and the Interstate 10 and 215 interchanges, are urban landscapes deeply marked by logistics, with hundreds of warehouses. These areas are well-deserved by major transport infrastructures (airports, federal highways, expressways, freight rail networks) serving the more distant hinterland and the connection with the port of Long Beach.

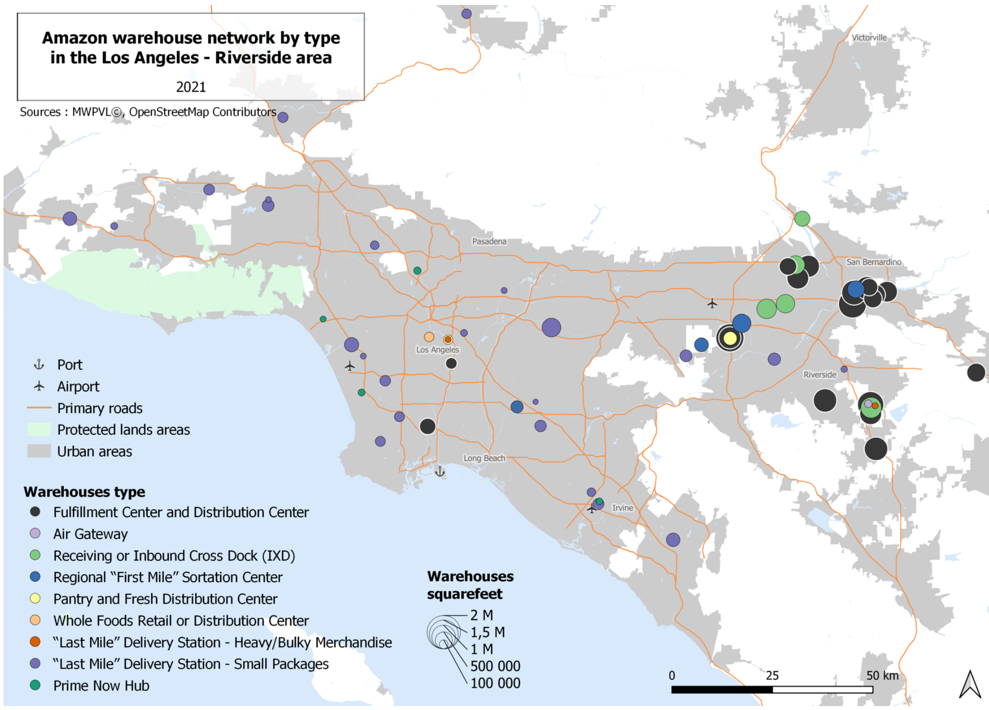


Figure 7. Amazon's logistics network in the Los Angeles CSA (Inland Empire) metropolitan area (Los Angeles-San Bernardino-Riverside) in 2021
Sources: MWPVL ©Authors, 2022

In the San Bernardino and Riverside regions, there are more than ten distribution centers, some of which are considered XXL (over 1.5 million sq ft), especially around San Bernardino airport. These large distribution centers are themselves complemented by an extensive logistics network with several Inbound Cross-Dock centers (IXDs) and several regional sortation centers, as well as by specialized facilities, as demonstrated by the presence of a large Pantry and Fresh Distribution Center. In the east of the urban center, there are in fact only four small urban logistics areas. The network becomes more distant when we leave this eastern zone, where the warehouse map reveals the importance of the Los Angeles urban market, with a large but not completely polarized network of local delivery points and three Prime Now hubs in the high-income residential areas of the west near the coast (Gardena, Inglewood) and near this Los Angeles International Airport.

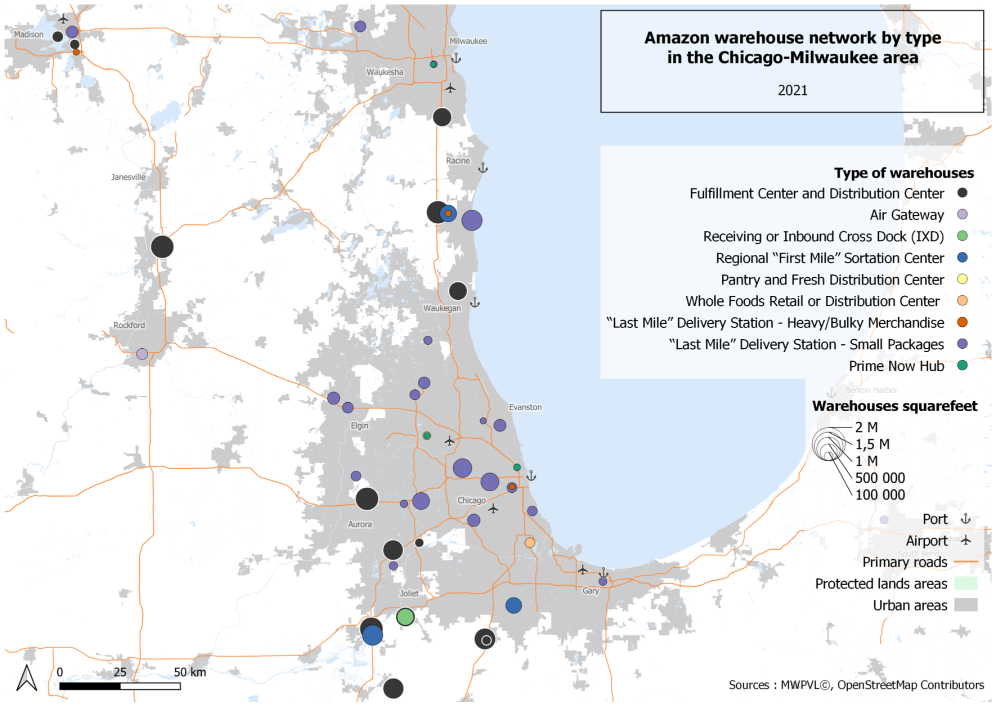


Figure 8. Amazon's logistics system in the Chicago metropolitan area in 2021.
Sources: MWPVL ©Authors, 2022

Amazon's logistics network in the Chicago area extends as far north as Milwaukee since there is an urban continuum between the two metro areas. It presents different spatial characteristics from the other two metropolitan areas studied (Fig. 8). Indeed, the concentration effect around a few main logistics centers does not seem to be clearly visible in Chicago. The structure of the network here is conventionally based on the polycentric city with small logistics facilities in the center and large facilities in suburban areas.

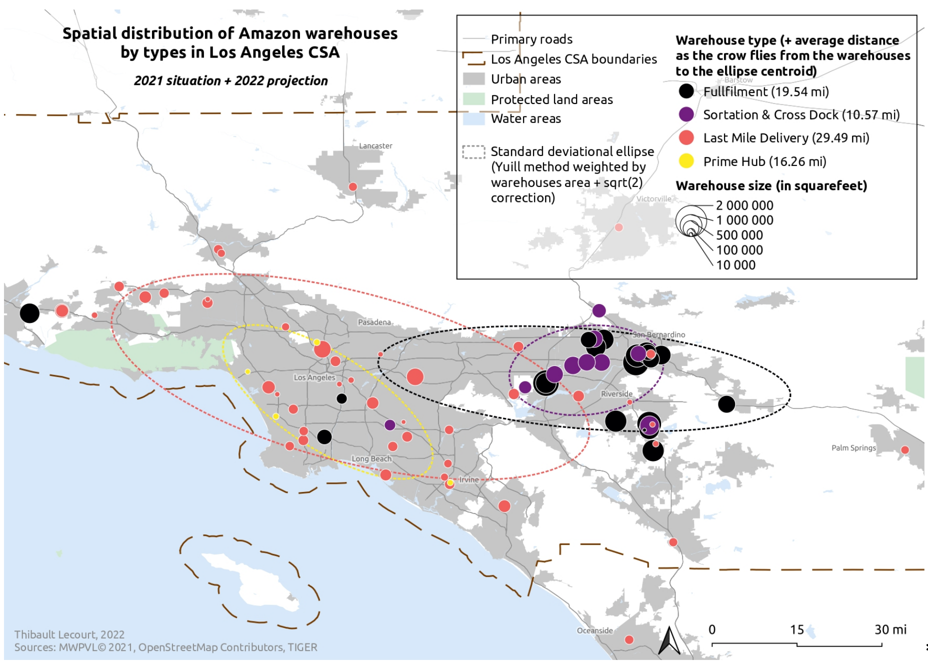
Last-mile local distribution centers are concentrated in the urban core (plus a few structures in some suburban areas in the north and north-west), and large distribution and fulfillment warehouses are in the western, southern, and northern suburban areas. Large distribution centers, as well as a large IXD and two regional sortation centers, are concentrated in the south-western part. Another area of concentration is to the north of the Chicago metropolitan area and to the south of the Milwaukee metropolitan area around the city of Kenosha, with several large warehouses near an Interstate 41 interchange and Kenosha Regional Airport.

Throughout this subsection, we identified similarities and differences among the three cases. For starters, the spatial patterns of logistics facilities are not always similar from one city to another. As logistics activities rely on available space and the proximity to ports, airports, and hinterland hubs, the above-mentioned patterns vary in each city. For example, in New York, the largest fulfillment centers are well-distributed within the urban corridor from New York and Washington DC. These XXL logistics facilities are exclusively located on the outskirts of the Chicago metropolitan area. In contrast, fulfillment and sortation centers are almost all concentrated in the eastern suburbs of the Los Angeles metro area. Yet all three city cases converge in developing urban logistics facilities, close to residential and commercial areas, or so-called "proximity logistics"

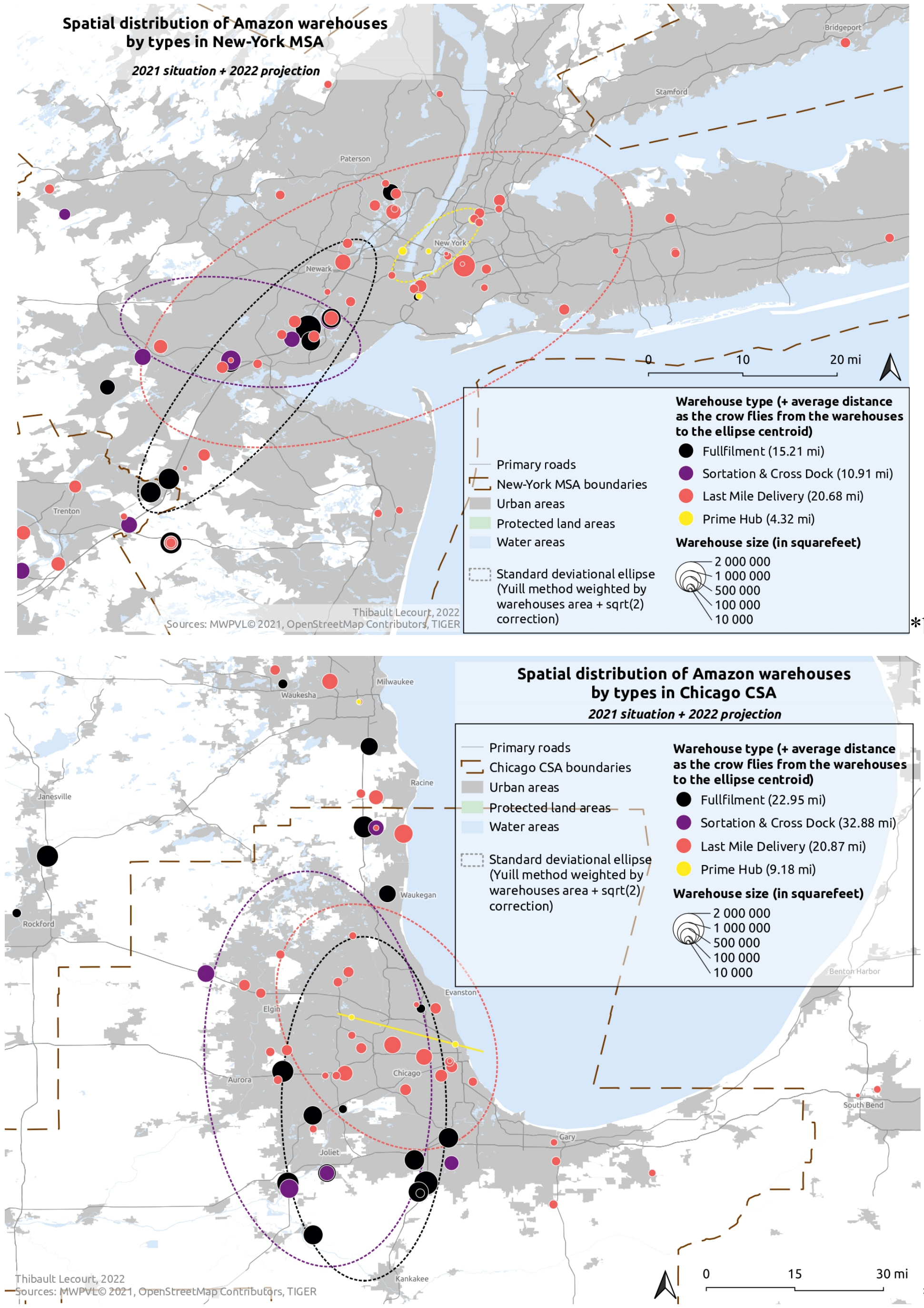
(Buldeo Rai et al., 2022) facilities. More generally, we confirm the location close to major transport infrastructures (Giuliano et al., 2016).

5.2 Investigating differential spatial patterns by the size and type of warehouse

In this last section, we make the hypothesis that with more complex data on Amazon warehouses (by size, by type of warehouse), we could identify differential spatial patterns for logistics facilities and show that the location of logistics facilities and logistics sprawl depends on the size and the type of facilities. This approach has been explored in a few previous studies. For example, Kang (2020b) examined the spatial distribution of warehouses relative to the distribution of logistics businesses, goods movement businesses, and consumer demand in 64 major US metropolitan areas. He distinguished the warehouses by two sizes (large and small). Raimbault et al. (2012) have differentiated logistics facilities in the Paris Region (between the parcel industry, distribution centers, and inland ports). Heitz and Beziat (2016) have illustrated this heterogeneity through a comparison of the location of the parcel industry facilities and that of other logistics activities. Heitz et al. (2019) proposed a new methodology for the Paris region to survey and classify logistics facilities to observe the spatial patterns of the different logistics facilities, according to logistics sectors.



*a



*b

*c

Figure 9. ***(a)** Spatial distribution of Amazon warehouses by types in Los Angeles CSA; ***(b)** Spatial distribution of Amazon warehouses by types in New York MSA; ***(c)** Spatial distribution of Amazon warehouses by types in Chicago CSA
Sources: MWPVL ©Authors, 2022

The case of Los Angeles presents a well-developed network (Fig.9.a) (and therefore the largest ellipse) of last-mile delivery sites across the metropolitan area, while the largest facilities are concentrated in the eastern part of the metro area. This configuration is similar in the case of New York (Fig.9.b) – we chose to use the MSA and not the CSA to have a more readable display, especially in the core area. In the case of New York, the largest fulfillment warehouses are concentrated in the southern part of the metropolitan area; last-mile delivery sites are very numerous around Manhattan. Smaller Prime Now facilities are found only in the central part of the urban area. The case of the Chicago CSA differs in part with larger dispersion ellipses for fulfillment and cross-dock facilities (Fig.9.c).

First, we observe that a significant concentration of small warehouses and logistics facilities (last-mile delivery and Prime Now) in dense urban areas, is located in core areas and their closest suburbs. In contrast, large facilities have spread to the outskirts of the urban areas. We have analyzed four specific types of warehouses, to identify their different location patterns. The warehousing industry is very heterogeneous, and warehouses do not share the same spatial pattern (Kang, 2020b). With this case study focused on Amazon, we show a complex freight landscape and a specific spatial pattern for each type of logistics facility thereby complicating the understanding of the geography of logistics facilities in major urban areas. Finally, we show consistency across warehouse sizes and types, along a center-periphery geographic gradient.

Table 1. Relative distribution by metropolitan area and by type of warehouse (in kilometers)

Warehouse type	New York, Newark, New Jersey	Los Angeles, Long Beach, Anaheim	Chicago, Naperville, Elgin
Whole Foods Retail or Distribution Center	134.2	41.5	31.1
Prime New Hub	23.2	51.1	19.7
Last-Mile Delivery Station – Heavy/Bulky Merchandises	35.6	49.1	43.3
Pantry and Fresh Distribution Center	26.2	37.0	16.5
Air Gateway	-	53.0	-
Receiving or Inbound Cross-dock	66.2	39.7	54.1
Regional “First Mile” Sortation Center	58.0	37.5	50.0
Last-Mile Delivery Station – Small Packages	40.0	54.3	29.2
Fulfillment Center and Distribution Center	52.4	50.2	43.6

Measuring barycenters[11] in these three metropolitan areas yields significant results (Tab.1). The average distance of large distribution warehouses (fulfillment centers, regional sortation centers, inbound cross-dock centers) from the population is significantly higher than for local distribution facilities that require relative proximity to consumers (last-mile delivery station, pantry and fresh distribution center, Prime hub). This is particularly true of the New York and Chicago areas, while the Los Angeles area shows the smallest differences. This specificity of Los Angeles is probably due to its extensive urban sprawl and the polycentric nature of its residential and commercial development. The spatial distribution of small warehouses is most closely associated with

[11] General population data is organized by zip code. For each studied area, the barycenter of the population is calculated. By utilizing the distance matrix functionality in QGIS, average distances between establishments and the barycenter of the general population are computedfor the years 2015, 2018, 2020, and 2022. This analysis provides valuable insights into the spatial characteristics of logistical activities within the study areas.

that of the population. It is not a measure of shipment distance but more of relative destination accessibility. E-commerce firms such as Amazon choose warehouse locations that help them optimize their operations and reduce costs and delivery times.

From 2015 to 2022 (Table 2), the distance between warehouses and general population regarding the type of warehouse leads to several findings: (i) the barycenters for large warehouses are greater than those for small warehouses and greater for the functions of import, fulfillment, and regional sortation than for the last-mile operations; (ii) Amazon tends to operate more fulfillment and distribution facilities near populated areas (-34.9% for the barycenter of Amazon fulfillment centers in the New York CSA, -51.8% for the Chicago CSA, but +4.2% for the Los Angeles CSA); (iii) relative distribution for last-mile facilities (Prime Now hubs, last-mile delivery stations), generally small warehouses, has increased significantly.

Table 2. Evolution of the relative distribution by metropolitan area by type of warehouse (in kilometers and in %)

Warehouse type	**2015**	**2018**	**2020**	**2022**	**Evolution from t0 to t4 (%)**
Los Angeles, Anaheim, Riverside CSA					
Whole Foods Retail or Distribution Center	-	41.5	41.5	41.5	**0**
Prime Now Hub	51.5	48.8	51.1	51.1	**-0,7**
Last-Mile Delivery Station – Heavy/Bulky Merchandises	-	-	45.5	49.1	**+7,9**
Pantry and Fresh Distribution Center	49.7	43.8	37.0	37.0	**-25,5**
Air Gateway	-	55.0	55.0	53.0	**-3,6**
Receiving or Inbound Cross-Dock	55.9	45.8	40.3	39.7	**-28,9**
Regional “First Mile” Sortation Center	50.3	41.5	31.7	30.3	**-39.7**
Last-Mile Delivery Station – Small Packages	48.1	46.9	52.7	56.1	**+16.6**
Fulfillment Center and Distribution Center	47.6	45.2	44.9	49.6	**+4.2**
New York, Newark, New Jersey CSA					
Whole Foods Retail or Distribution Center	-	134.2	134.2	134.2	**0**
Prime Now Hub	15.4	28.2	25.9	23.2	**+50.6**
Last-Mile Delivery Station – Heavy/Bulky Merchandises	-	53.7	41.5	35.6	**-33,7**
Pantry and Fresh Distribution Center	26.2	26.2	26.2	26.2	**0**
Air Gateway	-	-	-	-	**-**
Receiving or Inbound Cross-Dock	-	-	46.6	46.6	**0**
Regional “First Mile” Sortation Center	82.2	80.3	58.0	58.0	**-29,4**
Last-Mile Delivery Station – Small Packages	11.8	13.6	37.6	38.4	**+225,4**
Fulfillment Center and Distribution Center	76.5	39.1	45.8	49.8	**-34,9**
Chicago, Naperville, Elgin CSA					
Whole Foods Retail or Distribution Center	-	31.1	31.1	31.1	**0**
Prime Now Hub	22.9	19.7	19.7	19.7	**-13,9**

Last-Mile Delivery Station – Heavy/Bulky Merchandises	-	-	47.4	43.3	**-8,6**
Pantry and Fresh Distribution Center	-	16.5	16.5	16.5	**0**
Air Gateway	-	-	-	-	**-**
Receiving or Inbound Cross-Dock	42.3	42.3	42.3	42.3	**0**
Regional “First Mile” Sortation Center	84.7	59.7	56.7	56.1	**-33,7**
Last-Mile Delivery Station – Small Packages	19.4	32.1	29.7	30.6	**+57,7**
Fulfillment Center and Distribution Center	86.1	43.5	44.1	41.5	**-51,8**

6 Conclusions and discussions

From the analysis of Amazon’s logistics facilities, we can determine the importance of e-commerce’s real estate footprint and its spatial patterns and confirm certain characteristics of the e-commerce sector: (i) first, an increasingly specialized logistics facilities to support the company’s vertical integration strategy (distribution centers and local delivery points for packaged and unpackaged products, Amazon’s own airport hubs, and small logistics facilities for the Prime service or last-mile delivery) ; (ii) second, a diversification in the scale and location characteristics of warehouses (location in dense urban or dense suburban zones as opposed to location in ex-urban areas or even on the outskirts of the metropolitan areas); (iii) third, a dual business model between large suburban warehouses (fulfillment centers, inbound cross-dock centers, regional sortation centers) on one side, and a new segment of intermediate and small urban logistics facilities (last-mile delivery stations, Prime hubs) on the other.

Our research confirms specific spatial patterns for the distribution structure of e-commerce. This cartographic analysis makes it possible to identify several land-use patterns for Amazon’s logistics system. A dual pattern of networking and concentration of logistics warehouses, with the development of warehouse clusters around major transportation infrastructures (highway interchanges, regional or international airports, ports, rail freight networks) and the creation of a network of warehouses of varying sizes and densities, especially in dense urban areas. This dual pattern enables the attainment of broad market coverage even in secondary markets, the reduction of processing and delivery times, and economies of scale. This dual logic exists both at the national level (concentration in the largest megaregions) and at the metropolitan level (concentration of warehousing clusters and deployment of a network of urban logistics facilities).

This research confirms the emergence of a dual logistics real estate market, with on the one hand large suburban or even exurban warehouses that structure logistics chains on an international, national, and regional scale (Heitz et al., 2017), and on the other hand small urban warehouses or urban logistics spaces designed to serve metropolitan areas and the last-mile segment. In this last-mile segment, new logistics spaces are constructed to support the development of new market segments, in particular fast deliveries (one day, same day, instant deliveries). The growth of e-commerce and the increase in goods flows that it brings with it have created an interest in developing urban logistics facilities, or “proximity logistics” facilities (Buldeo Rai et al., 2022). E-commerce pure players are one of the drivers of the logistics real estate sector, seeking to meet their growing needs for logistics space by turning to new asset classes, ranging from XXL warehouses of hundred thousand square feet to small urban warehouses of a few hundred or thousand square feet. This dual entry into the logistics real estate market is well illustrated by developments in Amazon’s US locations.

The process of expanding the spatial coverage of warehouses, which contributes to logistics dispersal through the proliferation of warehouses in suburban zones and more generally in low-density areas (Dablanc et al., 2014; Giuliano et al., 2013). Several previously identified location-related relationships (Dablanc et al., 2020) are confirmed by this empirical investigation on Amazon. Logistics sprawl is positively correlated with the availability of large parcels in suburban areas, and the intensity of logistics sprawl differs depending on the type of facility (greater for large distribution and processing centers and less for parcel sorting terminals). Therefore, Amazon contributes to logistics sprawl in the United States, both through the location of large distribution warehouses in suburban areas and even on the outskirts of metro areas, and through an increasingly dense network of urban warehouses that enlarge Amazon's land and real estate footprint. In terms of urban spatial planning, as well as the management of vehicle flows and the negative externalities of urban logistics, this raises regulatory, land, real estate, and environmental concerns.

The spatial patterns of Amazon warehouses can be explained first by a change in the size of Amazon's business (rapid growth of e-commerce, further accelerated by the COVID-19 pandemic and Amazon's dominant position on the US market), and second by the general evolution of global supply chains (Hesse, 2008). Indeed, Amazon's logistics real estate strategies parallel the dominant market trends observed on the global logistics real estate market: development of a logistics real estate supply that meets the needs of logistics operations (adaptability, automation, need for space and large land parcels, modern equipment); recognition of logistics buildings as financial and real estate assets (Fender et al., 2016); a process of vertical integration that relies on direct control of several links of the supply chain in order to reduce reliance on third-party actors (3PLs, shippers, carriers); and development of a logistics real estate market that meets the needs of logistics operations.

Our research also confirms differentiated logistics sprawl patterns regarding the type of warehouse or logistics facility and regarding the urban structure of each metro region. To completely understand Amazon's spatial logic, it is necessary to scrutinize their warehouse location strategies on a finer scale. From the analysis of the three case studies, it appears that regionalized logistics strategies are being implemented, with several significant characteristics in common (concentration of large warehouses on the outskirts of metropolitan areas, deployment of a fine network of urban logistics facilities, development of intermediate logistics facilities). Nonetheless, it appears that there are local variations on these regionalized strategies, apparently adapted to specific territorial arrangements and socio-economic and urban dynamics: the case of the Chicago metropolitan area demonstrates a logistics system built according to a pattern of distinct radio-concentric areas (large warehouses on the outskirts, urban logistics spaces in the city center, with a few rare urban logistics facilities in suburban areas). The case of Los Angeles, on the other hand, reveals a polycentric logistics system reflecting the polycentric organization of the metropolitan area, with several major clusters of suburban warehouses along the outskirts of the city, another cluster near the port infrastructures of Los Angeles/Long Beach, and a scattering of urban logistics sites in residential and employment areas. Lastly, the southern portion of the Northeast region, from the New York metropolitan area to Baltimore and Washington DC, suggests a new form of spatial organization, this time linear, which follows the urban corridor that structures the Northeast megaregion with, for instance, several clusters of suburban and exurban warehouses on the outskirts of the major metro areas, but also in secondary cities.

This work could be complemented by further research in a context of rapid development in Amazon's logistics system and continued growth in the e-commerce sector, particularly during the COVID-19 crisis. Other analyses of Amazon's locations in other urban regions and large agglomerations could be conducted to refine the initial findings on the regionalization of Amazon's logistics system and to identify other regionalized processes. In addition, two other lines of research could be pursued: first, a multifactorial analysis (transportation, land, traffic flows and congestion, socio-demographic and economic factors, environment, size of facilities (Kang, 2020a)) on the location logic of Amazon warehouses in order to assess its negative impacts; second, an analysis of land and real estate costs in order to understand the impact of these costs on the location of warehouses and the growth of the warehouse network and to gain a better understanding of the differential relationship between warehouse location (in urban and suburban areas) and real estate and land costs (Oliveira et al., 2022). Finally, a new direction for research can be identified in the quantitative analysis of the impacts of Amazon's logistics facilities on land use, on traffic conditions, and on negative externalities on local communities (Fried et al., 2023).

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Author contribution

Matthieu Schorung: formal analysis, methodology, literature review. Thibault Lecourt: cartography, spatial analysis. Mattieu Schorung and Laetitia Dablanc: conceptualization, writing.

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