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Capturing a hidden part of urban traffic: an approach to get a grip on urban goods movement

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Abstract

Limited data is available on the size of urban goods movement and its impact on numerous aspects with respect to livability such as emissions and spatial impact. The latter becomes more important in densifying cities. This makes it challenging to implement effective measures that aim to reduce the negative impact of urban good movement and to monitor their impact. Furthermore, urban goods movement is diverse and because of this a tailored approach is required to take effective measures. Minimizing the negative impact of a heavy truck in construction logistics requires a different approach than a parcel delivery van. Partly due to a lack of accurate data, this diversity is often not considered when taking measures. This study describes an approach how to use available data on urban traffic, and how to enrich these with other sources, which is used to gain insight into the decomposition (number of trips and kilometers per segment and vehicle type). The usefulness of having this insight is shown for different applications by two case studies: one to estimate the effect of a zero-emission zone in the city of Utrecht and another to estimate the logistics requirements in a car-free area development.

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Keywords: Urban goods movement; Urban goods data; City logistics; Logistics decomposition;

1. Introduction

An efficient urban goods movement (UGM) system is essential to the functioning of modern urban areas. UGM contains numerous vehicle movements of light commercial vehicles (vans) and trucks to transport goods and perform services. It is estimated that those vehicles account for 10-15% of urban traffic (Holtslag et al., 2020). Even though

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these movements are essential for livable cities, it is also a major source of environmental and societal issues that negatively affect livability, such as air pollution, safety and accessibility issues. In recent years, these negative impacts have led to increased awareness for UGM by local authorities. In light of climate change, UGM is targeted by European and national governments to reduce its carbon footprint. In the Netherlands this has been made tangible by the announcement to implement zero emission zones in 30-40 cities that gradually apply to light commercial vehicles and trucks from 2025 onwards (Klimaatakkoord, 2019). In addition to cleaner transport, there is a growing attention for ways to reduce the relative presence of vehicles. Compared to passenger transport, those vehicles contribute disproportionally to unsafety and occupancy of urban space (even though this is partly unavoidable due to their size and nature of operations) (Holtslag et al., 2020), as well as damaging (old) infrastructure in medieval city centers, such as quays and bridges (in for example Dutch cities as Amsterdam, Delft and Utrecht). And, additional to that, we see (in several European cities) that motorized traffic is slowly being pushed out of cities as urban space becomes scarcer due to a growing population and a different organization of available urban space with a preference for active transport modes (walking, cycling) and green areas (Nieuwenhuijsen, 2020).

Various measures are available to reduce UGM emissions, such as the implementation of low emission zones (Tretvik et al., 2014). Taking policy measures to stimulate logistics efficiency and herewith reduce its spatial footprint have been widely trialed but mostly with little impact on urban level. Examples are ways to stimulate consolidation and modal shifts to smaller and cleaner vehicles (Isaksson & Alm, 2022; Lebeau et al., 2017). The effectiveness of measures aimed to reduce the negative impact of urban goods movement (while also maintaining the supply of cities), is affected by two limitations:

- There are, in the first place, little data available on the size of UGM and its impact. Information is mostly generalized to urban traffic as such. When it comes to specific measures, the focus is often on limited areas, particularly city centers where some data are available due to access registrations. It is therefore difficult to effectively implement measures (and monitor the impacts). This is particularly important considering policies to reduce CO_2 emissions and air pollution. For instance, a zero-emission zone in a city center affects a number of vehicles. As electrification is one of the most feasible technologies, tank-to-wheel emissions of kilometers driven inside, but also outside that zone, are unknown.
- This leads to the second limitation: the need for a further decomposition of the UGM activities in a certain city. UGM is diverse and movements can be carried out by different vehicle types, can carry different type of goods, contain various load factors, have different drop densities, dwell time, number of stops and kilometers driven. To structure this heterogeneity a distinction is made between deliveries related to retail (to retail chains and SME), temperature-controlled (retail, HoReCa and home), parcels, waste, construction logistics and service logistics (Topsector Logistiek, 2017b). Even though it is termed as urban ‘goods’ movement or ‘logistics’, a part is more service-driven than aimed at transporting cargo. Examples are plumbers, greenkeeping services, and personnel in the construction sector (e.g., Figenbaum, 2018). As a consequence, there is no ‘one size fits all’ approach to effectively improve efficiency of urban goods movement from an urban perspective. Partly due to a lack of accurate data, this diversity is often not considered when taking measures. For instance, policy measures to facilitate efficient transport of heavy equipment to a construction site require a different approach than tackling the impact of light commercial vehicles in service-driven sectors. Measures should therefore be tailored by taking into account the characteristics of the trip. Understanding logistics characteristics of UGM is crucial for taking effective measures. Additionally, understanding the effects of policy measures and initiatives is fundamental for upscaling and formulating effective policies (Nesterova & Quak, 2016; Timms, 2014).

The two above-described limitations highlight the lack of data on the size, impact, and type of urban goods movement activities. This hampers the ability to design effective policies that aim to mitigate the negative impact associated with UGM activities. Without a clear understanding of which activities contribute to specific negative impacts, such as emissions, it becomes challenging to develop targeted measures that can adequately address the logistics characteristics of different UGM activities to effectively tackle their negative externalities. To improve policy design, and also to ensure a better assessment of policy effects, it is therefore crucial to have detailed data on UGM available. This data should encompass UGM activities capturing their diversity in vehicle types, type of goods, drop densities, dwell time, kilometers driven etc.

Overall, accurate and detailed data on UGM (which is more than 'just' information on commercial urban traffic) from the perspective of a city are very often lacking; for example, little is known on the dwell time, the specific customer requirements or the type of cargo carried. Although several initiatives to improve the data situation (from a city perspective) were taken, structural data collection – that would also allow for monitoring urban goods movement policy measures or initiatives – is non-existent. If we look at the data that are available, data collection of UGM data in general takes place on a national level. However, these data are often reported on a national scale without distinguishing between urban and non-urban movements (Allen et al., 2014). At a higher level of detail, data on trip characteristics are mostly absent (Buldeo Rai & Dablanc, 2022). In some cities, authorities carry out traffic counts by Automatic Number Plate Recognition (ANPR) cameras (for example to enforce low emission zones). Though these scans also include UGM vehicles, they are intended to manage traffic and are not collected for the purpose of urban goods movement. Consequently, these data often lack the details that are necessary to extract the UGM decomposition in the area. The available data could be helpful for providing a global overview of urban goods movement, but for gaining knowledge on the effects of specific policy measures or initiatives for companies, branches and cities, more detailed data on UGM is essential.

In this study we propose a methodology that allows for a decomposition of urban goods movement based on the data that are available. In section 2 the decomposition of UGM is elaborated after which section 3 deals with the required data to do so. This decomposition-methodology is subsequently applied to two different use cases i.e., to estimate the effect of a zero-emission zone in the city of Utrecht in section 4, and to estimate the logistics requirements in a car-free area development in section 5.

2. Towards a decomposition of urban goods movement

In order to simplify taking into account the diversity of urban goods movement, flows are categorized in several segments. These segments contain movements that share similar characteristics in their logistics organization. Although in literature several different segmentations exist (CE Delft, 2016; Dablanc & Rodrigue, 2014; MDS Transmodal, 2012), the segmentation in our methodology is primarily based on Topsector Logistiek (2017). This consists of six main segments and a number of subsegments as shown in Table 1. Although segmentation and decomposition already exist in literature, quantification of the actual operations in a city within the different segments is limited due to the aforementioned lack of detailed logistics data. Examples of previous successful modelling efforts that capture the heterogeneity of UGM by either type of business activity or type of good include FRETURB (Routhier & Toilier, 2007), which uses data on establishment characteristics, the agent-based model MASS-GT (De Bok & Tavasszy, 2018) and a tour-based microsimulation for Calgary in Canada by Hunt & Stefan (2007). However, spatial transferability of these models to other regions is not always straightforward (Ter Laag, 2019). Detailed statistics, which are not consistently available for urban areas, are required for successful implementation. Due to a lack of data, although most segments are very recognizable to the various stakeholders, it is mainly hearsay and own observations when it comes to actually estimating the numbers and dwell times of the various UGM vehicles. An example of this can be found in TNO (2015) where, for the city of Utrecht, traffic counts from license plate cameras were compared to the estimated numbers of UGM vehicles[1] obtained from supply profiles (where recipients in the city center such as shops and catering establishments had been asked how many vehicles came for supply per day): based on the supply profiles less than 15% of the UGM vehicles that were actually observed by cameras were explained. Another example of the difference between what is often thought and what data shows, comes from the perception that parcel vans in particular are a very large part of all UGM vehicles. However, research shows that in the Netherlands only between 5-10% of all vans are used around home deliveries, and that the vast majority of (sometimes white) vans therefore do something else, such as construction logistics and/or service logistics (see Topsector Logistiek, 2017a). In other words,

[1] With urban goods movement vehicles we mean all vehicles that are labelled as 'N'; i.e. the EU vehicle classification (see e.g. https://www.transportpolicy.net/standard/eu-vehicle-definitions/): N1 stands for vans (Vehicles for the carriage of goods and having a maximum mass not exceeding 3.5 tons), N2 (a maximum mass exceeding 3.5 tons but not exceeding 12 tons) and N3 (a maximum mass exceeding 12 tons) for trucks.

although the existing segmentation is recognizable, and helps in realizing how heterogenous urban goods movement is, it does not contribute to defining policies as the magnitude and the impacts of the movements in a segment are often not known and monitoring how effective certain interventions are is not possible at all. As a result, many efforts in making urban goods movement more efficient aim at the limited segments that are either very visible and well-known, such as parcel deliveries and supermarket deliveries, but these segments are often in fact already very well (logistically) organized, which means that effects of interventions are very limited, while the many journeys made by small own carriers remain out of the picture. In short, a recognizable decomposition in UGM segments is a good start, but to really move forward, it is necessary to also get a better quantified picture of what exactly happens in which (sub)segment.

Table 1. Urban goods movement segments and subsegments.

Main logistics segment	Description	Subsegments
Construction logistics	Transport of materials and personnel to and from construction sites.	Public space Shell construction Completion construction Personnel
Waste logistics	Collection of waste from households and offices.	Household Business
Parcels and express	Delivery of parcels.	
General cargo and retail	Transportation of goods to large retail chains and small and independent stores, but also two-man delivery services.	Retail Specialists Two-man delivery services
Facility and service logistics	Transportation of facility goods (such as office supplies) and transport movements by service companies.	Supply Maintenance and services
Temperature-controlled	Transportation of temperature-controlled goods from wholesalers and specialists and of fresh home deliveries.	Retail Specialists Home deliveries

3. A method to determine the decomposition of urban goods movement

To improve insights into the decomposition of urban goods movement, in our methodology we found an approach to deal with limited available data on UGM. This section elaborates on this. This methodology is represented schematically in Fig. 1. and will be explained in detail in below paragraphs.

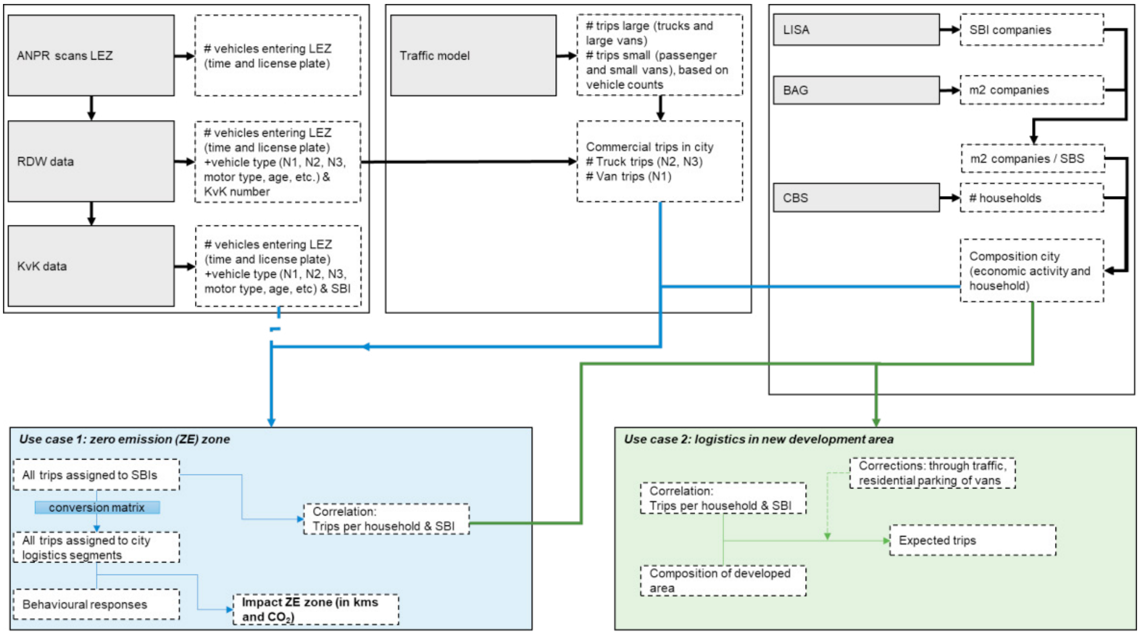

Fig. 1. Schematic overview of methodology to determine the urban goods movement decomposition of an urban area.

3.1. Quantifying the amount of commercial traffic in urban areas

In order to be able to find the urban goods movement decomposition of an urban area, first the amount of commercial traffic in the area needs to be retrieved. This paragraph describes the available data sources that are used in our methodology to estimate the size of UGM in urban areas. Although multiple data sources were explored to use, the below described data were assessed to be most useful for our application. It is also worth mentioning that, after exploring data availability, this methodology was developed based on available data from Dutch city Utrecht, which will be occasionally referred to in this outline for ease of description. In case (similar) data is available, the methodology can obviously be used for other cities as well. Furthermore, the methodology also takes into account that some of the data sources that are used are absent for other cities or specific urban areas. For these situations different approaches were developed (depending on data availability), which will be described in paragraph 3.4

Three main data sources (Fig. 1.'s grey boxes represent data sources that were collected in the city, with other purposes than UGM data collection or decomposition) were used to find the number of urban freight movements per vehicle type:

ANPR scans.

These data contain information on vehicles that are detected by ANPR (Automatic Number Plate Recognition) cameras which are used by some municipalities to enforce (amongst others) low emission zones (LEZs) in their city center. This includes information on the amount of passings, the license plates and the time at which they entered the zone. In our study we received a sample of the ANPR scans that aim to monitor the LEZ of Utrecht.

RDW data.

The ANPR scans could be enriched by merging it with data from RDW (the Netherlands Vehicle Authority, or any similar institute in other countries) on license plate number. This will provide additional details to the vehicle passings on license plate level, such as the emission standard of the vehicle, year of construction and other technical details. RDW data also contain information on the category of vehicles (following the definition of the European Commission, Directive 2007/46/EC). The vehicle category is valuable as it enables to distinguish between vehicles that are constructed to carry goods (EC category *N*) and vehicle categories that are not relevant for UGM (such as passenger cars). There is also a differentiation in subcategories. The subcategories of vehicles in category *N* (N1, N2, N3) give information on the maximum mass that vehicles are allowed to transport. In this study, vehicles of subcategory N1 (maximum mass not exceeding 3.5 tons) are classified as ‘light commercial vehicles’ (or vans). N2 and N3 vehicles (maximum mass above 3.5 tons) are classified as ‘trucks’.

Additionally, RDW has information on the registration number of the vehicle owners (businesses) at the Dutch Chamber of Commerce (in this paper referred to as KvK according to the Dutch abbreviation). In paragraph 3.2 the usefulness of this will be explained.

To conclude, and as shown in Fig. 1., enriching ANPR scans with RDW data leads to an overview of the amount of vehicles entering the LEZ per vehicle type (including information on the vehicle characteristics, such as vehicle age, weight, engine-type, etc. but that information was not used for the analyses presented in this paper and therefore not presented in the remainder of this paper) and the KvK registration number of the vehicle owners (based on license plate number).

Traffic model.

Traffic models simulate real-world traffic based on origin-destination (O/D) matrices that describe travel demand (number of trips) between all pairs of O/Ds in a network an aggregated level. Traffic models have the ability to show the impact of traffic on a city or region and how this differs in case specific decisions in relation to traffic management (such as future modifications to infrastructure) are made. In the methodology described by Goudappel Coffeng (2013, 2018) for two regional traffic models in the Netherlands, which include traffic in large cities, trip generation (production and attraction of trips) of passenger mobility and vans is based on data from The Netherlands National Travel Survey (ODiN), an annual study that surveys and maps the mobility patterns in the country. For trucks, trip generation relies on key figures derived from surveys considering factors such as retail floor space, type of industrial site, number of households or number of employees. To determine the destinations of trips and to construct O/D matrices, a gravity model is employed. This model uses trip generation data and generalized costs, which capture the level of accessibility in terms of time and distance, as inputs. The assignment of truck trips to the road network precedes that of passenger mobility and vans. The assignment follows the “all-or-nothing” (AON) technique (which assumes all traffic between an origin and destination will take the shortest route) assuming trucks are less sensitive to congestion and rerouting. The assignment of passenger mobility and vans depends on the specific regional traffic model being used. One example is the “ volume averaging” technique, which initially assigns traffic based on the AON principle. Subsequent iterations are performed, wherein generalized costs are recalculated based on the traffic load in each iteration. A portion of the traffic is then shifted to other links in order to balance the load and capacity.

These traffic models thus differentiate between small vehicles (passenger cars and small vans) and large vehicles (trucks and large vans). Note that passenger mobility is included and this specific distinction to vehicle types therefore differs from the vehicle types in our methodology, which are 1. light commercial vehicles (vans) and 2. trucks. In other words, traffic models generally do not differentiate to commercial traffic (yet). Traffic models are calibrated based on traffic counts by inductive-loop traffic detectors, but many of these counts cannot distinguish between small vans and passenger vehicles.

3.1.1. Necessary modifications to increase suitability of available traffic data

In our methodology, the O/D matrices from the traffic model are used to determine the number of trips and kilometers in the LEZ. However, in order to be able to extract commercial traffic, with distinction to vans and trucks, still some modifications had to be carried out. Traffic model data are especially not immediately suitable for acquiring information on the number of urban goods movements by vans. The reason for this is that assignment in the traffic model to vehicle type is based on the length of vehicles as detected by inductive-loop traffic detectors (and as a result large vans fall in the truck category and smaller vans are included in the passenger vehicle category). Furthermore, no differentiation to commercial traffic is made as mentioned before.

To begin with, since the vehicle length is used for assignment to vehicle category, large vans are possibly assigned to the category large vehicles. This means the category ‘large’ cannot immediately be assumed to be similar to our definition of trucks. By comparing the amount of traffic with an origin outside the LEZ and a destination inside the LEZ (hence incoming vehicles) in the traffic model with actual observations of incoming traffic by ANPR cameras (enriched with RDW data), indeed a discrepancy was observed. For this reason, a correction was performed on the

O/D matrices in the traffic model by applying an increasing factor for small traffic (x 1.68) and a decreasing factor (x 0.68) for large traffic.

Furthermore, in the traffic model trips with vans are (mostly) contained in the same category as passenger cars due to similarities in vehicle length. To account for this, the share of vans (13%) relative to vans and passenger cars as was observed in the ANPR scans was used to extract the number of trips by vans by taking a subset of 13% from the H/B matrix of light traffic.

Applying these modifications to the O/D matrices of the traffic model results in an estimation of the number of trips and kilometers by light commercial vehicles and trucks in the specific LEZ. It should be noted that trip and route characteristics of commercial vehicles are not specifically accounted for in the traffic model. This therefore affects the accuracy of the number of kilometers.

3.2. Enriching traffic data to gain knowledge on type of UGM activities

As the previous paragraph concluded, ANPR scans and traffic models can be helpful to retrieve a global overview of the amount and type of vehicles driving around in the city center. However, these data are not sufficient to be classified as good-quality basis data for urban goods movement. Both ANPR scans as well as data from traffic models do not contain information on vehicle routes, dwell time and type of transported goods or services provided. This is essential though for determining the UGM segment that vehicles participate in. Information on details that help to determine the UGM segment is vital to being able to show the decomposition of an urban area and, in turn, to increase efficiency of measures to decarbonize and organize urban goods movements more efficiently from city perspective. This paragraph will describe our approach to be able to assign the urban goods movements to the segments as were presented in Table 1.

To increase knowledge on the type of UGM activities of commercial vehicles, the KvK registration numbers (extracted from the enrichment with RDW data, see paragraph 3.1) can be merged with data from the (Dutch) Chamber of Commerce. The Chamber of Commerce has information about the business activity, referred to in this paper as SBI (Dutch abbreviation for Standard Industrial Classification) category, of vehicle owners (companies). Note that not all license plate numbers could be linked to a KvK registration number (for privacy reasons). For this reason, no SBI category could be retrieved for these vehicles. This occurred for about 40% of light commercial vehicles and for about 5% of trucks. To deal with this, these vehicle passings were equally distributed among all SBIs.

3.2.1. Assigning trips and kilometers to UGM segments

In the O/D matrices, that are used to determine the number of commercial trips and kilometers in the LEZ, no assignment to SBI categories has been made yet. Following the above-described enrichment of ANPR scans, the distribution of SBI categories for vehicles entering the LEZ is now known. Given that the O/D matrices cover the same zone as the ANPR scans, the distribution of SBI categories in the O/D matrices is considered to be equal to the observed distribution in the ANPR scans. Here, a differentiation was made between vans and trucks.

To be able to show the urban goods movement decomposition of the LEZ, the number of trips and kilometers need to be assigned to logistics segments. The obtained information on SBI categories of trips serves as a basis for this. In our methodology a conversion matrix is constructed in which each SBI category is assigned to one or more UGM segments. It is worth noting that for some SBI categories assignment to segments is not straightforward, mostly because not all SBI categories directly relate to transport of goods. Examples of these are vehicles used for services and vehicles owned by vehicle leasing companies for which it is unclear what type of UGM activities were carried out by the users. Another important sidenote is that SBI categories clarify the economic activity of the company that owns the vehicle. This does not necessarily comply with the activities of the user of the vehicle.

The formation of the conversion matrix is based on a similar conversion matrix as given by a study of CE Delft (CE Delft, 2016). Because the UGM subsegments in the matrix of CE Delft differ slightly from the subsegments in this study and since not all logistics flows in this matrix are categorized as urban goods movement, we adjusted the conversion matrix accordingly. The resulting conversion matrices for light commercial vehicles and trucks can be found in (Topsector Logistiek, 2020). Applying the conversion matrices to the number of trips and kilometers per SBI category results into the UGM decomposition of the LEZ: the number of trips and kilometers per UGM subsegment.

3.3. Modifications to apply the methodology to other areas than the LEZ

As has become apparent from the outline of the methodology as described in previous paragraphs, ANPR scans of the LEZ and a traffic model of the same zone were used for determining the UGM decomposition for the vehicles in the LEZ. This is referred to as method 1. However, ANPR scans and/or a traffic model are occasionally available and especially only for very specific areas such as LEZs. We therefore also developed approaches to enable finding the urban goods movement decomposition of areas different than the LEZ, specifically areas for which ANPR scans are not available. Two approaches are considered: one in case a traffic model is available for the area of interest, the second in case a traffic model is also absent (next to ANPR scans).

3.3.1. Method 2: a traffic model of the area of interest is available

Since in this case a traffic model is available for the area of interest, the number of commercial trips and kilometers can be extracted from the O/D matrices of the traffic model. The O/D matrices are modified based on similar assumptions are described before.

As opposed to before however, the distribution of SBI categories which were found in the enriched ANPR scans cannot be used here due to the fact that ANPR scans are unavailable for the area of interest. This calls for another approach to determine the share of each SBI category in the number of trips. In doing so, we first retrieved information on the composition of the LEZ, to be specific the number of employees (full-time equivalent) per SBI category of the businesses located in the LEZ and the total number of households. These data are publicly available in the Dutch employment register (abbreviated and referred to in this paper as LISA) and at CBS (Statistics Netherlands), respectively. These data in combination with the number of commercial vehicles passings per SBI category as observed in the ANPR scans are then used to define correlations between number of incoming commercial vehicles per SBI category and vehicle type on the one hand, and the number of employees per SBI category and number of households on the other hand. Before doing so, first a number of steps were taken to determine the exploratory variables per SBI category of incoming vehicles.

- For each of the 19 SBI categories that were found in the LISA data of the LEZ, it is determined by expert judgement whether the business locations belonging to the considered SBI category are destinations for UGM activities.
- For each SBI category, the number of incoming vehicles as observed in the scans are then linked to
  - the number of employees in the same SBI category;
  - the total number of employees in multiple (but specifically-chosen) SBI categories (SBI categories that were not defined to be destinations for UGM activities are omitted) or;
  - the total number of households.
- For vehicles in SBI categories that show limited correlation with number of employees or households, the share in SBI category is kept equal to what was observed in the scans.

Table 5 and Table 6 in Appendix A. show the outcomes of the above steps for respectively light commercial vehicles and trucks.

Note that instead of number of employees, also floor surface (m^2) of the businesses locations in the area can be used. These data are publicly available in BAG register (Netherlands Addresses and Buildings Key Registry) and can be merged with LISA based on address to link floor surface of businesses with SBIs.

Above steps were carried out for LEZs in two different cities (Utrecht and Rotterdam). Their data was combined to find relations between number of incoming vehicles per SBI and the composition of the area. After these relations are composed, the number of employees (or m^2) per SBI category and the number of households are extracted from LISA (or BAG) and CBS for the area of interest. To find an approximation of the number of incoming vehicles per SBI category in the area of interest, these data are filled into the relations that were found for each SBI category based on above-described steps. The resulting distribution of incoming vehicles over SBI categories is then used to distribute the number of commercial trips in the O/D matrices of the traffic model to SBI categories. Lastly, the conversion matrix to go from SBI categories to UGM subsegments is applied to arrive at the urban goods movement decomposition of the area of interest.

3.3.2. Method 3: no traffic model of the area of interest

In this case, in addition to ANPR scans, also a traffic model is absent for the area of interest. Instead of using O/D matrices obtained from a traffic model for the number of trips, the established relations (see 3.3.1) between number of incoming vehicles per SBI category and the number of employees (or m^2) and households are used to approximate the number of trips. Similarly, the composition of the area of interest as extracted from data of LISA (number of employees) and CBS (number of households) is used to fill in the relations for each SBI category and vehicle type. The outcome is an approximation of the number of incoming vehicles per SBI category and per vehicle type. Again, the conversion matrix is used to assign these to urban goods movement subsegments.

3.4. Usefulness of having insight into the urban goods movement decomposition

In this section it was described how the urban goods movement decomposition of an urban area can be estimated based on a number of data sources. On top of that, it was shown how the decomposition can also be retrieved in case data sources on the amount of commercial traffic in an area are absent. The described methodology therefore helps to gain insights in the number and type of urban goods movements in an urban area. This is valuable, because as elaborated above a decomposition of urban goods movement is commonly unavailable. Following this, the decomposition of UGM can be used for calculating the effect of measures that aim to reduce emissions and UGM movements. To show the importance of knowing the number of urban goods movements and how they are distributed over the segments, two applications (case studies) of the methodology will be outlined in the next sections.

4. Case study: the impact of a zero-emission zone

4.1. A zero-emission zone in Utrecht – description

Dutch cities strive for zero-emission urban goods movement by implementing zero-emission zones from 2025 on (with a transitional scheme for new diesel trucks and vans until 2030) (Klimaatakkoord, 2019). The measure intends to reduce the yearly estimated carbon footprint of urban goods movement of 3.6 Mton by 1 Mton (Topsector Logistiek & TNO, 2021). Estimating the effect of zero-emission zones in the major cities in the Netherlands is complicated as there are limited data on UGM activities and vehicle movements. It is therefore unclear how many vehicles (vans and trucks) are affected by the implementation of a zone and what the effect of the zones will be on the potential reduction in CO_2 emissions. The latter depends on the size of the zone.

Based on available data, we made an estimation of the number of vehicle movements that are affected by the implementation of a zero-emission zone in the city of Utrecht. A threefold exploration has been conducted. First, a decomposition in vehicles and related kilometers is made, whereby those are divided over the different UGM segments. With such a decomposition it can be assessed what segments are responsible for which part of the total CO_2 emissions. Second, the number of vehicle kilometers is estimated when either a small or a large zone will be implemented. Fig. 2. shows the two zones that are studied. For the vehicle kilometers related to those zones, a distinction is made between those made inside and those made outside the zones. Herewith the total CO_2 emissions can be calculated, including the radiation effect; as a result of the implementation of zone, a proportion of the kilometers driven outside the zone also change (for instance with a different vehicle technology).

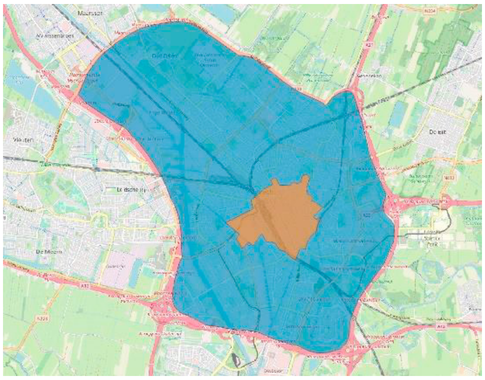

Fig. 2. Case study in Utrecht with a small zero-emission zone in the city center (orange) and a large one (blue).

Third, based hereupon, the effect of different behavioral responses to the implementation of the zone are calculated. When implementing a zone, transport must become zero-emission. To this end, electrification is one of the most applicable technologies. However, in addition to electrification, it potentially also leads to other behavioral responses by (logistics) operators that subsequently lead to a change in kilometers driven. Those responses are strongly segment-specific. Based on a literature study, interviews with stakeholders from the different segments and an expert judgment, segment-specific behavioral responses are estimated. Even though the responses vary, it can essentially have one of the three following effects:

- Emissions of the vehicle kilometers driven change as a part becomes zero-emission. The assumption is that all kilometers inside the zone become zero-emission. Outside the zone a proportion becomes zero-emission due to a distinction between plug-in hybrid and full electric vehicles.
- Trips change, whereby, for instance, a modal shift from a van to a cargo bike or consolidation at a hub, leads to a reduction in the number of trips and hence in kilometers. For instance, in retail larger vehicles are deployed, which leads to an estimated maximum reduction of 10% in trips of trucks related to this segment. Inside the zone, trips are zero-emission.
- Kilometers change because trips are made more efficiently, for instance, by aligning time windows in the deliveries of conditioned goods.

For a full overview of the behavioral responses per segment see Topsector Logistiek (2020a). The next paragraph describes the results.

4.2. Effect of zero emission zones in Utrecht – Results

Fig. 3. shows the presence of vehicles across different segments with a distinction between light commercial vehicles and trucks. Light commercial vehicles can be mostly found in service-related movements, construction logistics and SME who own a van (retail and temperature-controlled). Trucks are more related to the supply of retail stores (temperature-controlled and general cargo) and the supply of institutions (facility). In addition, the supply of construction sites requires trucks.

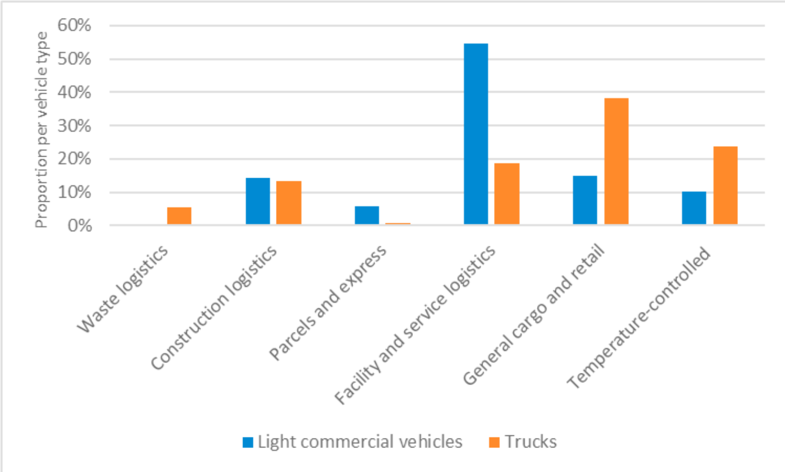

Fig. 3. Relative division of vans and trucks over the various segments.

The results show, first of all, the number of kilometers and CO_2 emissions (for one day) when the city of Utrecht implements a small zone (see Table 2). After the behavioral response (over all the segments), the CO_2 emissions within the zone are reduced to zero (as the assumption is that this is a strict requirement). A part of the vehicles that drive zero-emission within the zone, also drive zero-emission before they enter and after they leave the zone. Therefore, CO_2 emissions outside the zone reduce by 39%. However, because of other responses – whereby logistics is organized differently – a reduction in kilometers is expected within the zone (-11%) and also slightly outside the zone (-2%). The number of kilometers driven on a daily basis in the large zone is 20 times those driven in the small zone. As a result of the behavioral responses both kilometers and CO_2 emissions also reduce. The results also show that the majority of kilometers and CO_2 emissions related to the zones actually take place outside those zones.

Table 2. Results of a small and large zone in Utrecht for one day and the effect of behavioural responses.

	Small zone	**Effect**	**Large zone**	**Effect**
Km inside	15.689	13.905 (-11%)	338.399	289.380 (-14%)
Km outside	897.815	882.557 (-2%)	6.197.927	6.086.125 (-2%)
CO_2 emissions inside (kg)	5.280	0 (-100%)	105.072	0 (-100%)
CO_2 emissions outside (kg)	247.595	149.861 (-39%)	1.683.103	1.003.088 (-40%)

The exact response depends on various factors including the specific segment, available technology and policies. The results show what the potential impact of behavioral responses is on the implementation of a zero-emission zone as a policy measure. To a certain extent it is expected that this leads to a different organization of urban goods movements towards and into the zone (or city). The daily effects as calculated here could lead to a reduction in CO_2 emissions of 0.07 kton (small zone) to 0.6 kton (large zone). On a yearly basis this translates to an estimated reduction of 17.5 (small) to 150 kton (large). The effect on the reduction of CO_2 emissions is under the taken assumptions 18 to 7 times higher outside the respective small and large zone than inside these zones.

5. Case study: logistics in a limited traffic neighborhood

5.1. A limited traffic neighborhood in Utrecht – description

In the project CILOLAB (CIty LOgistics Lab, see also Cilolab, 2022) a case study in collaboration with the municipality of Utrecht was carried out to, firstly, approximate the UGM decomposition of a new development area. Secondly, it was explored how UGM can be integrated in this area while minimizing nuisance (Rondaij et al., 2022).

Particularly interesting is that the new development area, called Beurskwartier, will become a limited traffic neighborhood. This means that only authorized vehicles are allowed to enter the neighborhood, such as emergency services or vehicles that have been granted temporary exemption. Furthermore, residents will have limited access to private cars as no parking spaces will be created for privately owned cars. Instead opportunities to make use of shared cars will be created.

The plans for Beurskwartier consist of the construction of approximately 2.500 apartments, 50.000 m^2 floor space for offices and about 15.000 m^2 reserved for a supermarket and services such as education, health, leisure, food and creative business. The ambition of the municipality is to create a high quality and livable neighborhood for its residents.

Since Beurskwartier is a new development area, no ANPR scans neither a traffic model exist for this area. Method 3, as described in paragraph 3.3.2, was used to find an approximation of the UGM decomposition of Beurskwartier based on its area decomposition. Instead of number of employees per SBI category, in this case the total number of m^2 per SBI category was taken (retrieved using BAG registry and LISA). The relations to number of incoming vehicles as were based on the LEZs, as explained in 3.3.1, were adjusted accordingly.

Table 3 shows the number of incoming vehicles per UGM segment. Two adjustments were made to the outcomes which lead to the shown bandwidth. Because of the limited traffic-nature of the area it is expected through traffic is non-existent. Based on the share of through traffic observed in the traffic models of the LEZs, the outcomes were reduced by 25%. Additionally, the amount of light commercial vehicles was reduced by another 50% to correct for commercial vans whose users park at their own residence (Elaad, 2020). The results show that the number of light commercial vehicles is five to ten times as high as the number of trucks. The majority of the light commercial vehicles are related to services.

Table 3. Decomposition of daily urban goods movements in Beurskwartier.

Logistics segment	**Light commercial vehicles**	**Trucks**
Waste logistics	0	6 – 8
Construction logistics	64 – 168	14 – 17
Parcels and express	24 – 64	0
Facility and service logistics	218 – 579	24 – 31
General cargo and retail	42 – 111	16 – 20
Temperature-controlled (retail, accommodation and food service activities)	32 – 83	14 – 17
Totals	380 – 1.005	74 – 93

5.2. Integrating logistics in Beurskwartier area – results

In further steps with the municipality, the decomposition of urban goods movement was used as a basis to reflect on how to integrate logistics in the limited traffic neighborhood. The proposed logistics system is composed of a combination of four solutions:

1. *Parking garages.* Below the residential building blocks parking garages will be created. A number of parking spaces will be reserved for urban goods vehicles. Usage of the parking garages is especially suitable for light commercial vehicles due to the maximum height of the garage. Parcel lockers can be placed in the parking garage or in the residential building blocks to increase delivery efficiency. Besides parcel deliveries, this solution could also be used for service-related vehicles. Therefore, this solution mainly applies to the logistics segments *parcel and express, facility and service logistics* and *temperature-controlled*.
2. *Loading and unloading zones.* At the edge of the Beurskwartier loading and unloading zones will be created for urban goods vehicles. This is especially applicable to trucks of the segments *general cargo and retail, facility and service logistics* and *temperature-controlled* that have no access to the parking garages. The

loading and unloading zones can be used in combination with a dynamic reservation system to ensure availability upon arrival.

3. *Mobility hubs.* The remaining vehicles can go to one or more mobility hubs at the edges of Beurskwartier. At the mobility hubs transfer to light electric vehicles and cargo bikes will be facilitated to enable delivery of goods and service provision in the neighborhood. This solution particularly applies to vehicles in the segment *facility and service logistics*.
4. *Increased use of light electric freight vehicles.* A share of the urban goods movement will be by light electric vehicles entering Beurskwartier from other parts of the cities, for example a city hub. This is likely to occur in UGM segments *parcels and express, facility and service logistics, general cargo and retail* and *temperature-controlled.*

The above-mentioned solutions describe for which UGM segments they are suitable while taking into account the particular characteristics of a segment (such as vehicle type and type of goods). Waste and construction logistics are not mentioned because these require a customized solution.

Based on the proposed system it was calculated how many vehicles would make use of each proposed solution per day. Based on this and assumptions on, amongst others, number of deliveries, number of stops and dwell times, it was approximated how many parking spaces are daily required for each solution. This is shown in Table 4.

Table 4. Number of daily parking spaces required for two scenarios of opening times.

	Opening time: 8 hours		**Opening time: 12 hours**	
Proposed solution	Vans	Trucks	Vans	Trucks
Parking garages	6 – 28	N.A.	4 – 19	N.A.
Loading and unloading zones	N.A.	2 – 11	N.A.	1 – 7
Mobility hubs	22 – 128	0.5 – 4	15 – 85	0.5 – 2

The above-described case study shows how insights into the decomposition of urban goods movements can provide a point of departure for designing solutions to integrate logistics in the spatial planning of an urban area. In this particular case study this is valuable because it helps to take UGM into account at an early stage to prevent inefficient integration of logistics afterwards that would disqualify the ambitions to create a livable neighborhood.

6. Discussion and conclusion

Cities are dealing with numerous challenges when trying to decrease the negative impact of urban goods movement, such as emissions, congestion, unsafety and occupancy of space. Though it is evident that measures should be taken to be able to fulfill ambitions on livable cities and though several measures have been trialed, the effectiveness of measures that aim to reduce negative impact of urban goods movement are affected due to limited available data on the size of urban goods movement. UGM is diverse and it therefore requires a decomposition, which subsequently demands a tailored approach in terms of measures to reduce negative impact. This study illustrates an approach how to use available data on traffic, and how to enrich these with other sources, to gain insights in the urban goods movement decomposition of number of trips and kilometers per segment and vehicle type.

As was also shown by two case studies, such a decomposition is supportive to a number of applications. First of all, the decomposition reveals the extent of the challenge in terms of goals or ambitions to reduce emissions and trips resulting from urban goods movement. Furthermore, the decomposition can be used to show the effect of technological (such as electrification) or other policy measures. Additionally, it can be used to show the impact of urban goods movement in smaller-sized urban areas (such as local neighborhoods) which can support in the process to find solutions to (improve) spatial integration of urban goods movement.

Though in this study we found ways to deal with limitations to the data (availability), an important recommendation is to increase efforts to collect data on urban goods movement on city/urban area level. This is crucial for being able to determine, first of all, the size of urban goods movement, but also to be able to show the effect of measures. In addition, a more structural approach to data collection also benefits the monitoring of measures in practice which is important to be able to steer in case measures do not have the desired effect or when additional measures are necessary to be able to reach goals related to climate, air quality or other aspects connected to livability.

Apart from data on number of movements and its decomposition to segments, also more detailed data with respect to route characteristics, such as number of stops, dwell times, origin and destination location and distance, is required. This would help to improve the accuracy of calculations on the effect of measures and, potentially, its actual effect. More detailed data will not only help to improve the decomposition (also to subsegments), but it will also help to do justice to the diversity of urban goods movement since improved insights in its decomposition and the behavior of commercial vehicles will help to better tailor measures. In the method proposed in this paper, the route characteristics have not been derived. However, for future research, it would be beneficial to explore the incorporation of these details using simulation or analytical models.

Finally, logistics service providers usually own very detailed data on their own logistics operation. In order to achieve the above, and to work towards structural data collection, these companies should be willing to share their data. This requires an initiative where municipalities, logistics service providers and statistical agencies together work on large scale data collection and making these available for purposes of impact assessment and monitoring of the effects of measures that aim to reduce negative impact of urban goods movement.

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Appendix A. Constructing linear relations to approximate number of incoming vehicles

Table 5. Variables in linear relations to approximate number of incoming vehicles per SBI category – light commercial vehicles.

<table>
<tr><th>Independent variable
Number of incoming vehicles per SBI category</th><th>Dependent variable
Number of employees per SBI category or number of households</th></tr>
<tr><td>Consultancy, research and other specialized business services</td><td rowspan="4">Sum of number of employees in SBI categories:
1. Construction;
2. Consultancy, research and other specialized business services;
3. Financial institutions;
4. Human health and social work activities;
5. Information and communication;
6. Manufacturing
7. Mining and quarrying;
8. Other service activities;
9. Public administration, public services and compulsory social security;
10. Renting and leasing of tangible goods and other business support services;
11. Renting, buying and selling of real estate;
12. Transportation and storage;
13. Water supply; sewerage, waste management and remediation activities;
14. Wholesale and retail trade; repair of motor vehicles and motorcycles;</td></tr>
<tr><td>Information and communication</td></tr>
<tr><td>Manufacturing</td></tr>
<tr><td>Other service activities</td></tr>
<tr><td>Construction</td><td rowspan="4">Number of households</td></tr>
<tr><td>Financial institutions</td></tr>
<tr><td>Renting and leasing of tangible goods and other business support services</td></tr>
<tr><td>Transportation and storage</td></tr>
</table>

Water supply; sewerage, waste management and remediation activities	
Accommodation and food service activities	Sum of number of employees in SBI categories: • Accommodation and food service activities
Culture, sports and recreation	Sum of number of employees in SBI categories: • Culture, sports and recreation
Human health and social work activities	Sum of number of employees in SBI categories: • Human health and social work activities
Public administration, public services and compulsory social security	Sum of number of employees in SBI categories: • Public administration, public services and compulsory social security
Renting, buying and selling of real estate	Sum of number of employees in SBI categories: • Renting, buying and selling of real estate
Wholesale and retail trade; repair of motor vehicles and motorcycles	Sum of number of employees in SBI categories: • Wholesale and retail trade; repair of motor vehicles and motorcycles
Mining and quarrying	Kept equal to observation in scans

Table 6. Variables in linear relations to approximate number of incoming vehicles per SBI category – trucks.

Independent variable **Number of incoming vehicles per SBI category**	**Dependent variable** **Number of employees per SBI category or number of households**
Consultancy, research and other specialized business services Manufacturing Public administration, public services and compulsory social security Renting and leasing of tangible goods and other business support services Water supply; sewerage, waste management and remediation activities	Sum of number of employees in SBI categories: • Construction; • Financial institutions; • Human health and social work activities; • Information and communication; • Manufacturing • Mining and quarrying; • Other service activities; • Public administration, public services and compulsory social security; • Renting and leasing of tangible goods and other business support services; • Renting, buying and selling of real estate; • Transportation and storage; • Water supply; sewerage, waste management and remediation activities; • Wholesale and retail trade; repair of motor vehicles and motorcycles;
Accommodation and food service activities	Sum of number of employees in SBI categories: Accommodation and food service activities
Financial institutions	Sum of number of employees in SBI categories: Financial institutes
Other service activities	Sum of number of employees in SBI categories: Other service activities

Transportation and storage	Sum of number of employees in SBI categories: Transportation and storage
Renting, buying and selling of real estate	Sum of number of employees in SBI categories: Renting, buying and selling of real estate
Wholesale and retail trade; repair of motor vehicles and motorcycles	Sum of number of employees in SBI categories: Wholesale and retail trade; repair of motor vehicles and motorcycles
Culture, sports and recreation	Kept equal to observation in scans
Mining and quarrying	Kept equal to observation in scans
Human health and social work activities	Kept equal to observation in scans
Construction	Kept equal to observation in scans
Information and communication	Kept equal to observation in scans
Agriculture, forestry and fishing	Kept equal to observation in scans
Education	Kept equal to observation in scans

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