Data collection for microscopic modelling of urban parcel transport to and from establishments – empirical insights into city logistics in the region of Karlsruhe, Germany

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ABSTRACT

City logistics plays a central role in supplying and disposing goods for establishments and residents in urban areas. However, the steadily rising demand for transporting goods puts cities under pressure. Hence, municipalities strive for alternative solutions for urban freight transport, especially parcel shipments on the first and last mile. Freight demand models are suitable to evaluate the transport-related effects of such solutions. However, developing those models requires a sufficient amount of data, which, to date, especially for establishments, cannot be covered in its necessary scope and accuracy by publicly available sources. Although parcel shipments to and from establishments make up to 40 % of the overall courier, express, and parcel market, these are often neglected in existing modelling approaches. Hence, in this study, we present a data collection concept for generating highly relevant data for the microscopic modelling of urban freight, i.e., parcel transport focusing on establishments. To reflect transport demand (i.e., establishments that need to have goods shipped) and transport supply (i.e., carriers that provide a transport service), a mixed-method approach is developed comprising complementary components. On the one hand, an online establishment survey is designed aiming to reveal disaggregated transport demand data for the subsequent modelling process. The survey focuses on the delivery and shipment characteristics of goods, such as temporal and spatial demand patterns. On the other hand, expert interviews are conceptualized to identify relevant patterns of transport supply carriers such as courier, express, and parcel service providers and shall further work as secondary data for the modelling process. The approach is applied in the region of Karlsruhe, Germany. It can be shown that the survey is generally suitable for generating freight transport data on a disaggregated level and that the mixed-method approach is capable of mutually validating the data obtained. However, our approach also emphasizes the necessity to conduct an establishment survey as a personal rather than a self-reporting interview, even if the costs are higher.

1. Introduction

City logistics plays a central role in supplying and disposing goods for establishments and residents in urban areas. However, a steady increase in urban goods movements, i.e., courier, express, and parcel shipments (CEP), could be observed in the past decades, stressing urban infrastructure and putting cities' logistic systems under pressure. One of the reasons for this development is the increased popularity of e-commerce, not only amongst private households but also establishments such as retail, industry, authorities, etc. To deliver and pick up all parcels, CEP service providers (CEPSP) need to deploy more vehicles. In addition to space conflicts, e.g., due to stopping delivery vehicles on bicycle paths,

cities are, amongst others, confronted with increasing emissions and pollutants. In order to improve the quality of life in cities and reduce the strain on road infrastructure, municipalities strive for alternative transport solutions for urban freight, i.e., parcel transport.

To estimate transport-related effects of CEP shipments in the future and to analyse the effects of such alternative shipment concepts, transportation planners use freight demand models. On the one hand, existing models in the literature focus on heavy freight transport, where CEP shipments are only considered implicitly. On the other hand, distinct freight demand models for CEP shipments typically focus on private household shipments and neglect CEP shipments between establishments, although these contribute to about 40 % of the overall parcel

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volume, e.g., in Germany (BIEK, 2023). This can mainly be referred to the lack of data on establishments' in- and outgoing parcel flows. While data on private CEP shipments can easily be obtained in traditional household surveys, this data is much harder to collect from establishments. Hence, CEP shipments to and from establishments are currently insufficiently researched from an empirical perspective (Dabidian et al., 2016), leading to a poor consideration of these shipments in existing freight demand models for CEP shipments.

Especially for developing microscopic, disaggregated approaches, insufficient data poses challenges to researchers in freight demand modelling. Even though these require a larger amount and more detailed input data as aggregated approaches, they are capable of reflecting the transportation effects of CEP shipments and possible alternative concepts in more detail. Officially available, centrally organized data sources for modelling establishments' parcel demand are scarce. For example, in Germany, a vehicle-based survey was conducted by official parties, which can be used, e.g., for calibrating a disaggregated model regarding the tour simulation. However, this data is incapable of microscopically modelling freight, i.e., parcel, demand in the generation step of a commodity-based modelling approach. Moreover, an officially available survey on establishments' in- and outgoing good flows in terms of actual quantities to be transported and their structure does not exist either. Current approaches are limited and typically private, decentral studies, where the data is not accessible. However, this information is necessary to reliably model freight demand on a microscopic base as it determines the corresponding transportation demand. In addition, available statistics on good flows are mainly based on spatial- and sector-wise aggregated data of economic activities in general and not establishment-specific, making this data also less suitable to microscopically model freight and transportation demand of establishments, respectively.

To address the research gap of a missing empirical database for establishments' in- and outgoing goods, i.e., parcel flows, we developed a data collection concept for generating highly relevant data for microscopic modelling of urban freight transport, focusing on parcel shipments in the commercial segment, but also addressing freight in general at the margin. The data aims to be utilized in a commodity-based modelling framework for demand generation. These models are still scarce in literature due to missing data. However, they are necessary for profound urban planning processes. Generating a detailed urban freight database for microscopic urban freight demand models can enhance, e.g., urban infrastructure planning such as the appropriate planning of loading zones, but also a more reliable land use planning in general, improving the urban transportation system. For that purpose, we have chosen a mixed-method approach comprising two complementary components: a survey of establishments obtaining information on the demand for freight transport and expert interviews with CEPSPs obtaining information on the supply of transport. Both sides, transportation demand, and supply, are mutually dependant, which also allows for the mutual validation of both data sets generated.

The paper is structured as follows. First, we give an overview of existing literature. Second, the developed concept is introduced in detail. Third, we provide insights into the results obtained by applying the data collection concept in the city of Karlsruhe, Germany. Finally, we evaluate the concept by critically reflecting on the results and provide implications for further adaptions of the concept, which is followed by a conclusion.

2. Literature review

Freight data is substantial for the planning of urban delivery processes. Since data sovereignty belongs to freight operators and their customers, municipalities need to collect this data through surveys to close the data gap on their side. In Germany, for example, these collection procedures are typically not organized centrally, leading to an increased need for relevant freight transport data (van den Bossche

et al., 2017). However, shipment volumes, type of freight, delivery vehicle activities, and process-specific indicators are the aim of such surveys, while the mentioned can further be differentiated according to the research purpose. The following sections describe the three most used traditional data collection methods first, which are, according to Allen et al., 2012, surveys addressing establishments, freight operators, and delivery vehicle observations. Subsequently, new approaches emerging from recent advancements in Information and Communication Technologies are presented.

Establishment surveys have several advantages so that, if successfully implemented, they can provide a comprehensive overview of freight transport processes in an area. They provide freight flow and vehicle activity data linked to the establishments' branches, land use, supply chain, etc. As promising as this sounds, some burdens remain to overcome during the implementation. Since the data quality relies on the respondent's knowledge and recall ability, the survey must be addressed to the correct person who has an overview of the overall process and an understanding of the specific process details. Depending on the available time and budget constraints, face-to-face and telephone interviews should be conducted, which promise higher response rates than self-completion surveys due to personal contact (Allen et al., 2012, 2014; Beagan et al., 2007). Thus, concerns about non-participation could be reduced (Bengel & Mauch, 2021). An example of such a survey was conducted in Berlin by Thaller et al., (2019), who examined urban establishments' delivery and shipping behaviour, emphasizing the success of short interviews via telephone due to busy employees who were averse to time-consuming online surveys and face-to-face interviews. Implementing an establishment survey in Lisbon, Alho and Abreu e Silva (2015) confirm that though these surveys require a high investment at various levels, they can deliver a considerable quantity and variety of freight data. Further, Pani and Sahu (2022) focus on the non-responses in establishment surveys and conclude that establishments handling high-valued commodities are likely to be underrepresented in surveys. Gonzalez-Feliu and Sánchez-Díaz (2019) assess the homogeneity within establishment categories to identify sub-sectors that need more extensive efforts for data collection.

Another effective method is the *freight operator survey,* which provides data about an entire vehicle fleet and corresponding travel patterns. In addition, qualitative information about problems encountered by the interviewed freight operator in urban freight operations can be obtained (Allen et al., 2012). This data is usually highly confidential and is generally only provided in highly aggregated form. Accordingly, only selective information on operational data can be expected (Bengel & Mauch, 2021). However, freight operators also tend not to have detailed information on the characteristics of the freight they deliver (Beagan et al., 2007). Hence, existing applications typically focus on the operational processes of freight operators. As an example, Castro and Kuse (2005) interviewed freight operators to examine the affections of considerable truck restrictions on freight carrier operations. Their results indicate that freight operators cope with restriction policies by shifting their delivery times and routes.

Delivery vehicle observations involve a surveyor positioned near establishments to record data about in- and outgoing delivery vehicles by the time of day and week. Similar to establishment surveys, they can collect data about vehicle types and delivery activities. However, this method is limited to the present time of the surveyor and does not capture the overall trip pattern of vehicles. Further, once establishments have multiple entry/exit points for delivery vehicles, the survey's scope grows strongly, which is reflected in a further increase of the already high costs (Allen et al., 2012; Browne et al., 2010). A method to overcome these two limitations is the vehicle trip diary, which does not belong to the most effective survey methods but provides comprehensive information about vehicle tours. Though this method is likely to fail due to the survey burden on the drivers, some successful implementations exist, such as the nationwide commercial vehicle trip diary 'Kraftfahrzeuge in Deutschland (KiD)' from 2010 (Wermuth, 2012). Focusing on motorized commercial traffic in Germany, the KiD provides

a database of around 70,000 vehicle diaries, which sufficiently allows analysis of commercial trip purposes and trip chains in urban areas. Casey et al., (2014) conducted a vehicle observation study to understand last-mile freight delivery in Melbourne's central business district and the involvement of different delivery vehicle types. Moreover, Moufad and Jawab (2020) used the same data collection method to study road occupancy of pickup delivery vehicles during loading and unloading activities.

In recent years, an increasing number of establishments have been willing to collaborate with various institutions for research purposes by permitting the installation of GPS tracking devices on freight vehicles to monitor their movement or simply granting access to their GPS data sources. Before, freight operators collected and utilized the data to maintain records of their operational efficiency, but sharing such data externally was typically avoided due to concerns regarding privacy, monetary value, and commercial confidentiality (Shoman et al., 2023). However, new data sources are now becoming increasingly available in large quantities and at lower costs compared to traditional freight surveys. This data is primarily utilized to identify individual freight vehicle activities, including the determination of average trip chains, stops per trip chain, dwell time per stop, and travel time per trip (Duan et al., 2020). Holguín-Veras et al., (2020) propose a method to identify urban freight vehicle stops from raw GPS logs of freight vehicles by utilizing vehicle speed, acceleration, and distance travelled between measurements. Additionally, Sun and Ban (2013) utilize GPS data to classify vehicles, such as distinguishing general trucks from passenger cars. Another instance of GPS data usage is illustrated by Yang et al. (2022), who identified truck stops and time thresholds by capturing temporal characteristics of intercity freight trips in China. However, GPS data alone is deemed insufficient for identifying activities and stops, necessitating validation from other complementary data sources like travel diaries. Additionally, the absence of behavioural explanations, such as trip purposes and degraded data quality due to signal issues, can complicate the extraction of knowledge from the data (Gingerich et al., 2016).

None of the involved agents, either shippers, receivers, or freight operators, have sufficient information to fully describe the entire freight shipment process. Therefore, combining different survey methods to supplement, link, and especially validate freight data is essential for holistically viewing a city's freight flows and developing a microscopic urban freight model. According to the literature, creating an effective data collection methodology is a fundamental challenge requiring the use of a systematic approach (Holguín-Veras & Jaller, 2014).

3. Study design and data collection concept

As a result of the previously described literature, we developed a data collection design that, on the one hand, allows to obtain detailed information on establishments' in- and outgoing good flows and, on the other hand, reveals relevant characteristics on the handling and transportation of goods by transport suppliers. As transport demand caused by establishments and transport supply offered by service providers are mutually dependant, we have chosen a mixed-method approach consisting of two complementary components. First, we developed an empirical survey design addressing all establishments in a designated planning area that generate transport demand, such as retailers, other commercial businesses, and industrial companies. It aims to understand the transport demand patterns of establishments by obtaining information on their in- and outgoing good flows in a disaggregated manner and revealing relationships to establishments' characteristics. Second, the data collection concept includes expert interviews with transport suppliers. Expert interviews were chosen as transport suppliers are typically represented only by a small number of actors within a planning area, making a survey less suitable. The interviews focus on the delivery and shipment process of goods on the last and first mile and, hence, do not consider long-haul freight legs. Moreover, they also consider

organizational aspects of the transportation process, such as contractual relationships with establishments. The expert interviews are aligned with the survey of transport demand but regard the transportation of goods from the supply perspective. It is important to mention that we did not include GPS data in our data collection approach. Following a commodity-based rather than a trip-based modelling approach, we consider GPS data more beneficial for calibrating and validating modelled freight trips. However, we primarily rely on commodity-related information collected through self-reporting surveys to build our models. The overall data collection concept is summarized in Fig. 1. The survey design, as well as the design of the expert interviews, are explained in more detail in the following subsections. Due to the focus of the study, the design of the data collection concept is aligned with parcel shipments rather than freight in general. This means that the depiction of establishments' good flows within the survey is focused on parcel flows and aspects of freight shipments other than parcels are only considered in the margin. The expert interviews mainly address courier, express, and parcel service providers (CEPSP), respectively.

3.1. Survey

Surveying the in- and outgoing good flows of all establishments within a designated planning area is challenging, as establishments differ in many characteristics such as sector, branch, and size, resulting in different implications for the type of good flows. Hence, the first premise for the survey design was to create a questionnaire that is as generic but also as detailed as possible to be able to consider the diversity of establishments without losing relevant information at the same time. Additionally, in contrast to private persons, establishments are more time-sensitive in responding to a survey, and monetary incentives cannot be applied to increase the motivation to respond. Consequently, the second premise for designing the survey was a highly time-efficient concept that employees can respond to during their working hours. As a result, the survey was designed to take only 10–15 min. To obey data privacy regulations and stimulate establishments to provide the necessary information, the survey was designed as an anonymous survey. A summary report of the survey results was offered as a non-monetary incentive to all establishments to achieve a higher response rate. The survey is structured in three hierarchical sections, where the previous sections are used to filter efficiently and hereby reduce the questions of the subsequent sections.

The first section of the survey asks for the specific characteristics of an establishment. This includes questions about the sector and branch according to the NACE classification (Eurostat, 2008) as well as the establishment's location and size in terms of the number of employees. Furthermore, responding establishments are asked to provide information about their area size in square meters as well as the relative distribution of different functional areas (e.g., retail, production, and office area) as this may affect the quantity and structure of in- and outgoing good flows. If applicable, the establishments are also asked about the size and mix of their vehicle fleet, what shares of the good flows are handled by their own vehicle fleet, and what shares by external service providers, such as CEPSPs, respectively. In addition, if an establishment ships goods by external service providers, questions about the number and kind of service providers are asked, and if any contracts exist between the establishment and transport service providers. This information is essential to consider in the freight demand model as it directly impacts the overall vehicle miles travelled.

The second section contains all questions regarding the ingoing good flows of an establishment. As the delivery of goods could differ between single weekdays, all the questions refer to the duration of a typical week to record possible variations. First, this section includes questions on the temporal and quantitative delivery structure, such as the frequency of deliveries within a week, the time windows in which deliveries can be accepted, and the duration of the overall delivery process. Second, the shipment structure of typical deliveries is focused. An establishment is
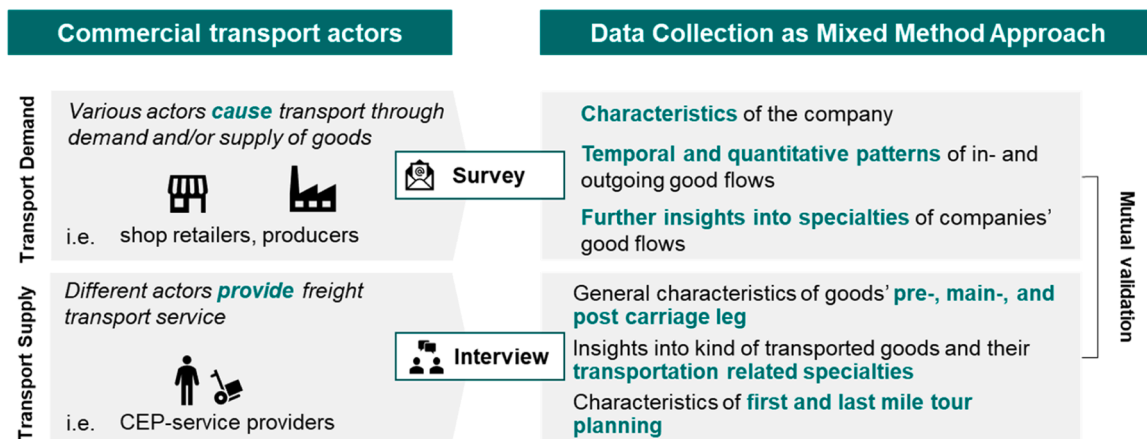
Fig. 1. Overview of data collection concept.

asked to determine which type of delivery units (parcels, pallets, containers, etc.) are typically delivered in which quantities. For a more specific focus on parcel flows, these are further differentiated between different sizes, i.e., small and large parcels. General freight units are also addressed in a simplified manner to reduce the complexity for the survey respondents who may not be logistical experts. However, for studies in which freight, in general, is in the focus, one may adopt the segmentation approach suggested by Schwemmer (2021). The information on delivery unit type and quantity can be used to model transport demand in the freight demand model. Further questions focus – if applicable – on requirements of delivery units such as cooling of goods or express deliveries. Those aspects are necessary to precisely reflect the mode choice in a later freight demand model.

The third and last section of the survey is parallelly structured to the second section but focuses on establishments' outgoing goods flows. In addition to ingoing goods flows, this part of the survey also captures the shipped goods' destinations to differentiate between shipments with a destination inside (short-haul) and outside (long-haul) the planning area. Furthermore, the distribution of shipments between private and commercial recipients is obtained.

3.2. Expert interviews

The expert interviews focus on the delivery and shipment process of CEPSPs' parcels from regional distribution centers to the final customer and vice versa. They take around one and a half hours and mainly address local district managers who are more likely to have a comprehensive overview of the entire process and relevant figures. In our study, we contacted solely leading CEPSPs (DHL, HERMES, UPS, DPD, GLS, FedEx/TNT), who together make up 99 % of the total German parcel market (Pitney Bowes, 2022). The recruitment of experts as interview partners was carried out indirectly via an open invitation to the head office of the service providers or directly using our network. To ensure comparability between several expert responses, we prepared an interview guideline containing six chapters of targeted questions. Follow-up questions were also asked to gain more in-depth information on specific topics (Patton, 2015).

The interview starts with collecting general information about the interview partner and the related delivery centre. Questions are asked explicitly about each interview partner's professional background, providing credibility for the following responses. To reveal specific differences compared to the default transportation process, the respondents are asked to qualitatively describe their logistical process with an emphasis on the time frames of each step (shipment receipt, transport to the delivery centre, shipment handling, etc.). For the purpose of modelling local resources of transport suppliers, operative figures about the involved delivery centers are asked, such as fleet size and

mix, number of employees, and outgoing tours on a typical day.

The following chapter focuses on the services offered, which are determined by the shipment size, measured by girth, shipment type (parcel, pallet, trolley, bulky goods), delivery options (standard, express, same day, etc.), and delivery guidelines. The latter arranges formal rules in case nobody is present at the delivery time, such as handing the shipment to the neighbour or depositing it in an agreed location.

The third chapter serves to understand the receipt of shipments by the transport supplier. Therefore, questions about the frequency of receipt along different shipper types (private, retail, wholesale, industry), over the week and day, and entry channels (local post office branch, parcel pickup station, parcel pickup shops) are asked. Alternatively, if the interview partner has no permission or cannot provide information on the shippers' type, the shipment volume for each type is requested. To assess further customer requirements, but from the receivers' perspective, the fourth chapter is built on questions similar to those in the preceding chapter.

The fifth chapter should provide information on contracts between transport suppliers and their business customers. In these medium or long-term relationships, delivery characteristics such as quantity, day, time window, and price are usually arranged. The questions are mainly linked to shipper types, as the interview partner can provide specific information.

The last chapter intends to identify the operative characteristics of delivery tours, which represent essential levers for cost minimization in the tour planning process. Thus, the deployment of tour planning algorithms and their associated input factors, such as delivery vehicle type, delivery area, shipping type, etc., are considered and, therefore, asked explicitly. Several statistics for a typical delivery tour are asked, e. g., the number of stops, average tour length, proportion of empty trips, and successful deliveries.

4. Results

We applied the previously described data concept in the region of Karlsruhe, Germany, in the first half of the year 2022. The results obtained from both components, the survey as well as the expert interviews, are presented in consecutive sections, followed by a brief methodological discussion in the next section of the study.

4.1. Survey

The field phase of the survey was from March to June 2022 and addressed all the establishments in the city of Karlsruhe, Germany, but also in the suburban areas outside of Karlsruhe. The survey was implemented as an online questionnaire using the survey engine 'Unipark' by 'Questback'. As there is no publicly available register with

establishments' contact dates, we contacted business associations of the Karlsruhe region to invite establishments to participate in our survey. Several associations supported us and invited establishments to the online survey through their newsletters. The total number of contacted establishments is unclear; however, it is estimated to be around 4,000 establishments reached by the newsletters. About 10 % followed the invitation and opened the start page of the survey. Nevertheless, only 105 establishments started to fill out the questionnaire, whereas 52 completed the survey, resulting in a completion rate of around 13 %. The results of the completed responses are used for the following analyses.

According to the characteristics of the surveyed establishments, about 43 % stated to belong to the manufacturing/production industry, whereas about 57 % said to be an establishment in the service sector. The sectoral aggregation chosen is rather rough aiming to avoid small sub-sample sizes considering the overall small sample. This must be considered to interpret the following results as establishments are aggregated in one category, which may differ in their supply chains. As presented in Table 1, most service-related establishments belong to the retail sector, namely clothing, books, etc. The sectoral distribution shows greater deviations from the official statistics, and hence, the sample is not representative according to sectors. However, this was to be expected, facing a small sample size of only 52 establishments. The same applies to the distribution of the establishment size. Although every second establishment in our sample reported having 1 to 10 employees, this share is less than the official statistics indicates. Nevertheless, similarly to the statistical data, establishments with a high number of employees have a lower share in our sample than establishments with a smaller number of employees.

The establishments reported a median area size of 500 m^2, with a minimum of 40 m^2 for a service establishment and a maximum of 400,000 m^2 for establishments in the manufacturing sector. However, the participating establishments had problems indicating the distribution of different functional areas, resulting in many missing values. Moreover, according to that question, followed by the survey's first page, the most dropouts of participants were recorded.

In the further course of the questionnaire, it became clear that more than 90 % of the establishments receive or ship goods regularly within a typical week. Half of all establishments surveyed have their own vehicle fleet to transport goods, independently from the establishment's sector. Over two-thirds reported having only a small vehicle fleet with 1 to 5 vehicles, mainly passenger cars and light vehicle trucks with up to 3.5 tons. However, the survey shows that the vehicle fleet only serves as a supplement because 4 out of 5 establishments stated to resort additionally to external service providers such as CEPSPs and freight forwarders in the same proportions.

Regarding the questions about the ingoing goods flows, all but one establishment reported receiving at least one delivery per week on a regular base. In contrast, 13 % of all establishments said that they do not regularly ship goods in a typical week and, hence, do not have a regular

outgoing goods flow. This is reasonable as establishments also receive consumables such as office materials that are not part of an establishment's value chain and, consequently, do not leave an establishment as an outgoing shipment. The in- and outgoing good flows also differ in their absolute frequency within a typical week. More than every second establishment reported receiving goods at least six times a week, which is on a daily base or even several times a day. According to outgoing shipments, this holds only for about 40 % of the establishments. The comparison of the frequencies of in- and outgoing shipments is presented in Fig. 2. According to the distribution of shipments over a week, establishments reported only minor differences between in- and outgoing goods flows, as presented in Fig. 3. For both shipment directions, an almost equal distribution of shipments between Monday and Friday can be observed, with peaks in the middle of the week. On Saturdays, only each fifth establishment receives or ships goods. A small number of establishments also reported receiving or sending shipments on Sundays.

We also analysed when establishments typically receive or send goods each day. Most shipments are handled within the typical business hours between 8 a.m. and 6 p.m. for both the in- and outgoing goods. On Saturdays, the time window ends earlier. It becomes clear that the peak for receiving goods is before and around noon, whereas the most frequent time window for establishments to send goods is in the (early) afternoon. On Saturdays, the goods are also primarily sent out before noon.

Establishments also specified the type of shipment units within the survey. About two-thirds of the establishments receive and send parcels. This finding stresses the importance of considering parcel shipments to and from establishments when modelling urban parcel movements. The shipped parcels differ in size, whereas small parcels (less than 5 kg and/ or longest edge < 120 cm) are used slightly more frequently than large parcels. However, each second establishment also reported receiving and sending out pallets. Other units, such as containers, play a minor role for the surveyed establishments. Typically, a shipment contains less than five parcels for at least two-thirds of all surveyed establishments. According to pallets, a shipment typically contains a maximum of two pallets. In general, the establishments reported that the larger the shipment unit, the smaller the number of units within each shipment.

Focusing on the destinations of outgoing goods flows, establishments reported that about 79 % of all shipments are sent to destinations outside the city of Karlsruhe. Moreover, about 46 % of all sent goods have a commercial recipient. This considerably high proportion of commercial recipients is reasonable, reflecting, e.g., the already high share of about 40 % of all parcels being delivered to establishments in Germany (BIEK, 2023).
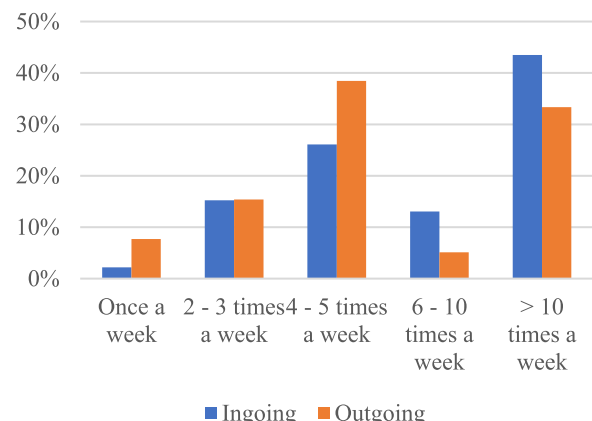
Table 1

Distribution of sector and establishment size of surveyed establishments.

Sectors	Statistics	Survey
Agriculture, forestry, and fishing	0 %	0 %
Manufacturing/production industry	12.1 %	42.6 %
Services	87.9 %	57.4 %
Retail	15.8 %	42.6 %
Others	72.1 %	14.8 %
Establishment Size		
1 – 10 employees	86.9 %	48.1 %
11 – 50 employees	10.5 %	25.0 %
51 – 500 employees	2.2 %	15.4 %
> 500 employees	0.4 %	11.5 %

Statistical data for sectors refers to Karlsruhe region specific data based on Hammer, et al., 2021; statistical data for establishment size refers to national German data based on Destatis (2021).

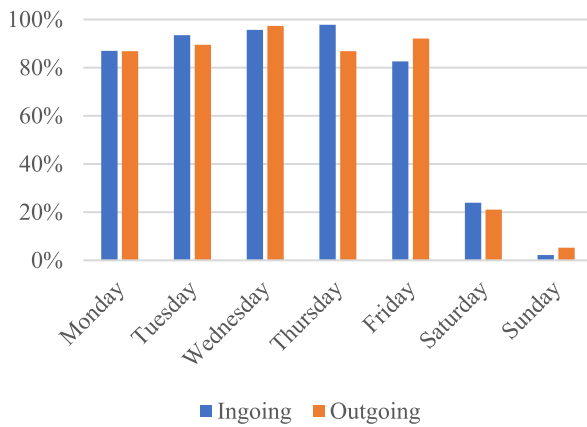**Fig. 2.** Frequency of in- and outgoing shipments, n = 52.

Fig. 3. Distribution of in- and outgoing shipments over a week, n = 52.

4.2. Expert interviews

In total, we interviewed four local district managers from distinct CEPSPs with an average work experience of >20 years in either operative or managerial positions of CEPSPs. In the following, we summarise their responses on an aggregated level to prevent traceability based on a confidentiality agreement with the experts respecting their business.

First, the interview partners reported similar characteristics of their operational parcel delivery processes. In general, incoming shipments are transported to the nearest regional distribution centre, where they are sorted and transshipped. According to their target destination, the shipments get either forwarded to other distribution centres or loaded in a delivery vehicle for local delivery the next day. Due to differences in resources and customer requirements, the process time windows for each CEPSP can vary on average by one day. While the employees and fleet size of the respective distribution centre are adapted to the average quantity of demanded shipments by the region, the number of outgoing delivery tours can vary depending on single and multiple tour policies for each vehicle and day. Further, we received consistent responses about the execution of delivery tours with mainly diesel-powered light vehicle trucks up to 3.5 tons and 7 tons. In contrast, a small proportion is handled with electric vehicles such as e-bikes or e-vans.

Moreover, differences in provided services derive mainly from the varying competitive strategies of the CEPSPs, such as focusing on specific customer segments and freight types. While parcels generally dominate through all possible shipment types, business recipients, i.e., establishments, strongly prefer express delivery due to contractual discounts and minor price differences compared to standard delivery. The offer of delivery time options before 9, 10, or 12 a.m. represents a complement to the express service and is highly appreciated by many commercial customers. However, same-day delivery is not very popular considering the respective shipment volumes, especially not for private customers but particularly for pharmacies. Thus, some CEPSPs do not offer this option at all. Concerning formal delivery rules and depending on the CEPSP, the number of delivery attempts is between 2 and 4. Across all interviews, the importance of delivery on the first attempt was emphasized. Otherwise, higher operational costs arise due to a return shipment to the last depot and a new delivery attempt the next day.

Experts' responses also indicate the importance of pick-up tours. These pick-up tours usually take place in the afternoon. Beyond that, there is also substantial agreement amongst all experts that private households tend to do online shopping on weekends. This results in a peak of shipment orders and receipts on Mondays, representing around a quarter of the total weekly volume. In the following days, the daily volume asymptotically adjusts to the weekly average while dropping firmly on Saturdays due to the weekend rest of a large part of establishments. Nevertheless, an observed variation between the operating hours amongst the service providers, as well as other differences in

operational approaches, can still lead to slight differences in the weekly distribution of incoming parcels.

In line with the increased shipment orders on Mondays, many deliveries occur between Tuesday and Thursday. While commercial customers receive 2.5 parcels for each shipment on average, private customers receive only around 1.5. Furthermore, there is agreement across all experts on the deviation of delivery quantities from the planned due to unpredictable internal and external events such as vehicle damage, suddenly occurring driver shortages, poor weather conditions, or abnormally high parcel handover times (e.g., elevator reliance) during the day. In contrast to shipment pickup, especially the delivery of establishments' parcels usually takes place in the morning due to the restricted opening hours of the majority of the business recipients. In addition, urban entry restrictions can limit delivery windows, requiring multiple employees and vehicles to enter urban spaces and keep delivery promises. Another noticeable aspect is the involvement of subcontractors who carry out a flexible share of shipments at lower wage rates.

Contracts play a significant role in the case of commercial customers / establishments who are usually engaged in medium to long-term relations with CEPSPs. The underlying reason is the bilateral need to regulate liability issues, collection and delivery times, quantities, and prices. According to one expert, most commercial customers have contracts with different service providers to minimize dependence on just one CEPSP and thus minimize shipment risk. Withdrawing from the contractual agreement does not have relevant consequences, except that the negotiated discounts on the price lose their validity. However, this may also be the case with fluctuations in the agreed shipment volume.

Responses to the characteristics of delivery tours have shown that no industry standard exists for tour planning algorithms. Some CEPSPs renounce the use entirely, while others consider them as a supplement. In those cases, the driver is solely responsible for identifying the shortest route for the daily delivery volume in a fixed area. These areas are adjusted dynamically as soon as substantial deviations from the expected shipment quantity occur. The normal range for delivery stops is between 50 and 150 depending on the customer type (private, establishment) and the related shipment size, vehicle capacity, and tour length. Further, all CEPSPs strive for the shortest possible handover time of the shipments to meet their daily target of deliveries. In such a time-critical environment, commercial recipients ease the operations of CEPSPs due to their higher probability of reception on the first attempt than private recipients. While the experts commonly stated a reception probability of almost 100 % for establishments, this is only 90 % for private customers.

5. Implications and discussion

The previously described results of the data collection concept as a mixed-method approach comprising a survey of establishments and expert interviews with transport service providers to reveal the characteristics of urban freight transport show overall reasonable results. The example of the number and type of shipment units supports the assumption that the survey is suitable for capturing relevant characteristics at the necessary level of (dis-)aggregation. The information on the number and structure of shipments can be used to develop, e.g., Discrete Choice Models, enabling the reflection of freight demand on a microscopic base, which was the goal of the data collection approach. Moreover, the information on the number and type of shipment units shows quite well the benefits of the mixed-method data collection approach as the information gained in both components, the survey and the expert interviews, covers the same topic from two perspectives, which in turn can be used for mutual validation of the data and the consequent model. As an example, in the expert interviews, it was said that a typical shipment to establishments contains 2.5 parcels on average, whereas in the survey, typically, 5 or fewer parcels were reported, which fits well with the value obtained in the interviews. In

addition to the aspect of data validation, the information gained from the expert interviews can be used as secondary data to calibrate microscopic models estimated based on data from the survey.

Taking the example of the commodity-based, microscopic urban parcel demand model logiTopp, which considers private parcel shipments (Reiffer, Kübler, Kagerbauer, & Vortisch, 2023) but in its newest extension also parcel shipments to and from establishments (Barthelmes et al., 2023), the survey data could be used to model the transport generation in more detail than in its current version. LogiTopp has a microscopic representation of each establishment within the study area based on OSM data, whereas each establishment is represented by specific characteristics such as sector, etc. For example, a Discrete Choice Model based on the survey data could model the parcel quantity as a dependant variable, taking the structural information of an establishment, such as sector, size, etc., as independent variables. Applying this model to logiTopp's establishments could replace the current transport generation approach with a more sophisticated and flexible approach. The information obtained from the expert interviews could be used to calibrate, e.g., the parcel quantity, while the overall model simulation results, i.e., the simulation of the delivery and pick-up tours, can be validated with external data sources such as from KiD. Furthermore, the data collection concept introduced in the study at hand can be used to implement new features in freight demand models such as the relevance of contracts between establishments and service providers, which already has been done for logiTopp (Kübler et al., 2023).

From an urban planning perspective, the data itself, as well as the results of the subsequent microscopic freight demand model, can be used to enhance the sustainability of the urban transportation system. Having a quantitative understanding of urban goods, i.e., parcel movements, improves infrastructural planning processes regarding necessary dimensions. For example, the data and model results can be used to identify the appropriate number and location of loading zones within the urban area to reduce the occupancy of other infrastructure such as bicycle or pedestrian paths by freight vehicles. Moreover, a detailed freight demand model as a planning base allows for a more reliable testing of possible policy measures before implementing them. As an example, the transportation-related effects of alternative shipment concepts, such as intermodal freight transport, can be analysed before realizing them, fostering the identification of the most beneficial concept for the urban environment (Barthelmes et al., 2023). Hereby, the mixed-method data collection approach shows its advantage in bringing together the perspectives of forwarders, shippers, and receivers of goods. Individual requirements can be captured and considered in the urban planning processes possibly increasing the acceptance of distinct measures.

However, the first application of the presented data collection concept has also shown potential for further adoptions of the overall concept. First, based on the survey, it became clear that parcel shipments to and from establishments play an essential role in establishments' freight flows and need to be explicitly addressed in further urban freight models. However, the survey also revealed that a non-negatable proportion of urban freight shipments is carried out by freight forwarders or own vehicle fleets. Hence, in a subsequent application of the data collection approach these parties must be addressed in the expert interviews besides the CEPSPs. The under-representation of distinct freight forwarders other than CEPSPs in the expert interviews and the fact that establishments reported to send about half of their deliveries to commercial recipients may also explain the differences in the reported shipment volumes over the week between interviews and the survey. Whereas CEPSPs reported varying shipping volumes due to private consumers' e-shopping behaviour, a more evenly distributed shipment volume across the days of a week was reported in the survey.

Second, the questions about the temporal distribution of in- and outgoing good flows in the survey showed similar results to the information gained in the expert interviews. Both data collection components support the fact that establishments typically receive deliveries before

and around noon, whereas shipments are typically sent out in the afternoon. The expert interviews could even provide more detailed information on the reasons behind those characteristics, such as the popular option for establishments to receive deliveries before a specific time in the morning. Moreover, they revealed that CEPSPs typically plan designated pick-up tours in the afternoon. Within the survey, responding to this topic took quite a lot of time as establishments had to indicate for each day, based on two-hour time slices, when they receive and/or ship goods. As relevant information can already be obtained from the interviews, we would drop this question from the survey in the future to increase the overall time efficiency of responding to the survey.

Third, our approach showed that response rates in the survey are low when establishments are not addressed directly, and the survey is conducted as a self-reporting interview. This finding is in line with existing literature, such as Allen et al. (2012). However, we used different recruiting channels and chose a self-reporting survey as personal interviews require much time and are, consequently, cost-intensive. Furthermore, directly addressing establishments implies knowing their contact dates, which are not publicly available. In addition, even when the contact dates are available, it might be a problem, especially in establishments with many employees, that the relevant contact person within the establishment is unclear. Although the latter restrictions applied in combination with a non-representative sample, we could still identify reasonable results with our procedure as the comparison with the results obtained in the expert interviews could show. However, having the goal to microscopically model freight demand and hence, develop statistically robust models, a greater sample size would be necessary. This has to be determined depending on the required confidence interval and the permitted error margin. In our case, with a confidence interval of 95 % and an error margin of 5 %, a minimum sample of about 380 establishments would be necessary to guarantee robustness. The suggestion is also in line with Thaller et al. (2019), who did an establishment survey in Berlin, Germany. Hereby, we advise weighing the relevance of the question on the area size of establishments, since at this question, the most dropouts were recorded, and consequently, omitting this question could increase the completion rate.

6. Conclusion

In the present study, we developed a data collection concept for capturing establishments' in- and outgoing goods, i.e., parcel, flows, as well as the characteristics of transport service providers' transportation-related processes in an urban context. Hereby, we aimed to address the generation of disaggregated data that can be used to model freight demand on a microscopic basis as this kind of data is – in contrast to passengers' travel demand – not centrally available in Germany but also in other countries worldwide. To address the mutual dependency between transportation supply and demand, a mixed-method concept was developed comprising two complementary components: a survey directed at establishments that generate transportation demand for goods and expert interviews directed at transport service providers that offer a transportation supply. The overall analysis focuses on parcel shipments to and from establishments. Freight, in general, is also addressed but with less attention. However, the data collection approach would be capable of being expanded to general in more detail in a future application.

The application of the concept in the city of Karlsruhe, Germany, showed that the concept can reveal relevant characteristics of freight transport in an urban area. Based on the information obtained, we were able to show that the concept is generally suitable for generating freight transport data on a disaggregated level, which in turn is sufficient as a basis for microscopic modelling of freight demand. Furthermore, the benefits of the mixed-method approach became clear: covering the same topic from two perspectives can be used for mutually validating the data obtained, especially when sample sizes are small. Moreover, when generating two data sources, one can be used as secondary data, for

example, in the calibration process of freight demand models. However, the approach could also support the finding that surveying establishments can be challenging. To recruit a sufficiently large sample that can be used to develop microscopic models, establishments should be addressed directly, and the survey should be conducted as a personal rather than a self-reporting interview, even if the costs are higher.

For further research, we will adapt the data collection concept according to the previously elaborated aspects in order to reduce the time needed to fill out the survey. Moreover, we will repeat the adapted survey as a personal interview with a representative sample of establishments in Karlsruhe and compare the results obtained with those from the study at hand to investigate the necessity of representativity when surveying establishments. All efforts are aimed at improving central data availability for research when investigating and modelling freight demand microscopically, but also to achieve a standardization of surveying establishments' goods flows in general.

CRediT authorship contribution statement

Lukas Barthelmes: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mehmet Emre Görgülü:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation. **Martin Kagerbauer:** Supervision, Project administration, Conceptualization. **Peter Vortisch:** Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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