From XXS to XXL

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From XXS to XXL: Towards a typology of distribution centre facilities

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ABSTRACT

Distribution centres are becoming more and more relevant for spatial planning, due to their rapidly increasing size and number. There is little literature, however, that provides a generalized analysis of the size and functional attributes of distribution centres, and none that discusses the relationships between these attributes. Our aim is to fill this gap by providing new evidence and analysis to understand this relationship. We make use of an extensive database of 2888 DCs in the Netherlands to develop a new typology of DCs based on the geographical location of DCs, their functional attributes and client sector characteristics. The analysis shows that the context in which medium sized DCs are operating is more heterogeneous than in the case of very large and small size DCs. This study is a first attempt to analyse this relationship between facility size and functions based on a rich and extensive dataset of large population of DCs. The results can serve as input for further quantitative statistical analysis and international comparison.

1. Introduction

In the context of increasing globalisation of production networks, the increased complexity of supply chains and change in consumer behaviour, a broad range of logistics facilities has emerged during the past decades to support the distribution of products from producers to consumers. These facilities serve to consolidate and deconsolidate goods flows. Their size varies from small parcel lockers and city hubs to mega distribution centres.

Different terms are used in the literature to denote logistics facilities, e.g. distribution centre, warehouse, freight hub, e-fulfilment centre, logistics depot, or city hub. A standard typology for these, however, is lacking (Higgins et al., 2012; Notteboom et al., 2017). Our aim with this paper is to make a step towards such a typology, based on size and functional characteristics, where types are collectively exhaustive and mutually exclusive. We base the typology on the literature about logistics facilities and a large database about such facilities in the Netherlands. A typology can be helpful to support communication and debate between scholars and practitioners, as there is a great heterogeneity of logistics facilities that can be observed in the field – e.g. wholesale facilities, retail facilities, or logistics service provider facilities (Heitz et al., 2019). A typology is also a necessary starting point to study specific logistics facility types (ibid) – for example, research on logistics sprawl (Cidell, 2010; Heitz et al., 2020) could differentiate between small and large facility types. As such, the typology can support scholars to differentiate between types when studying their impact on urban areas in terms of land use, freight traffic, emissions, and employment. The proposed typology is based on size and other functional characteristics (such as activity type), as these characteristics influence the impact (of a facility) on the urban area. Currently, there is a dearth of knowledge on the impact of logistics facilities at the metropolitan level (Kang, 2020; Sakai et al., 2019). Spatial planners could use the characteristics of each type to discuss what are suitable locations for different facility types and accordingly design spatial plans.

Our approach has been to study the characteristics of various DCs present in a large database of DC real estate in the Netherlands. The database used contains information about both size and function of the DC, which allows us to study these characteristics together and leads to the combined typology. We derived a general framework of relevant functional characteristics based on the scientific literature. Next, we arrive at a typology which is based on size and function.

The remainder of this paper is organised as follows. Section 2 reviews

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the literature on previous typologies and provides perspectives on the impact of logistics facilities on urban areas. Section 3 explains the research method and database used, while Section 4 describes the population of DCs in the Netherlands. Section 5 includes the framework of criteria of the typology. Section 6 presents the typology and discusses the results, and Section 7 includes conclusions and recommendations for research and practice.

2. Literature review

2.1. Impacts of logistics facilities on urban areas

Over the last decade there is increased research on how logistics facilities impact urban areas in terms of land use, employment, and negative externalities such as freight traffic, emissions, and congestion (Kang, 2020; Sakai et al., 2017; Sakai et al., 2019). There is, however, still a lack of knowledge on the impact of logistics locations at the metropolitan level.

Most research in this area studies the impact of logistics sprawl, i.e. the spatial deconcentration of logistics facilities in metropolitan areas, and concludes that there is a positive relation between spatial deconcentration and negative externalities of logistics facilities (e.g. Dablanc and Ross, 2012; Woudsma et al., 2016). Operational shifts of the logistics industry towards large-scale regional distribution centres resulted in an increase in the distance between the distribution centre and the final customer, which in turn has resulted into an increase in negative environmental impacts such as greenhouse gas emissions, pollutions, noise nuisance, congestion, and fuel consumption (Aljohani and Thompson, 2016). A scenario study by Wagner (2010) confirms that in a scenario with dispersed logistics land use there are indeed more externalities compared to concentrated logistics land use. Freight trucks have to travel longer distances into urban areas and total distance travelled increases as shipments are moved from large trucks into smaller delivery vehicles (Crainic et al., 2004). According to Sakai et al. (2017) the externality of increased freight traffic is not only caused by sprawling warehouses, but also by sprawling freight demand. Although DCs generally spread outwards into the periphery because of lower land costs and increased efficiency, there are also externalities if located within urban zones. Urban areas that host large facilities face more congestion and wear and tear of the local road network (Cidell, 2015), especially as local roads might not be suited for heavy trucks (Allen et al., 2012).

A typology can support to differentiate between types of logistics facilities when studying their impact on urban areas (e.g. freight traffic, emissions). Typologies of logistics facilities are important in understanding the underlying differences between the type of facilities that are more efficient and sustainable than others in terms of increasing productivity and employment, and/or attracting more or less freight traffic and logistics activities. Spatial planners can use a typology to examine the characteristics of logistics facility types. As some facilities require huge spaces, a typology can support spatial planning discussion on which facility types should be allowed in urban areas and which types are preferably located in peripheral areas.

2.2. Typologies of logistics facilities

Although the concepts of a warehouse and a distribution centre are well known in the Supply Chain Management (SCM) literature (Bowersox et al., 1968), a standard typology of logistics facility types is lacking (Notteboom et al., 2017). Four studies propose typologies - i.e. Desmet et al. (2010), Higgins et al. (2012), Notteboom et al. (2017) and Heitz et al. (2019). Desmet et al. (2010) developed a typology including four types of large-scale European Distribution Centres (EDCs). Higgins et al. (2012) propose a typology of logistics terminals consisting of five types. The smallest type S involves an individual warehouse, while the largest type XXL contains a large terminal including multiple logistics facilities, such as an airport or seaport. Their typology, however, does not differentiate at the level of individual logistics facility types as is the goal of our paper. Heitz et al. (2019) propose a systematic classification of 20 facility types based on four criteria - i.e. function (storage, cross-docking), operator (shipper, wholesale, retail, LSP), goods type, and goods destination (example types are generalist LSP facility, or express parcel terminal) – combined with a case study of logistics facilities in France. This analysis does not reflect on the relationship with magnitude of the DCs, however. Notteboom et al. (2017) propose a taxonomy of facility types based on activity type, i.e. warehousing and storage, transit and value-added services. Also here, the relationship with size is not discussed. Reviews of different, but possibly related types of logistics facilities include port-based logistics parks (Kuipers and Eenhuizen, 2004), intermodal terminals (Notteboom and Rodrigue, 2009), and mixed logistics nodes (Grundey and Rimienė, 2007). None of these explore a large empirical real-estate dataset and discuss the combined features of function and size of distribution centres. In summary, the literature review shows that existing typologies focus either on size or on functionality, but a typology based on both characteristics is lacking.

3. Method and data

3.1. Method

Based on the scientific literature we derived a framework of relevant criteria to differentiate between logistics facilities. These criteria include surface size (m^2) as well as six other characteristics, i.e. 1) activity type, 2) product type, 3) product range and speed, 4) network structure, 5) market service area (geographical market scope), and 6) service days - explained in Section 5.1. Each criterion contains multiple categories that are based on literature - for example, market service area includes categories ranging from local to international. The framework of criteria was used to study the characteristics of logistics facilities present in a large database of DCs in the Netherlands. This revealed types that occur frequently in the data and are based on diverse combinations of criteria (Fig. 1). For example, one of the types includes facilities that are used for regional (market service area) food (product type) distribution to retail stores.

3.2. Data

The Netherlands is well-suited as study area for DCs as the country is a preferred logistics location that hosts many different types of logistics facilities. The logistics facility database used here includes two merged data sets: a first data set with 1737 facilities with a surface area between 2.000m^2 and 122.000m^2 (Bak, 2017), and a second data set of 1686 facilities with surface areas ranging from 5.000m^2 to over 300.000m^2 (Rijkswaterstaat, 2017). Both datasets have a national geographic focus. The first dataset was purchased from Bak real estate consultancy office. This dataset is used for the yearly statistics of logistics real estate in the Netherlands (NVM, 2020). The second dataset was obtained from Rijkswaterstaat, which is the executive agency of the Dutch Ministry of Infrastructure and Water Management. The datasets of Bak and Rijkswaterstaat are updated on a yearly basis, i.e. by adding new facilities or new users and deleting facilities that are demolished or no longer used as warehouse. At any point in time, all DCs in the database have been in use, functioning in the supply chain of that time. Both datasets were merged because both are based on the same geographical decomposition (zip code level), and together they provide a more complete overview of

Fig. 1. Research method.

the total number of DCs in the Netherlands.

The Bak dataset includes data on the street address of facilities, zip code (6 digit), surface, year of construction, owner, and user, but not the industry sector. The Rijkswaterstaat dataset includes the street address, zip code (6 digit), surface, year of construction, user (but not the owner), and also the industry sector - i.e. 1.200 records include the industry sector code (Dutch SBI code, based on the EU NACE and UN ISIC classifications). We merged the datasets based on zip code (6 digit) and street address. We deleted 535 duplicate facilities from the Bak dataset since the Rijkswaterstaat dataset is more elaborate - i.e. it includes data on the industry sector (SBI codes) of the company operating the facility. We also deleted two facilities for which there are no data on surface size available.

The combined database has 2888 unique facilities that started operations between the year 1890 and 2016. Official counts of the total number of DCs in the Netherlands are lacking, but interviews with Dutch logistics experts indicate that the total number of DCs in the Netherlands is around 3500–4000. This means that our database represents approximately 75 to 80% of the total number of DCs in the Netherlands.

However, the database has a limitation as it does not include data of small logistics facilities (i.e. $< 2.000m^2$). Based on the research of Piepers (2018), these facilities were estimated to at least 8.680, based on the total number of small parcel pickup points in the Netherlands. As there are limited data on the smallest logistics facilities, there are two types based on definitions from literature - i.e. parcel locker and city hub. Another limitation is that there is one large facility, i.e. the flower auction in Aalsmeer, that consists of multiple individual facilities in the database because the flower auction expanded multiple times throughout the years.

4. The population of DCs in the Netherlands

Fig. 2 shows the share of the total facility surface area (m^2) per size range as this gives a better picture than the number of large scale DCs - the number of large facilities $>20.000m^2$ is relatively small (i.e. only 19% of the total number), but they represent almost half (47%) of the total of 42 million m^2 logistics facility space in the Netherlands in 2016 (Fig. 2).

The share of the total constructed surface of mega DCs - i.e. with a total surface area larger than $40.000m^2$ - has increased significantly in the Netherlands, from 11% of the floor space constructed in the 1980s to 38% in the 2010s. The first DCs with surface size of more than $100.000m^2$ floorspace were constructed in the 1970s. In the period 1980–2016, the construction of small facilities (between 5.001 and $10.000m^2$) decreased, while the surface share of midsize facilities ($15.001–20.000m^2$) remained more or less the same over the same period.

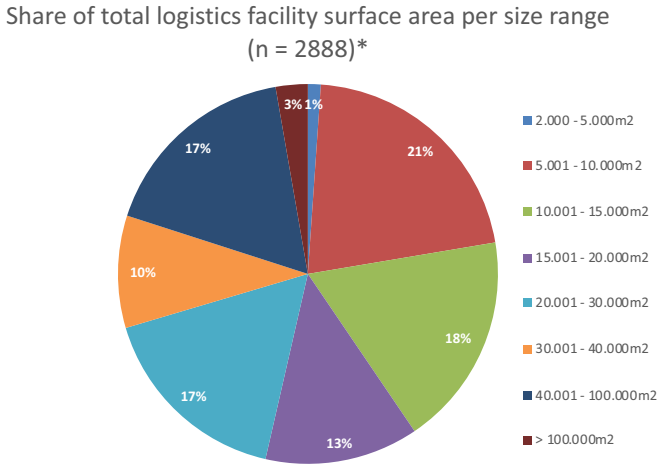

Fig. 2. Share of logistics facility surface area per size range in 2016 ($n = 2888$). (Note that there are no data including surface areas of the smallest facilities ($0–2.000m^2$). There are, however, at least 8.680 pickup points in the Netherlands (Piepers, 2018). If we assume a pickup point has an average surface of 30 m^2 these facilities would represent 0,62% ($260.400m^2$) of the total logistics facility surface area in the Netherlands.)

Further analysis at industry sector level shows that the companies operating the facilities are classified into 10 broad sectors (SBI chapters): i.e. seven Wholesale trade sectors (SBI 461–467); Freight transport by road (4941); Warehousing and storage (521), and Support activities for transport (522). In each sector (except SBI 461) the highest share of logistics facilities has a size between 5.001 and $7.500m^2$, implying that middle-sized logistics facilities are very popular to companies of diverse industry sectors. Fig. 3 shows the shares of different size ranges in the total surface area (m^2) of logistics facilities per industry sector.

In industry sectors 464 (Wholesale consumer goods) and 466 (Wholesale of machines and equipment) the small facilities ($5.001–10.000m^2$) represent a relatively large share of the total existing surface area, while in industry sectors 4941 (Freight transport by road) and 522 (Support activities for transport) the large facilities ($>40.000m^2$) represent a relatively large share of the total existing sectoral surface area. In sectors 4941 (Freight transport by road) and 522 (Support activities for transport) the large share of large facilities ($>40.000m^2$) can be explained by the domination of large LSPs that need very large facilities to store and distribute products for multiple shippers - e.g. CEVA and GVT in sector 4941, and CEVA, Docdata and DHL in sector 522. In the same 4941 sector (Freight transport by road), there is also a significant share (31%) of small facilities ($5.001–10.000m^2$) in the total sectoral surface area for which there are three possible explanations, i.e. first, freight transport is a sector in which there are many start-up companies, second, the average year of construction of the corresponding facilities is 1990, which was a time at which there were less consumers to serve per facility, and third, DCs were smaller because they more often served national customer markets before the start of free trade in the European Union in 1993. The wholesale Food sector (SBI 463) is represented by a large share of small and medium-sized facilities in the total surface area ($5.000–15.000m^2$) (Fig. 3). This is because Food wholesalers often serve a regional market. The wholesale Agriculture sector (SBI 462) shows a higher share of larger DC surface ($>20.000m^2$) than in the wholesale Food sector, which can be explained as wholesale Agriculture (SBI 462) is one step before wholesale Food (SBI 463) in the food supply chain.

Overall, the analysis of the data indicates there are multiple facility sizes and facility types per industry sector (Fig. 3) – as was also concluded for facilities in France (Heitz et al., 2019). Therefore, it is difficult to assign industry sectors to individual facility types in our typology. It is, however, possible to explain individual facility types based on various functional criteria. For example, the size of a mega flower distribution facility ($112.000m^2$) in the sector wholesale Agriculture (SBI 462) can be explained by the worldwide market service area of the facility in combination with flowers being a space extensive product to store and distribute. To understand how sizes can be related to function, however, we need to define the functional characteristics first. This is the subject of the next section.

5. Functional characteristics and their relation to size

According to Notteboom et al. (2017), logistics facilities can be categorized by their main activity in a supply chain - i.e. warehousing and storage, transit, or value-added services. Other possible criteria to capture the variety of logistics facilities are, e.g. size, geographical market scope, product type, product range, operator of the facility, or position in the transport chain (Higgins et al., 2012; Notteboom et al., 2017; Heitz et al., 2019).

In this paper, the typology of logistics facilities is based on six functional criteria extracted from literature: 1) activity type, 2) product

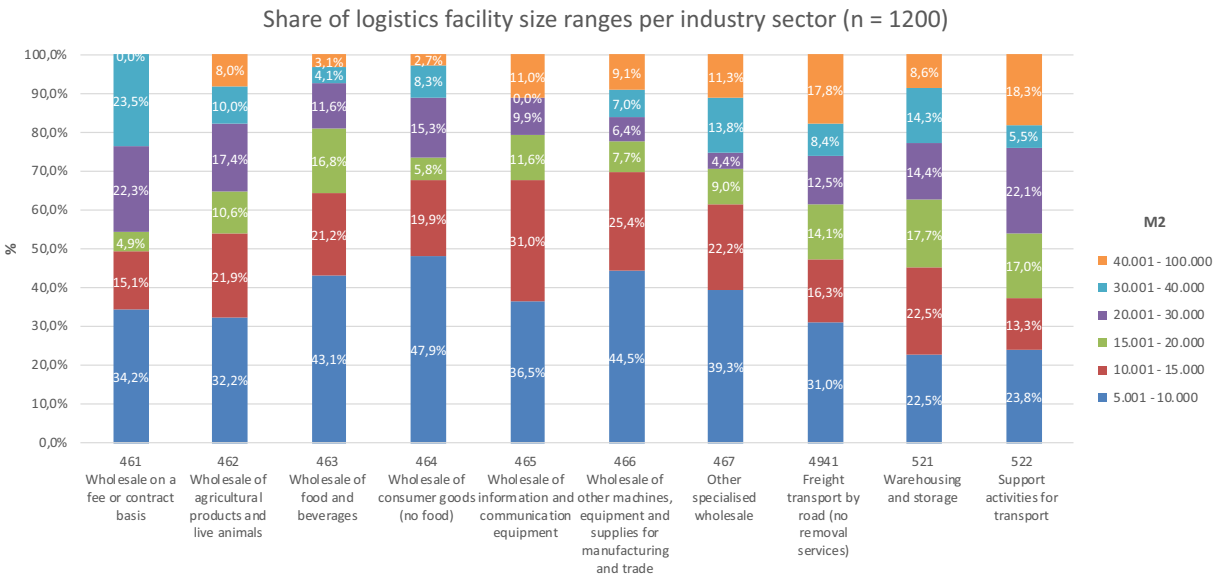

Fig. 3. Share of logistics facility size ranges per industry sector in 2016 (n = 1200) (source: Rijkswaterstaat, 2017).

type, 3) product range and speed, 4) network structure, 5) market service area (geographical market scope), and 6) service days – related to size (i.e. the seventh criterion). The operator, which can be represented by e.g. shipper, LSP, or retail company (Heitz et al., 2019), is not considered as a criterion in this typology because of the existence of multiple possible operators for different types. The position in the transport chain criterion (by Notteboom et al., 2017) is incorporated in the network structure criterion. We discuss these criteria in the next subsection. Together, the criteria result in what we call 'size logic', or interaction between functional criteria and size. We introduce this in the second subsection.

5.1. Functional criteria

5.1.1. Activity type

This criterion is important to differentiate logistics facilities based on the main activity performed at the facility. The criterion includes six possible activities, i.e. storage (S), consolidation (C), warehousing (W), distribution (D), cross-docking (CD), and Value Added Logistics (VAL) (Higginson and Bookbinder, 2005) – comparable to the categories in Notteboom et al. (2017). A logistics facility often performs multiple of these activities at the same time. Logistics facilities that have Storage (S) as main activity, are dedicated to the storage of goods, i.e. finished goods, semi-finished goods, or raw materials. They can be used for short-term storage or long-term storage. The Consolidation (C) activity means that goods are merged for outbound distribution to a specific customer or geographic area (Higginson and Bookbinder, 2005). Small logistics facilities – e.g. a parcel locker or parcel pickup point - are too small to consolidate goods, the goods are delivered consolidated to the facility for further distribution to address locations and neighbourhoods in the city. Small facilities can, however, be used as consolidation points for goods returns. In opposition, large logistics facilities are often used to consolidate large goods flows into smaller goods flows for specific regions or customers. Warehousing (W) includes the receiving, put away, and order picking of goods for distribution towards the final customer, or towards a subsequent node in the supply chain (Higginson and Bookbinder, 2005). Large facilities can accommodate many warehousing activities - for example online company DCs in which employees pick many small orders. At the smallest facilities there are usually no order picking activities, here the main activity is to distribute parcels into a specific geographic area. The Distribution (D) activity implies that the facility is used to reduce transit times and increase the speed at which goods move through the supply chain (Notteboom et al., 2017). Today, most facility types are used to increase distribution speed towards the customer. At large facilities it is possible to apply cross docking to reduce transit times. Small facilities such as city hubs can contribute to high delivery speed because of their location near consumer areas. Cross-docking (CD) means that a product is received at a facility and then shipped at the earliest opportunity. Goods only pass through from one dock to another dock, they are already consolidated at another facility (Higginson and Bookbinder, 2005). Value Added Logistics (VAL) contain activities that maximise the goods value in the supply chain, including repacking, pricing, or labelling of goods (Notteboom et al., 2017).

5.1.2. Product type

The type product handled at the facility can be generic (parcels, pallets, bulk) or specific (e.g. industrial goods, equipment, or fresh food) (Heitz et al., 2019). The product type criterion is important because specific products may require a specific type storage facility, for example a cold storage.

5.1.3. Product range and speed

This criterion includes the range of products that are distributed from a facility as well as the distribution speed of the products. Both elements are characterised along a single dimension, the product range can be small / large while distribution speed can be low (slow movers) / high (fast movers).

5.1.4. Network structure

Network structure refers to the layout of the transport system between production and consumption locations, including a number of logistics facilities. Examples are the direct, centralised, decentralised, and hub and spoke structure (Onstein et al., 2020).

The direct structure implies that products are distributed directly from production to the end customer, there are no other intermediate hubs. In case of direct network structure, goods are (temporarily) stored in a facility located at or near the production location. The direct structure is not often used, there are often intermediate facilities to save transport costs. In a centralised structure there is a single facility at which goods are consolidated - usually a large DC - and from there they are distributed to the customer. The decentralised structure includes multiple facilities in multiple echelons, for example a national DC combined with three smaller regional facilities. The hub and spoke

system is a transport system in which a central hub is used for transport to multiple smaller facilities ("the spokes").

5.1.5. Market service area

Market service area refers to the geographic market focus of the facility (Grundey and Rimienė, 2007), of which there are five categories, i.e. neighbourhood, town/city, regional, national, international. The market service area criterion is important because different facility types serve different geographical areas.

5.1.6. Service days

The service days criterion includes the delivery time (in days) between the facility and its customer. Customer service is a very important aspect in today's businesses as customers expect high service levels for goods distribution, i.e. deliveries within single or few days (Christopher, 2011). Small facilities located within urban agglomerations - such as parcel pick up points or Urban Consolidation Centres - can offer faster delivery times than large facilities located outside urban areas.

All characteristics that are presented above determine what we call the 'size logic'. A facility located in an urban area is often small (because of high land prices) and difficult to access by large freight vehicles. Because of the small size the facility is inefficient (automation of parcel handling is not possible), it can only handle parcels or small city deliveries (e.g. fresh food orders for restaurants) and serve a small geographic area. However, because of their small size they can be located in close proximity to the customer, which allows quick deliveries and convenient return options, especially for parcels ordered online.

5.2. Relation of functional criteria to size

In this subsection we explain the interaction between the six functional criteria and size. Size (measured as the surface area in m^2) is an important criterion to include in a typology for two reasons. First, size determines which logistics activities are possible to organise from the facility, and second, a typology based on size can support the spatial planning authorities in their decision-making process about the suitability of facility types and their locations at different geographical level.

The first criterion includes the *activities* performed at the facility, which influence its size, i.e. a facility used for long term storage requires a larger space compared to a facility that is used for cross-docking (of the same goods). In case there are VAL activities performed at the facility these activities will require additional space. *Product type* (space extensive or space intensive) also affects the facility size, for example, a sand company requires a large semi-open storage space, whereas a company selling smartphones needs a small hub to deconsolidate goods for rapid transport to the retail or online customer. *Product range* affects the size of a facility in such a way that a broad product range generally requires more storage space - and therefore a larger facility - compared to a small product range. *Distribution speed* influences the size of the facility in another way, i.e. in case there are many slow moving goods handled at the facility, there is more space needed to store products (e.g. pallets racks) compared to a facility that cross-docks fast moving goods.

The *network structure* of the transport system may include single (centralised) or multiple (decentralised) facilities. In case of a centralised structure all inventories are stored at a single location, which influences the surface size of the facility. *Market service area* and the size of a logistics facility are positively related - a large facility generally serves are large geographic area. The *service days* criterion is also positively related to facility size, i.e. in case the customer demands a low number of service days (e.g. same day delivery) the goods are often sent to the customer from a small (local) hub. Large hubs are often located further from consumer areas, from where it takes multiple days to transport goods to the customer.

The *size* criterion includes seven categories, i.e. XXS to XXL. The XXS size is based on the size of a parcel locker or small store or pickup point where customers can collect or return their parcel, i.e. up to $200m^2$. The XS size is based on the size of a city hub (up to $2000m^2$) (Browne et al., 2005). The sizes S, M and L are arbitrary; determining these facility types is complex because multiple types and industry sectors are represented in multiple size ranges (Table 1). It is, however, necessary to propose a typology to support our research and discussion. The XL ($20.001–40.000m^2$) and XXL ($>40.000m^2$) sizes are based on business literature (NVM, 2020) as well as the database which shows an increased construction of XXL facilities (i.e. $>40.000m^2$).

6. Proposed typology

This section presents the proposed typology including eight logistics facility types. Each facility type is illustrated based on the criteria explained above. The eight types are, in order of average size:

1. Parcel lockers and pick-up points
2. City hubs
3. Parcel and postal sorting facilities
4. Regional food wholesale and retail facilities
5. National retail and e-commerce facilities
6. Manufacturer DC facilities
7. Bulk facilities
8. Global agricultural auctions

In this typology the sectoral dimension is leading. Other functional criteria help to explain the underlying variation in DCs and, as we will see below, their sizes. We present these types below, discuss the variations in terms of size within each category and summarize the typology.

6.1. DC types

6.1.1. Type 1: Parcel lockers and pick-up points

Parcel lockers are self-service lockers at which consumers can collect and return goods purchased online (Vakulenko et al., 2018), they are often situated in places that attract many visitors, e.g. public buildings (libraries, universities), supermarkets or gas stations. Parcel lockers enable high speed distribution, customers can pick-up their parcel the same day. Parcel locker facilities have become increasingly popular because they aggregate individual customer demand and therefore reduce delivery costs towards the customer (Janjevic and Winkenbach, 2020).

Parcel pick-up points are generally small, behind the counter areas, having a small size of e.g. $5m^2 – 30m^2$ (Fig. 4). This type facility is used to store small parcel volumes for a short period of time (e.g. 2–3 days) during which customers can collect their product. The number of service days is low, it is often possible to collect products the same day or next day. The parcel pick-up point can also function as consolidation point for goods returns (Higginson and Bookbinder, 2005). Parcel pick-up points have a local (neighbourhood) market service area, they are often located in stores (supermarkets), post offices, public buildings (libraries, schools), gas stations, or other areas that generate consumer trips (Weltevreden, 2008). In the Netherlands, there are at least 8.680 parcel pick-up points (Piepers, 2018). Grocery retailer Albert Heijn, for example, offers parcel pick-up points for Bol.com (webshop) customers. In case the parcel pickup point is located in a store there is the advantage of upselling opportunities.

6.1.2. Type 2: City hubs

City hubs are logistics facilities from where consolidated deliveries take place within urban areas, they are located in the vicinity of their market service area and are mostly used for fast city deliveries. A city hub is usually owned by single company. Possible city hub activities are storage, warehousing or consolidation of returned goods. Warehousing could include order picking for a large organisation, for example a university (Browne et al., 2005). A special type in this category is the

Table 1
Cross section of facility types into size ranges.

Name	Building size	Function[a]	Product type	Product range and speed	Market service area	Service days	Number of facilities in the Netherlands	Types represented in each size range
XXS	< 200 m^2	S / D / (and C only for online goods returns)	Parcels	Broad range High speed	Local: Neighbourhood	Same day Next day	> 8.680 pick up points and parcel lockers	Parcel locker Pick up points
XS	200 - < 2.000 m^2	S / C / W / D	Parcels Fresh food delivery	Broad range High speed	Local: Town / City	Same day Next day	Unknown	City hub
S	2.000 - < 8.000 m^2	S / C / W / D	Parcels	Small / broad range Fast-movers / slow-movers	Regional	Next day	995	Parcel and postal sorting facility
M	8.000 - < 15.000 m^2	S / C / W / D / CD / VAL	Parcels Pallets Bulk	Small / broad range Fast-movers / slow-movers	Regional National	Next day Multiple days	1024	Parcel and postal sorting facility Regional food wholesale and retail National retail or e-commerce facility Bulk facility
L	15.000 – < 20.000 m^2	S / C / W / D / CD / VAL	Parcels Pallets Bulk	Small / broad range Fast-movers / slow-movers	Mostly National and International (although there are large regional Post and Food retail DCs)	Next day Multiple days	319	Parcel and postal sorting facility Regional food wholesale and retail National retail or e-commerce facility Manufacturer DC facility Bulk facility
XL	20.000 - < 40.000 m^2	S / C / W / D / CD / VAL	Parcels Pallets Bulk	Small / broad range Fast-movers / slow-movers	Mostly National and International (although there are very large regional Post and Food retail DCs)	Next day Multiple days	411	Parcel and postal sorting facility Regional food wholesale and retail National retail or e-commerce facility Manufacturer DC facility Bulk facility Global agricultural auction
XXL	> 40.000 m^2	S / C / W / D / CD / VAL	Parcels Pallets	Small / broad range Fast-movers / slow-movers	National International (although there are very large regional Post and Food retail DCs)	Multiple days (online possibly faster)	146	Parcel and postal sorting facility Regional food wholesale and retail National retail or e-commerce facility Manufacturer DC facility Global agricultural auction

[a] Storage (S), consolidation (C), warehousing (W), distribution (D), cross-docking (CD), Value Added Logistics (VAL).

Urban Consolidation Centre (UCC) in which goods from multiple companies are consolidated for last mile distribution. Logistics companies deliver their loads at the UCC, and the UCC operator delivers the loads, often with environmentally friendly transport modes (Browne et al., 2005). UCCs are often operated by last-mile specialists. A sub type of the city hub is the mobile depot from which goods are delivered by cargo bike to the final customer (Janjevic and Winkenbach, 2020).

Since city hubs and UCCs are used to serve a local area (city deliveries), they have a small size between 200 < 2000 m^2. Their location close to the customer enables next day or even same day deliveries. There are no data on the total number of city hubs and UCCs in The Netherlands, but there are at least 14 UCCs included in the Dutch national network of Binnenstadservice.nl.

6.1.3. Type 3: Parcel and postal sorting facilities

This facility type is used by parcel and post companies - such as Sandd, DPD, UPS and DHL – for rapid last mile distribution to the customer – but also for consolidation and warehousing. Parcel and postal sorting facilities are situated at the outskirts or outside urban areas, at locations that are highly accessible by truck. During night times, parcels are distributed between a decentralised network of facilities, from where regional deliveries take place the next day. Because of the regional focus, next day deliveries are possible. Parcel and postal sorting facilities have an S – M – L – XL or XXL size (between 2.500 and 66.000 m^2 according to our database) depending on the number of residents in the focus region. The largest number of facilities owned by the six largest post- and parcel companies in the Netherlands have a size S (i.e. 39 facilities) or M (i.e. 29 facilities). The largest facilities in this category (i.e. 45.000–66.000m^2) are owned by DHL.

6.1.4. Type 4: Regional food wholesale and retail facilities

This category includes logistics facilities that are used for regional food distribution towards retail stores or online customer's homes. Other types of activities of these facilities include storage, consolidation, warehousing, cross-docking and VAL. These type facilities are operated by large grocery retail companies or their LSPs. Wholesale grocery facilities are also included in this category because these companies also typically apply a regional distribution system. The main reason to apply regional facilities is to reduce outbound transport costs. Companies that use these facilities often sell a broad range of high demand products.

The facility is ideally located in the transport centre of gravity of its regional focus area. The size of the facility can range from L – XL to XXL (examples from our database include 15.000m^2 (Albert Heijn: AH) - 19.000 (Deen, AH) – 27.000 (AH in Rotterdam) – 35.000 (AH in Tilburg) – 41.000 (AH in Nieuwegein) – 55.000 (AH in Delfgauw) - 62.000m^2 (AH in Zaandam), depending on regional product demand. The largest number of facilities from food wholesalers and retailers in the Netherlands have a size M (i.e. 40 facilities) or XL (i.e. 30 facilities). There is also a subcategory of Medium-sized facilities of online grocery retailers such as Picnic and Hello Fresh that also apply regional facilities

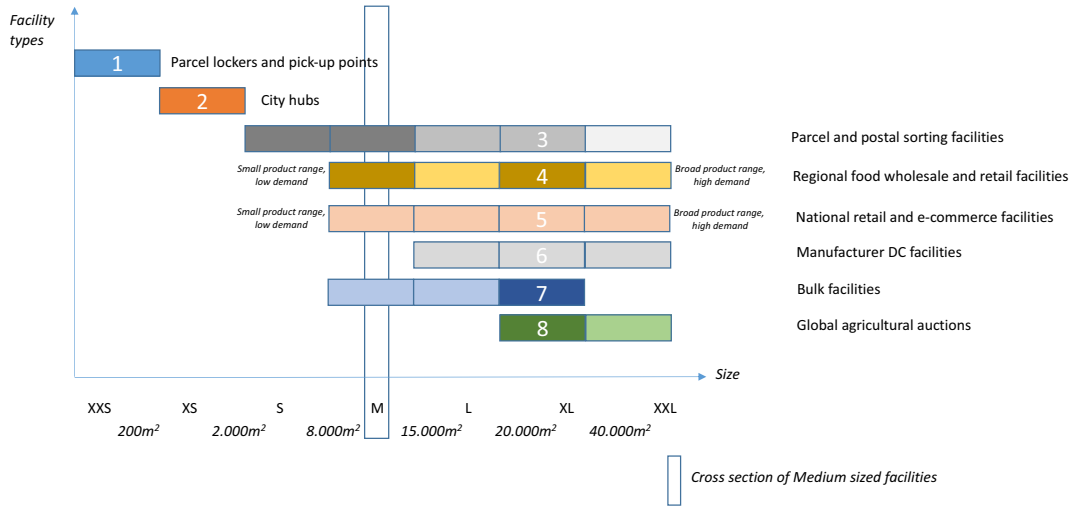

Fig. 4. Logistics facility typology.

to supply city hubs – their Medium size is influenced by the small product range and small market service area compared to offline grocery retailers. Goods are typically transported in boxes, roll containers, or pallets towards the retail. Some fresh products require temperature-controlled storage and distribution. The distribution speed depends on the product, i.e. high (next day) for fast movers or low (>week) for slow movers. The network structure consists of two echelons, i.e. regional facilities that are supplied by a central (national) facility (see Type 5).

6.1.5. *Type 5: National retail and e-commerce facilities*

This type facility is used for storage, consolidation, warehousing, cross-docking, and Value-Added Logistics. The main goal is national distribution towards retail chains or online customers. Ecommerce facilities are also included in this category because ecommerce facilities often have the same functionalities, for example the same national market service area. National retail / e-commerce facilities are operated by offline or online retailers, or outsourced to LSPs.

This type consists of a single (centralised) facility from where goods distribution takes place towards multiple sorts of customers, i.e. regional facilities, retail stores, pick-up points, or online customers' homes. Companies that use this facility type can specialise on a single goods type (e.g. online sale of photo cameras) or sell a broad product range. The delivery speed can be high (next day) for fast movers such as t-shirts or low (>week) for slow movers such as a leather belt. The goods are delivered in parcels (to online customers), boxes or pallets (to regional facilities or retail locations). The size of the facility ranges from M – L – XL – to XXL (examples from our database include 17.600 (Hema) – 18.000 (WE) – 19.000 (Bart Smit) – 34.000 (Xenos) – 36.000 (Foot Locker) – 44.000 (Leen Bakker) – 45.000 (Zeeman) – 50.000 (Bol.com) – 55.000 (Wehkamp) - 116.000m^2 (Ikea)), depending on product range and demand. Hema, for example has a large customer base, but their facility is relatively small because the company sells a small product range and stocks many items in their retail stores. Bol.com, however, sells a broad range of products and their facility supplies a national geographic area resulting in a mega distribution centre. To reduce outbound transport costs, the facility is preferably located in the transport centre of gravity of its national market service area. It must be noted that some retail companies, e.g. Hema, have started international operations, implying this facility type may evolve towards an international distribution type. As a second note, there are many small (S) retail stores (e.g. a DIY store), but these are not included in this standard type since the main activity of these stores is commerce instead of logistics.

6.1.6. *Type 6: Manufacturer DC facilities*

This type logistics facility is used for storage, consolidation, warehousing, VAL, and national or international distribution. These facilities are operated by manufacturers or outsourced to their LSPs. Distribution can take place from 1) Manufacturer to retail stores owned by the manufacturer (e.g. Nike), 2) Manufacturer to retail chain not owned by the manufacturer (e.g. to MediaMarkt), 3) Manufacturer to wholesale (e.g. to food wholesalers such as Hanos and Sligro). The network structure is centralised, i.e. it includes a single facility.

The product range can be small or broad, many manufacturers focus on a broad product range (e.g. different sorts of apparel), but there are also manufacturers that focus on a single product (e.g. photo camera's, printers) of which they sell different types. The preferred location is in the transport centre of gravity of the (inter)national consumer market – although some consumer electronics manufacturers locate outside the centre of gravity to gain tax advantages. Because of the national or international geographic market focus, this facility type is characterised by a large size ranging from L – XL to XXL (e.g. 24.000 (Forever21) - 28.000 (Samsung) – 31.000 (Grolsch) – 39.000 (Timberland) – 52.000 (Ricoh) - 70.000 (Canon) - 122.000m^2 (Michael Kors)). High delivery speed (e.g. next day) is possible for national deliveries, but international deliveries often take multiple days.

6.1.7. *Type 7: Bulk facilities*

Important activities of this facility type include storage and distribution of bulk goods. The main goal is regional (e.g. sand, soil) or national (e.g. oil) distribution to customers such as construction companies, industry or gas stations. Bulk facilities can be operated by manufacturers or wholesalers. Because of the high costs to transport bulk goods, these type facilities are often located near the location of the raw materials or near a port of entry. In case of regional wholesale, the facility can also have a central location within the regional market service area that is highly accessible by truck or barge. The network structure is centralised, a single facility is used to serve the customer target market.

The facilities have a size M – L or XL, of which XL size is the most frequent. Examples include 8.200m^2 (Kroon Oil), 13.700 (Aluminium Verkoop Zuid), 16.900 (Konings Staal), 21.400 (Kroger Staal), 31.700 (Douma Staal) and 33.500m^2 (Vogten Staal), depending on the market service area as well as the space required to store the goods. The product range is small, most facilities are used to distribute single or few products - examples of bulk products are sand, soil, oil, grain, gas, salt, iron ore, coal, bauxite, aluminium. The delivery speed depends on the market service area, i.e. single day for regional deliveries or multiple days for

national deliveries. Most facilities have a regional service area as it is costly to truck bulk goods over large distances. In case of national service area, barge transport can be used to save transport costs.

6.1.8. Type 8: Global agricultural auctions

Auctions are a special type since these facilities are not only used for logistics activities – i.e. storage, consolidation, warehousing, VAL and distribution - but also to auction and trade goods. Agricultural auctions are located near production areas to save transport costs of large inbound goods flows, i.e. between production sites and the auction. An auction is a cooperation that is owned by its members, e.g. flower producers. The product range handled at the facility is small, it only includes agricultural products such as vegetables or flowers. There is a centralised network structure, the auction is the only logistics facility between production and retail locations.

Most auctions have a size XL or XXL, there are six fruit and/or vegetables auctions in the database that have sizes of 11.200m^2 (Geldermalsen), 17.000m^2 (Venlo), 20.000m^2 (Breda), 23.000m^2 (Venlo), 23.600m^2 (Zwaagdijk), 29.500m^2 (Barendrecht), and four Dutch flower auctions which have the following sizes, 20.000m^2 (Naaldwijk), 25.800m^2 (Eelde), 316.000m^2 (Rijnsburg) and 500.000m^2 (Aalsmeer). The auctions serve national as well as international customers. The delivery speed depends on the market service area, national retail deliveries often take a single day, while delivery times of international deliveries take up multiple days.

6.2. Relationship between function and size

The contexts in which very large (type 8) and small size DCs (types 1 and 2) operate are relatively easy to identify, while the context for medium sized DCs (type 3–5) is more heterogeneous (Fig. 4). Type 8 are agricultural auctions that have a very large size because of their European or worldwide market service area in combination with agricultural products being space extensive products to store. Types 1 and 2 are parcel lockers, parcel pick-up points and city hubs. These facilities have a small size because they handle small volumes and serve a minor geographic area such as a neighbourhood. Types 1 are often located in urban areas (e.g. city centres, suburban shopping centres) that are too expensive to construct large logistics facilities.

Types 3–7 have facilities in similar size ranges, but the diversity in sizes within each type can be explained by the functional criteria. Type 3 are Parcel and postal sorting facilities of which the largest number of facilities has a size S or M, followed by L, XL and XXL. Sizes S and M are somewhat older facilities or facilities that serve a small geographic area, for example PostNL has constructed a network of decentralised S and M facilities - each facility serves its own city or region. The larger facilities are especially popular to parcel companies (i.e. UPS, TNT, and particularly DHL) because of two reasons. First, larger regional facilities are needed because of the rapid e-commerce growth, and second, because parcel companies apply a network structure that includes large national hubs - used to supply regional hubs.

Type 4 are Regional food wholesale and retail facilities, the largest number of these facilities have a size M or XL (Fig. 4). The Medium facilities are older facilities, while the XL facilities are recent facilities that include new constructions (e.g. Lidl) or facility expansions (e.g. Albert Heijn, Jumbo) by food wholesale or retail companies in order to centralise operations that were previously executed from multiple facilities. Type 5 (National retail and e-commerce facilities) have a size ranging from M to XXL, while type 6 (Manufacturer DC facilities) have a size between L and XXL. The variety in sizes can be explained by their functional characteristics such as product range, customer demand and market service area. Bulk facilities (Type 7) have a size between M and XL, but most bulk facilities have a size XL as bulk products are space extensive products that require large storage space. Table 1 presents a summary of the above facility types categorized into diverse size ranges.

6.3. Discussion

This section compares the proposed typology of logistics facilities with previous typologies and analyses the geographical locations of the logistics facility types.

The proposed typology consists of two layers, a first layer in which there is distinction between sectors (e.g. parcel, food, wholesale, retail, bulk, agriculture), and second layer including functional criteria which explain the variation within the first layer – for example, functional criteria such as market service area can explain whether a parcel facility has a small or large size.

The typology is unique as it combines the aspects of size with other functional characteristics of logistics facilities. Our results show that the relation between size and facility type is ambiguous since size ranges M – XXL include multiple facility types (Fig. 4). Size ranges of facility types can, however, be explained by the functional criteria - as we did above.

6.3.1. Comparison with previous typologies

To discuss the results, we compare our proposed typology with previous typologies. Compared to Heitz et al. (2019), our study contains less facility types (i.e. 8 versus 20), which can be explained as we do not subdivide the types into possible users / operators, e.g. shipper versus LSP. It is, however, possible to disaggregate types by adding possible operators. A second distinction is the geographical base of the typology, i.e. Heitz et al. (2019) base their typology on logistics facilities in France. The Netherlands are, however, a very urbanised country compared to other popular logistics countries such as France and Germany. As there are larger rural areas in these countries, other facility types could be observed to supply these areas. As a third distinction, our typology combines e-commerce facilities with national retail facilities. We argue that e-commerce facilities can be considered retail facilities that often have the same national market service area.

Notteboom et al. (2017) provide a detailed overview of the reasons behind the ambiguity around the concept of a logistics facility – i.e. two main causes for the conceptual ambiguity are temporal dimensions (e.g. technological changes) and spatial dimensions (e.g. institutional and political contexts in which companies operate). The authors also provide a comprehensive taxonomy of logistics centres based on seven criteria – including size and functionality as in our typology. The main difference is that our analysis starts by examining logistics facilities in the Netherlands, whereas Notteboom et al. (2017) start with a taxonomy and position existing facility types (including their definitions) within the taxonomy. Another difference is that the taxonomy by Notteboom et al. (2017) contains conceptualisations including multiple logistics facilities (e.g. Distripark, Freight village), whereas our typology focuses on individual logistics facility types.

Higgins et al. (2012) use a method and scope comparable to the approach by Notteboom et al. (2017). The authors distinguish between an individual warehouse or distribution centre, but also between concepts including multiple facilities such as an inland port, or freight village. Our typology is different as it includes a sectoral layer, which is important as there are multiple types of (sectoral) distribution centres that have different functional characteristics.

One of the aims of this paper is to develop a typology that can be of use to policy makers to design spatial policies on where to locate specific types of DCs. A cross section of our typology (Table 1, Fig. 4) shows there are multiple facility types included in size ranges M – L – XL and XXL. As there are multiple facility types represented in these sizes, it is not possible to design a single spatial policy per size range. Therefore, each of the eight types in the proposed typology deserves own spatial policy, and within each standard type a differentiation of spatial measures based on size – e.g. Medium (M) retail facility versus Large (L) retail facility – is needed.

6.3.2. Locations of the logistics facility types

Analysis of the total logistics floorspace (m^2) per municipality

(Fig. 5) indicates there are concentrations of warehouses in municipalities near the ports of Rotterdam and Amsterdam, near Schiphol Airport (Amsterdam), and along the main hinterland corridors (indicated by yellow lines) - these locations are in line with findings from Bowen (2008) suggesting that air and highway transportation strongly influence warehouse locations. Rotterdam and Amsterdam not only have the largest seaports and airport, but they are also the largest urban agglomerations of the country. The northern part of the Netherlands hosts less logistics facilities as there are less and smaller urban areas, and less consumer areas in the hinterland.

As mentioned there are no data on the total number and locations of parcel lockers & pick-up points (Type 1) and city hubs (Type 2) in the Netherlands. However, examples suggest that city hubs are found at strategic locations at the edge of the city - often near major roads for goods distribution into the city. Companies prefer these locations because they are easily accessible for large freight trucks (incoming goods) (Browne et al., 2005). Parcel lockers and pick-up points can be found in stores, post offices, public buildings, and gas stations, as explained in Section 6.1.

The locations of parcel and postal sorting facilities (Type 3) shows an overlay of two spatial patterns. First, facilities are located near Dutch cities (large consumer areas) for regional and national distribution. Secondly, there are concentrations of facilities located along the German border for international distribution. The older medium-sized parcel sorting facilities of the national postal company are located at industrial terrains near medium sized cities and within 500 m of a motorway entrance. These facilities are used as a network for regional distribution. Newer facilities are located further away from the central city, probably because of their large size (45.000–66.000 m^2) and (inter)national market service area.

Regional food wholesale and retail facilities (Type 4) show a network of regional facilities throughout the country. These facilities are used for regional distribution to wholesale and retail locations (e.g. supermarkets) and/or for e-commerce deliveries. Large grocery companies often use regional facilities that are supplied by a national facility, but there are also grocery companies that use a single (national) facility to supply all their retail locations. Large food DCs - of large grocery chains - are often located at an industrial terrain at the edge of a large city, having its own highway access - which corresponds to a case study of supermarket DCs in Paris (Heitz et al., 2019). Older, medium sized food company facilities (e.g. 8.000–13.000m^2) can be found at older industrial terrains that are nowadays located within the city. Sometimes these facilities are not only used for distribution but also for production. Type 5 "National retail and e-commerce" facilities do not show an immediately identifiable spatial pattern. Type 5 facilities can be found in central as well as peripheral areas, supplying the whole country. Large companies may decide to move their DC to the centre of the country to reduce transport distances to their consumers, while medium-sized (e.g. online) companies may decide to stay in their peripheral 'home' area and distribute via the network of a Logistics Service Provider. Type 6 (Manufacturer DC) facilities can be found near the port of entry (Rotterdam, Amsterdam) and along the main hinterland corridors. Note that Type 5 and Type 6 often use LSPs, however, the logistics facilities of these LSPs are not included as the type of customer of each LSP is unknown. Including these LSP facilities would probably mean that Type 5 and 6 facilities are in many Dutch municipalities. Bulk facilities (Type 7) are located at industrial terrains that are accessible by barge or train for inbound transport. For example, the largest facility (100.000m^2), which is used by a company that supplies raw materials for the construction sector, is located in the port of Terneuzen. Global agricultural auctions (Type 8) - i.e. only 10 facilities - are located near production areas to reduce inbound transport costs between production locations and the auction.

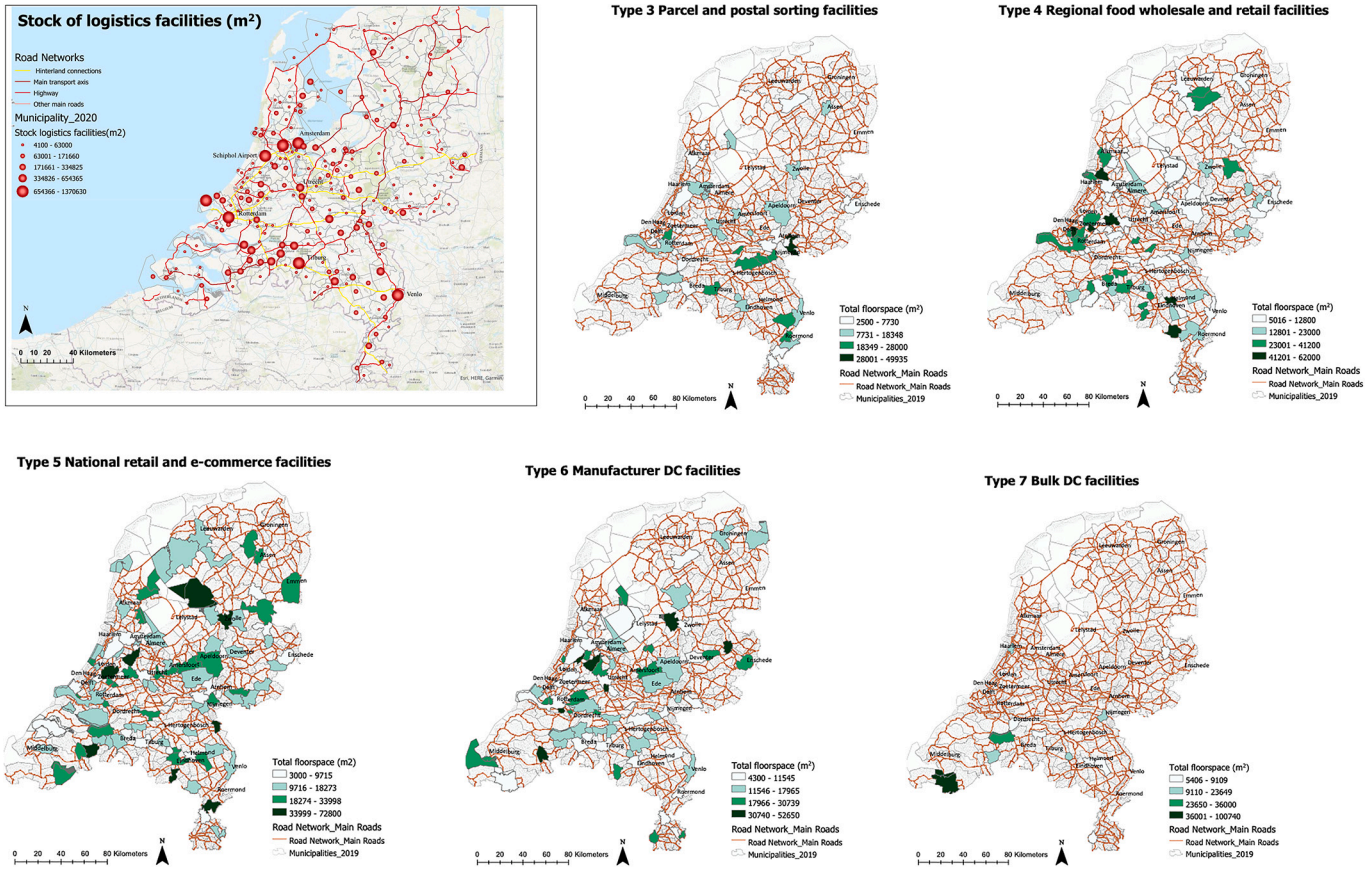

Fig. 5. Logistics facility locations in the Netherlands: total logistics floorspace (m^2) per municipality.

7. Conclusion

Many concepts related to logistics facilities can be found in the literature – e.g. distribution centre, warehouse, freight hub, e-fulfilment centre, Urban Consolidation Centre (UCC), logistics depot - but a standard typology of logistics facilities is lacking (Higgins et al., 2012; Notteboom et al., 2017). Researchers often use one of these concepts to study a logistics problem, but a standard typology used by scholars to distinguish between concepts was not found in the literature. This paper proposes a typology of logistics facilities based on size as well as six other functional criteria – i.e. activity type, product type, product range and speed, network structure, market service area, and service days - that can be used by the scientific community and also by public and private actors for mutual understanding when discussing research, public policies, and public or private investments related to logistics facilities. To the best of our knowledge, there is no typology based on size as well as functionality of the facility. A typology based on size is important for scholars to differentiate between types of facilities when studying their impact on urban areas, for example in terms of land use, freight traffic and local emissions. Spatial planners can use the typology to discuss what are suitable locations for diverse facility types and develop spatial plans accordingly. The proposed typology could also support the public debate on the visual intrusion of logistics facilities - i.e. the visual pollution of the landscape because of the low architectural quality of logistics facilities - as it is now possible to differentiate between types in the discussion.

The typology is based on literature combined with data on 2888 logistics facilities in the Netherlands. The types are defined based on the seven criteria mentioned above. The data are used to exemplify the types, and also to analyse what are common size ranges of each type. The proposed typology includes eight facility types, e.g. parcel and postal sorting facility, and bulk facility.

Results show that the importance of large facilities has increased over the years, not only in absolute numbers, but especially in their contribution to the total constructed surface area. The share of facilities $>20.000m^2$ is relatively small (19%), but they represent almost half (47%) of the total 42,1 million m^2 logistics facility surface in the Netherlands. Large facilities are therefore important in the development of spatial planning policies. These spatial policies could focus on suitable locations, but also on spatial measures to mitigate accessibility problems, or sustainability questions related to e.g. visual intrusion. Another aspect is that it is not possible to design a single spatial policy per size range, because a cross section of the size ranges M – L – XL and XXL (Table 1) shows there are multiple facility types represented in each size range. Therefore, each of the eight types in the proposed typology deserves own spatial policy.

We derive several opportunities for future research. First, as the evolution of logistics facilities proceeds, the typology will need to be updated on a regular basis. Future research could therefore address new types of logistics facilities (e.g. mega city hubs). Secondly, new work could focus on collecting examples of spatial measures that can be used to design policies that mitigate visual intrusion or other sources of external effects. Thirdly, dynamics in warehouse types over time did not fall inside the scope of this research but could be presented in follow-up work. Fourthly, we find that very large facilities are mostly found outside urban areas. Future research could study the relation between facility size and proximity to urban areas. Finally, in other countries there will be different sorts and volumes of data about logistics real estate. Future research could develop typologies based on other countries and make comparisons with our proposed typology.

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Declaration of Competing Interest

None.

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