INTEGRATED AGENT-BASED MODELING AND SIMULATION FRAMEWORK FOR URBAN PARCEL SHIPMENTS TO AND FROM ESTABLISHMENTS

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ABSTRACT
In recent decades, a substantial increase in courier, express and parcel (CEP) shipments has been observed. This development is particularly problematic in urban areas, where an increase in first- and last-mile shipments further strains existing infrastructure. To evaluate and identify alternative shipment concepts, transport planners use freight demand models. However, existing models that analyze CEP shipments focus primarily on parcel deliveries to private recipients, although establishments of all kinds, such as retail, account for the major proportion of all parcels on the first mile and a considerable proportion on the last mile. Hence, this study aims to develop an agent-based model that explicitly simulates CEP shipments on the first and last mile induced by establishments in urban environments. A modeling framework is developed and integrated into the existing parcel demand model *logiTopp*, allowing for a comprehensive analysis of the overall CEP market within a designated study area. All integrated modules are based on open data sources and self-conducted expert interviews with CEP service providers. The framework simulates on parcel level over a simulation period of one week and is made available as an open-source project. The model is applied to the study area of Karlsruhe, Germany. The results highlight the importance of considering CEP shipments to and from establishments; otherwise, transport-related effects are massively underestimated. Moreover, the study reveals the impact of specifics in establishment's CEP shipments, such as carrier contracts, on key tour metrics.

Keywords: urban parcel movements, establishment and private household parcels, agent-based simulation, open data, integrated framework

INTRODUCTION

For several years, a continuous rise in courier, express, and parcel (CEP) shipments has been observed in Germany, Europe, and the world. One of the reasons is the growing popularity of e-commerce, which has been further accelerated by the COVID-19 pandemic and has led to a considerable increase in the number of goods ordered online by households and establishments such as retail, industry, authorities, etc. Consequently, CEP service providers (CEPSP) must deploy more vehicles. As a result, urban road infrastructure is further stressed, and the emissions exposure for the urban population is aggravated. Studies forecast a continuation of the steady growth of parcel volumes. On the one hand, this is due to the assumption of further growth in e-commerce activities. On the other hand, the economy faces a development toward increasingly higher-value but smaller-volume goods. Therefore, establishments can resort more often to the services of CEPSPs instead of being forced to use dedicated freight forwarders. For this reason, along with the trend of urbanization, transportation effects caused by CEP shipments are expected to intensify.

To examine the effects of urban CEP movements and to evaluate possible alternative concepts in terms of more sustainable and urban-friendly city logistics with a further increase in parcel volumes, freight demand models are used in transportation planning. On the one hand, the literature presents models that simulate general, heavy freight transport, typically carried out with trucks over 7.5 tons. So, these models consider CEP shipments only implicitly. On the other hand, there are freight demand models that focus on CEP shipments explicitly. However, their focus is mainly on simulating parcel shipments to private households. In contrast, parcel demand produced by establishments is hardly considered, even though shipments between establishments already account for nearly 40% of all CEP shipments, e.g., in Germany (*1*). One of the reasons for the intense focus on parcel demand of households is data availability. While households can be surveyed easily about their e-commerce behavior (e.g., number of orders), parcel shipment data of establishments is much harder to obtain. As a result, explicit modeling of CEP shipments to and from establishments is insufficiently researched.

Therefore, this study aims to develop a model that explicitly simulates CEP movements induced by establishments in urban environments. Specifics of this segment compared to private parcel shipments are considered, and their effects on the overall CEP market are investigated. The model simulates parcel demand over a week to reflect differences between weekdays and weekends. In contrast to households, parcel shipments to be picked-up from establishments are also modeled in addition to those delivered so that effects on the first mile can also be investigated. To enable an integrated evaluation of the entire CEP market, the model approach is integrated into the agent-based travel demand model (TDM) *mobiTopp* and its logistical extension *logiTopp*, which models the private household parcel demand over one week. The agent-based approach on the parcel level allows exceptionally high flexibility in investigating alternative shipment concepts.

This paper is organized as follows. First, we provide an overview of relevant literature. Second, we present results gathered in expert interviews with CEPSPs and introduce the private household parcel delivery model *logiTopp*. Third, we explain the model concept and its implementation in *logiTopp*. Fourth, we apply the integrated modeling framework and show the simulation results. Finally, we elaborate on the specifics of CEP shipments to and from establishments, discuss the results and give a conclusion.

LITERATURE REVIEW

Detailed studies of complex freight transport systems are performed mainly by microscopic, agent-based modeling. Due to differences in data availability and desired modeling accuracy, the approaches are either commodity- or trip-based. The former requires commodity flow data and enables more detailed assessments of logistical actors and processes. The latter is built upon vehicle movement data from trip diaries or GPS data and can also capture non-freight-related movements, such as service trips and fueling. Table 1 provides an overview of existing microscopic urban freight modeling approaches and underpins their main capabilities and weaknesses.

One of the first microscopic urban freight models is *GoodTrip* developed by Boerkamps and van Binsbergen (*2*), enabling the assessment of the interactions between shippers, receivers, carriers, and policymakers for the first time regarding the environmental impact of freight. The authors developed a commodity-based approach focusing on shipments to establishments without further considering households as receivers or CEPSPs as carriers, similar to Tamagawa et al. (*3*), Nuzzolo and Comi (*4*), and Anand et al. (*5*). However, Fischer et al. (*6*) propose a trip-based modeling framework based on commodity flow data without explicitly differentiating carriers as CEPSPs, thus disregarding the contractual relationships between them and receivers. In contrast, the authors call attention to parcel movements, pick-up activities, and households as receivers. Hunt and Stefan (*7*) also propose a trip-based model built on data from trip diary interviews with business enterprises, simulating freight movements to establishments. Nevertheless, the simulation is limited to a day and does not explicitly feature CEPSPs as carriers, parcel shipments to households, or carrier contracts.

By introducing further logistics considerations and operations research concepts, Wisetjindawat et al. (*8*) suggest a commodity-based approach based on an establishment survey and link survey data from the road traffic census in the metropolitan area of Tokyo, Japan. However, the simulation period is limited to one day and does neither consider CEP parcels nor CEPSP explicitly. Roorda et al. (*9*), as well as the subsequent work of Cavalante and Roorda (*10*), present the commodity-based modeling framework *FREMIS* for the city of Toronto, Canada, without implementing it. The novelty of their work comes from contractual relationships between carriers and shippers bundling shipments and, with this, making use of economies of scale. Another prominent approach stems from de Bok and Tavasszy (*11*), who built the commodity-based model *MASS-GT* in Rotterdam, Netherlands, using an extensive Dutch commodity flow database. However, their approach does not explicitly feature CEPSPs, parcel movements, and carrier contracts. Schroeder et al. (*12, 13*) introduce carrier agents into the agent-based transportation simulation *MATSim* to analyze interactions between passenger and freight transportation. Bean and Joubert (*14*) continued the work by integrating receiver agents into the model. However, only one day is simulated for a sandbox scenario without implementing the model on real-world data.

Authors	Year	Model name	Study area	Modeling approach	Main input data	Simulation time		Transport service type			Shipper/receiver type		Characteristics of business parcel operations		
						Day	Week	In-house	Out-sourcing	CEPSP	Households	Establishments	Carrier contracts	Parcel pickup tours	Tour planning algorithm
Boerkamps et al. (*2*)	1999	GOODTRIP	Groningen, Netherlands	Commodity-based	-	-	X (agg.)	X	X	-	-	X	-	-	Optimization (not further specified)
Fischer et al. (*6*)	2005	%	Los Angeles, USA	Trip-based	Commodity flow data	(framework only)		-	X	-	X	X	-	X (framework only)	Optimization (not further specified)
Hunt & Stefan (*7*)	2007	%	Calgary, Canada	Trip-based	Trip diary survey data	X	-	X	X	-	-	X	-	-	Savings algorithm (Clarke and Wright, 1964)
Tamagawa et al. (*3*)	2010	%	Unspecified urban area	Commodity-based	-	X	-	-	X	-	-	X	-	-	Vehicle routing and scheduling problem with time window-forecasted
Wisetjindawat et al. (*8*)	2007, 2012	%	Tokyo, Japan	Commodity-based	Establishment survey and link survey data (road traffic census)	X	-	X	X	-	-	X	-	-	TSP (shift time, vehicle weight capacity)
Roorda et al., (*9*) Cavalcante & Roorda (*10*)	2010, 2013	FREMIS	Toronto, Canada	Commodity-based	Stated Preference data is recommended	X	-	X	X	-	-	X	X (framework only)	-	TSP (driver availability and road network characteristics)
Nuzzolo & Comi (*4*)	2014	%	Rome, Italy	Commodity-based	Survey data, traffic count data, establishment and driver interview data	X	-	X	X	-	-	X	-	-	MNL model for each transport service type
Anand et al. (*5*)	2014	SMUrFS	Rotterdam, Netherlands	Commodity-based	Synthetic data, real GIS-data	Month (only 'toy-model')		-	X	-	-	X	-	-	Heuristic-based Tabu search vehicle routing algorithm
de Bok & Tavasszy (*11*)	2018	MASS-GT	Rotterdam, Netherlands	Commodity-based	Commodity flow data	X	-	X	X	-	-	X	-	-	Choice model for combined shipment and tour formation
Schroeder et al. (*12*), Schroeder & Liedtke (*13*), Bean & Joubert (*14*)	2012, 2017, 2019	Freight Transport Lab	(framework only)	Commodity-based	(framework only)	X	-	-	X	-	-	X	X (framework only)	-	Savings algorithm (*15*) / jspirit (*16*)
Livshits et al. (*17*)	2018	MAG	Arizona, USA	Trip-based	Establishment data (NETS), GPS data	X	-	X	X	X	X	X	-	X	MNL model for each transport service type
Dalla Chiara et al. (*18*)	2020	%	Singapore CBD	Commodity-based	Synthesized delivery data from carrier (UPS)	X	-	-	-	X	X (but not specified)		-	-	TSP (vehicle weight capacity, shift time, travel distance, delivery priorities)
Sakai et al. (*19*)	2020	SimMobility Freight	Singapore CBD	Commodity-based	Establishment survey, driver survey, parking survey, traffic counts, vehicle registry	X	-	X	X	X	-	X	-	X	MNL model (travel time, toll, (highway) length, max. vehicle weight, transport service type)
Zilske & Liedtke (*20*), Llorca & Möckel (*21*)	2012, 2021	FOCA	Munich, Germany	Commodity-based	Commodity flow data (est.), freight vehicle data, OSM-data	X	-	-	-	X	X	X	X	X	Vehicle routing heuristics (not further specified)
Reiffer et al. (*22*), Kübler et al. (*23*)	2021, 2022	logiTopp	Karlsruhe, Germany	Commodity-based	Household survey data, public data	-	X	-	-	X	X	-	-	-	TSP (route first cluster second approach (*24*))
Stinson & Mohammadian (*25*)	2022	CRISTAL	Chicago, USA	Commodity-based	Commodity flow data, establishment data (governmental), real estate data (commercial), annual company reports	X	-	X	X	X	X	X	X	X	Inventory-theoretic formulation

TABLE 1: Literature review on microscopic freight models with application in urban areas

Nevertheless, several recent models incorporate CEPSP explicitly in their models. To begin with, Livshits et al. (*17*) developed a holistic trip-based freight model called *MAG* for the Arizona Sun Corridor Megaregion, USA, connecting urban with regional freight transportation activities. Although parcel movement and even parcel pick-up tours are included in the approach, the simulation is limited to an average weekday and claims high data collection efforts. Dalla Chiara et al. (*18*) follow the commodity-based approach and develop an urban freight model for Singapore, thanks to access to an extensive delivery database from the CEPSP carrier "UPS". Parcel pick-up tours and carrier contracts are disregarded, though. Moreover, the authors do not differentiate between households and establishments as receiving agents but focus on delivery locations. In the same year and for the same area, Sakai et al. (*19*) propose the commodity-based modeling framework *SimMobility Freight*, which is implemented on several data sources, as seen in Table 1. While several transport service types are incorporated, the authors focus on freight relationships between establishments and ignore households as receiving agents. Furthermore, as already stated in several models, the simulation is being performed for only a day.

Focusing on parcel movements in Munich, Germany, LLorca and Moeckel (*21*) develop a framework comprising households and establishments in urban areas as receiving and shipping agents. While the approach further includes carrier contracts and pick-up tours, the simulation is implemented in *MATSim* (*20*) and is limited to a single day. Based on several commercial and public data sources, Stinson and Mohammadian (*25*) implement their proposed commodity-based framework for Chicago, USA. While the approach addresses important characteristics of urban parcel movements, it disregards changes in e-commerce behavior and parcel movements over a week by simulating only one average day. Lastly, Reiffer et al. (*22*) developed the *logiTopp*-framework modeling parcel movements in the urban area of Karlsruhe, Germany, over a simulation period of one week. However, the model is currently limited to households as recipients.

The literature review shows that microscopic, agent-based freight demand models started to consider CEP shipments only in the recent past. If so, besides few exceptions, CEP shipments to households are focused, but shipments to and from establishments remain mainly disregarded. Therefore, specifics of this segment, such as shipment contracts between CEPSPs and establishments or distinct pick-up tours at establishment sites and their possible transport-related effects (e.g., tour distance, tour duration, overall tour efficiency), are rarely addressed. Additionally, reviewed models are primarily based on commodity flow data or vehicle movements, preventing modeling single parcel movements. However, this becomes important when investigating alternative shipment concepts that rely on small-volume transport vehicles such as cargo bikes. For these, a rough approximation of transported volumes instead of single entities is insufficient to analyze a concept's overall transport-related effects. Moreover, the simulation period in existing models is typically a single day. However, a week is necessary to reflect differences between weekdays and weekends, i.e., Saturdays, and the consideration of repeated unsuccessful delivery attempts.

MODELLING FRAMEWORK FOR ESTABLISHMENTS' PARCEL DELIVERY AND PICK-UP

Based on the literature review and additional expert interviews with CEPSPs, we developed an integrated microscopic, agent-based modeling framework for explicitly simulating CEP shipments to and from establishments. Aiming at a holistic approach, the framework is integrated into the existing agent-based private parcel model *logiTopp*. In this chapter, relevant results of the expert interviews are introduced, followed by a brief introduction to the current *logiTopp* framework.

Finally, the overall microscopic, agent-based modeling framework for CEP shipments to and from establishments and its integration into *logiTopp* is presented.

Expert interviews with CEPSPs

To get a better understanding of CEP processes in general, but also regarding structural patterns of parcel deliveries to and pick-ups from establishments, expert interviews with leading German CEPSPs, namely DHL, Hermes, UPS, and FedEx, were conducted in spring 2022. As interview partners, experienced local branch managers of the corresponding CEPSPs were invited. The interviews aimed to reveal relevant aspects of the CEPSPs' business operation to be considered in the later modeling framework. Hence, they were structured along the typical CEPSPs' operational process, starting with the parcels' arrival in a CEPSP's distribution center, their allocation to distribution areas, the tour planning and actual delivery process, and ending with the pick-up of parcels needed to be shipped to the distribution center. Furthermore, particular focus was given to differences between private receivers of parcels and those shipped to or from establishments. In the following, however, we only present the aspects relevant for the paper at hand and refer to Barthelmes et al. (*26*) for further details.

One striking finding within the interviews is that establishments, i.e., retailers and any commercial facilities, experience a peak in picked-up parcels at the beginning of a week due to intense e-commerce activities of individuals at weekends. The peak adjusts to a weekly average over the course of the week. Parcels are also sent out on Saturdays, though the volume is much lower due to the weekend rest of many establishments. The peak in pick-ups from establishments at the beginning of a week results in a peak of deliveries to households in the middle of the week. Due to constant ordering behavior, establishments receive parcels evenly distributed besides lower volumes on Saturdays. The distribution of delivered and picked-up parcels to and from establishments and the delivery to private households based on the experts' experience is illustrated in Figure 1.

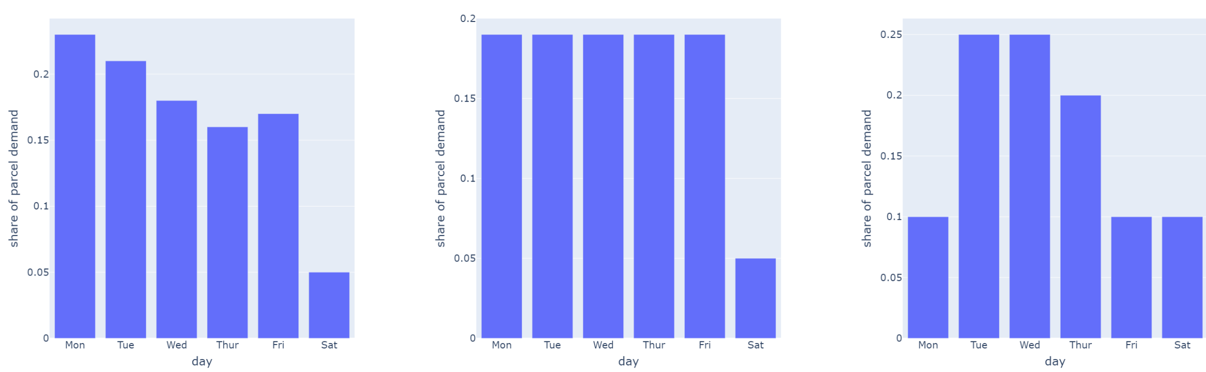

FIGURE 1: Weekly distribution of parcel pick-ups from establishments (left), deliveries to establishments (middle), and parcel deliveries to private households (right) based on expert interviews

Moreover, it became clear that in contrast to households, establishments mainly have contracts with one or more CEPSPs ensuring that their regular parcel shipments are transported at a defined time and for a specific price. Although the interviewees explained that these contracts are less formal than usual, they still form a relationship between an establishment and CEPSP. This finding is supported by an empirical survey conducted among establishments in Berlin, Germany, by

Thaller et al. (*27*). Another interesting aspect obtained from the interviews is that establishments' outgoing parcels are typically picked-up in separate tours. In contrast, the delivery is done together with parcels addressed to private households. An additional finding is related to the tour planning of last-mile deliveries. Although CEPSPs provide tour optimization software for their drivers, the interviewees revealed that their drivers typically ignore these. Especially work-experienced drivers assume to know their delivery area implicitly better and don't give credit to optimization software. This may also explain why the interviewees reported a delivery success rate to establishments of about 100%. Although the recipient type (household/establishment) is not stored in the CEPSPs' systems, the drivers typically know the recipients and can adapt their tour to possible opening hour restrictions of establishments.

Existing last-mile private household parcel delivery model *logiTopp*

Our work is based on the agent-based last-mile private parcel modeling framework *logiTopp* (*22, 28*), which is an extension of the agent-based travel demand model *mobiTopp* (*29, 30*). Hence, it allows interaction with private travel demand. According to the review of existing freight demand models in Table 1, *logiTopp* already fulfills many required preconditions to reflect CEP shipments to and from establishments. First, it is the only model able to simulate CEP shipments for one week rather than a single day. This is important considering fluctuations in shipped parcel quantities during a week, as observed in the expert interviews with CEPSPs. Second, *logiTopp* already uses parcels as the smallest logistical unit rather than overall shipments. This is also the preferred modeling entity for establishments' delivered and picked-up parcel volumes ensuring to be able to simulate alternative shipment solutions with small-volume transport vehicles. Third, *logiTopp* is available as an open source project on GitHub (*23*), making it, on the one hand, suitable to adapt, and on the other hand, builds the base to create an open source approach as well.

However, in its current version, *logiTopp* is only considering private parcel recipients that are delivered by CEPSPs. Therefore, in the following, we extend *logiTopp* by CEP shipments to and from establishments and present the newly integrated modeling framework that can model and simulate CEP movements to households as well as to and from establishments. The model structure of *logiTopp* is currently aligned with *mobiTopp* and, hence, consists of a long-term and short-term module.

Within the long-term module for each agent of the population generated in *mobiTopp*, the private parcel demand is modeled for one week. Further attributes such as the delivery type (home, work, parcel-locker) are modeled using discrete choice models. For each parcel, a CEPSP is selected based on the market shares, and a planned delivery day is drawn from an even distribution. Here, Sunday is excluded as, in Germany, no deliveries occur on this day.

In the short-term module, the last-mile delivery of all parcels is simulated. For each CEPSP, tour planning is performed for each day using a route-first cluster-second approach (*24*), and the tours are finally processed considering the chosen delivery types. For each CEPSP, specific delivery policies are respected, e.g., the maximum amount of delivery attempts as a person may not be at home when the delivery arrives.

Integration of establishments' delivered and picked-up parcels into *logiTopp*

Aiming at a consistent modeling framework for the overall CEP movements within an urban area, we followed the existing model structure of *logiTopp* when integrating CEP shipments to and from establishments. However, in each stage of the current *logiTopp* framework, adaptions to the status quo implementation had to be made, and further modules, such as the mid-term module, had to be included. Especially for establishments, relevant data for modelling CEP shipments is not easy to obtain as establishments often consider their data highly confidential. Governmental data sources enabling a microscopic modeling approach do not exist either, at least in Germany. Therefore, but also to achieve transferability, all integrated models are based on open data sources, making the approach easy to replicate in any study area. Figure 2 illustrates the extended modeling framework.

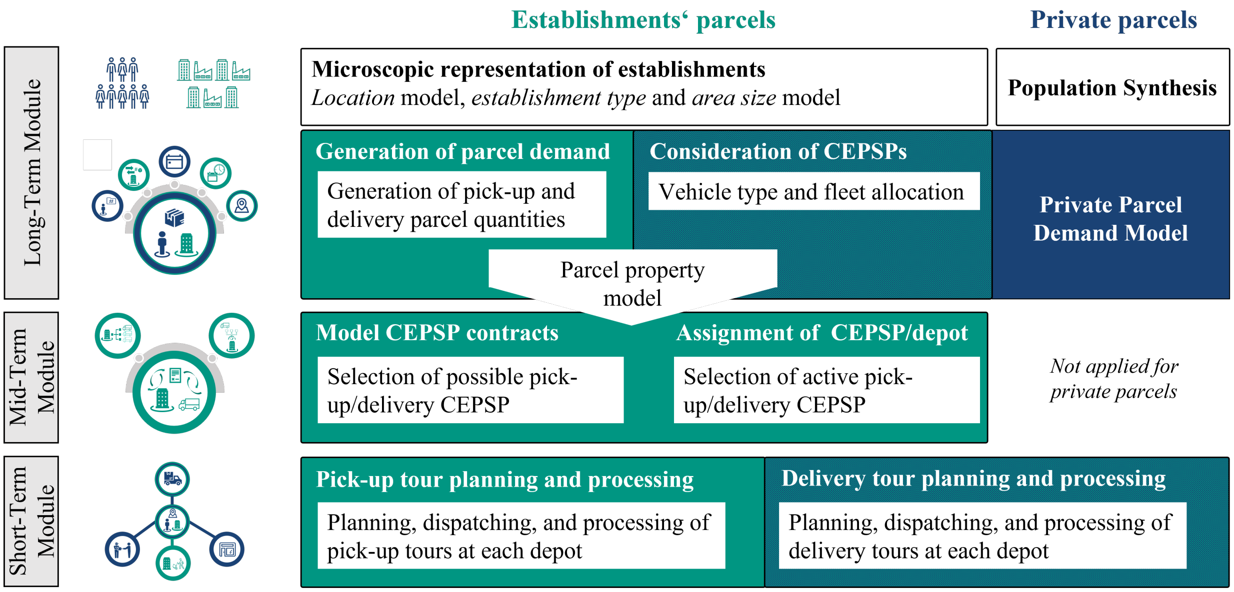

FIGURE 2: Modeling framework for establishments' delivered and picked-up parcels and its integration into the existing modeling framework for private household parcel deliveries

Analogous to the population synthesis, the model extension is based on a microscopic representation of all establishments within the study area, providing *structural data* for the modeling framework. This includes the depiction of each establishment's geographical location, its type in terms of sector classification, and its area size. All this information is gathered from the open data source *OpenStreetMap (OSM)* (*31*). Hereby, we extract establishment objects from OSM based on relevant feature variables using 'Osmosis'. The extracted data contains the type and geographical location of each establishment object. Based on the feature variables' values, each object is allocated to a higher-level sector-based classification, comprising *gastronomy*, *retail*, *leisure*, *service*, *industry*, and *administration*. Finally, all objects undergo geographical preprocessing using *ArcGIS*. Hereby, establishments are allocated to their corresponding travel analysis zone (TAZ) in the respective modeling framework, and an object's polygon surface is calculated to determine the area size of each establishment. Due to data quality issues, OSM cannot extract all establishment objects within a designated study area. Therefore, as a last step, the sector distribution of the extracted objects is compared with an official registry, and missing objects are up-sampled accordingly. We refer to Barthelmes et al. (*32*) for further details of the method and its application.

Within the *long-term module*, the transport demand side required by establishments is added. Whereas in the current version of *logiTopp*, only parcels delivered to private households are considered, for establishments also picked-up parcels are generated to reflect transportation-related effects caused by e-commerce activities. Hence, establishments' picked-up and delivered parcel quantities are estimated by distinct models. Due to the open-source requirement, we use literature-based data presented in the study of Thaller et al. (*27*). The study was successfully carried out among 431 establishments in the urban area of Berlin, Germany, in 2018, meeting the requirements of minimal representativeness. They provide information about the annual distribution of delivered and picked-up parcel quantities per sector. For our parcel generation models, we replicate these distributions and apply them to the number of all establishments within the study area, resulting in two ordered vectors for each sector, one for the delivered and one for the picked-up parcel quantities. The vectors are aligned with the overall CEP market evolution as the input data refers to 2018, and parcel quantities increased substantially since then. Moreover, the vectors are adjusted to the simulation period of one week. Finally, each establishment gets assigned a parcel quantity for delivery and pick-up over one week from the sector-wise vectors based on its area size. So, establishments with a greater area size are more likely to get greater parcel quantities assigned. Further details on the parcel generation model for establishments are given in Barthelmes et al. (*32*).

In contrast to the private parcel demand model for households, no delivery type is chosen. According to expert interviews, parcels are mainly delivered to or picked up from the establishment's site. Hence, the parcel property model is adapted accordingly.

The already implemented aspects of the transport supply side can be adopted as it already distinguishes different CEPSPs, including their distribution centers' locations, vehicle types, and fleet sizes. However, minor adjustments are necessary to consider establishments, e.g., CEPSPs focusing solely on private household deliveries are unavailable for shipments to and from establishments.

Newly integrated into the modeling framework is the *mid-term module*, which is only applied for establishment parcels. After the overall parcel quantities are determined, it must be decided which CEPSP is delivering or picking-up which parcels at which day of the week. For private parcels, the distinct CEPSP is chosen based on market shares. The delivery day choice is adapted from an even distribution to a distribution with a peak in the middle of the week, according to Figure 1. The decisions occur in the long-term module as part of the parcel property module. However, we learned from expert interviews that establishments typically have contracts with one or more CEPSPs, restricting the possible choice set of CEPSPs from which each parcel of an establishment can be transported. Therefore, we integrate a 2-stage CEPSP contract model, determining the number and set of possible CEPSPs able to deliver or pick-up parcels to or from each establishment.

Similarly to the procedure described for the parcel generation model, the number of possible CEPSPs, with whom an establishment has a relationship is determined and calibrated based on sector-wise distributions of potential contract partners provided in the study of Thaller et al. (*27*). In the second step, the distinct CEPSPs available in each establishment's choice set are determined using a Greedy algorithm. The algorithm considers the CEP market shares, the parcel quantities of establishments and the CEPSPs' transport capacity. Further details on this model are provided by Kübler et al. (*33*).

After determining the contractual relationships, the shipment day of each parcel is drawn from a weekly distribution for delivered and picked-up parcel shipments obtained in the expert interviews (see Figure 1). Next, the actual choice of which parcel is delivered or picked up by which CEPSP is carried out, considering the individual contractual relationships. This decision is modeled based on a weighted random draw and takes place separately for each day. The corresponding weights are dynamic and dependent on the remaining transport capacity of each CEPSP per day.

In the *short-term module*, the principal logic of the existing tour planning and processing for private parcels on the last mile can be adopted as household and establishment parcels are delivered in the same vehicles. However, according to expert interviews, tour planning is often less optimized and based on the drivers' implicit knowledge about the recipients in one's service area. Hence, instead of the existing optimization procedure, we develop and integrate an allocation heuristic for parcels to tours based on travel times between TAZs. The heuristic accounts for a delivery success rate of 100% for establishments. In contrast to private parcels, only direct delivery to establishments is simulated. However, our modeling framework also considers parcels being picked-up at an establishment's site. Consequently, the first mile is also simulated. For the pick-up of establishments' parcels, distinct pick-up tours are planned and processed. The same logic as for the delivery tour planning is adopted. For all tours, the time limit of eight hours working time of drivers must not be exceeded.

All extensions were integrated into the modeling framework *logiTopp* and made available as an open-source project on GitHub (*23*).

RESULTS AND DISCUSSION

We applied the modeling framework – considering private household and establishment parcels – to Karlsruhe, Germany. The study area has a maximum extension of about 17km in north-south direction and 19km in west-east direction. Within the *logiTopp* model, about 300,000 agents are depicted in the population synthesis reflecting the inhabitants of Karlsruhe. Moreover, about 15,400 establishments are registered in the study area and considered in the establishment synthesis. Karlsruhe is serviced by six major CEPSPs, namely DHL (48%), Hermes (16%), UPS (12%), DPD (10%), GLS (7%), and FedEx (6%). Their market shares (in parentheses) follow a national market report (*34*). For each CEPSP's distribution center, a sufficiently large fleet is integrated, containing solely 3.5t sprinters that carry up to 150 parcels.

logiTopp was run considering all adaptions described in the previous section. The model simulates 159,443 parcels delivered to households, 147,833 delivered to establishments, and 231,298 parcels picked-up from establishments within one week. The latter is by far the greatest proportion. However, these are picked-up parcels; hence, the receivers are households and establishments primarily outside the study area. The overall number of parcels and their distribution between private households and establishments is reasonable compared to an extrapolation based on national statistics provided by (*1*). Moreover, we also checked for the geographical distribution of parcel shipments. For example, picked-up parcels for establishments are illustrated in Figure 3.

All TAZs are shaded based on the number of picked-up parcels. Darker shaded TAZs are observable in the east and west, representing industrial zones. Moreover, more parcels picked-up from establishments are visible in the city center, where many retail shops are located. Hence, the approach seems to reflect parcels in their geographical distribution realistically. The same holds for parcels delivered to establishments. According to the contractual relations, each establishment across all sectors has contracts with, on average, three to four CEPSPs for parcel deliveries. For parcel pick-up, only one to two contracts exist for each establishment. The number of simulated contract partners is in-line with empirical data provided by Thaller et al. (*27*). However, the distinct constitution of choice sets cannot be checked as no data is available.

Selected results of the simulation of the short-term module over one week are presented in Figure 4-7. No disaggregated comparative calibration data is available for the study area, so the

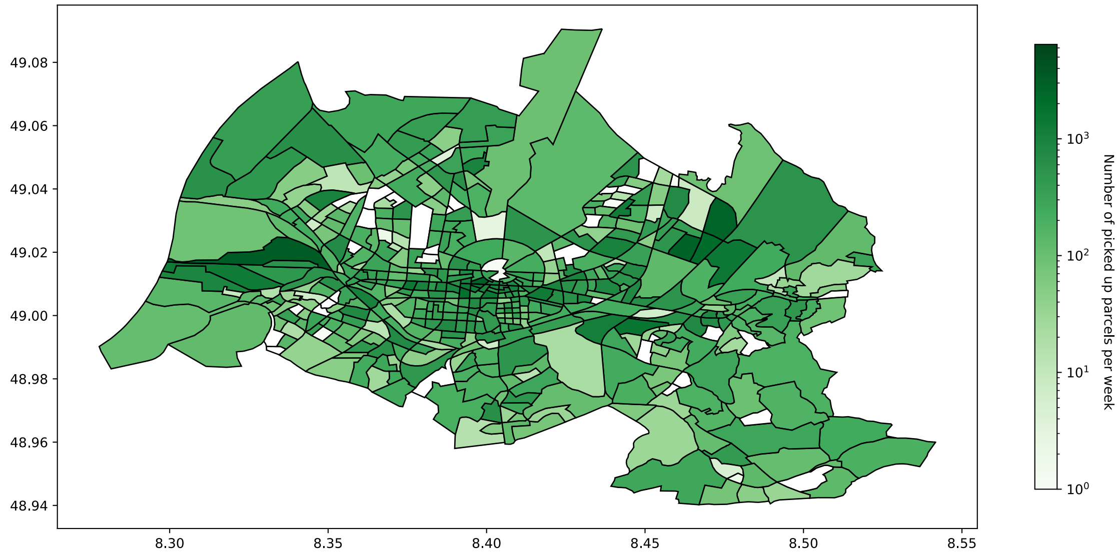

FIGURE 3: Geographical distribution of picked-up parcels per TAZ

results are tested for internal plausibility and interpreted below. According to the extended modeling framework, contracts between CEPSPs and establishments, and distinct pick-up tours, are considered in the simulation. Moreover, the simulation results are based on the newly developed parcel-to-tour allocation heuristic rather than the route-first cluster-second optimization reflecting the drivers' implicit knowledge about their service area.

Figure 4 shows the overall number of tours performed over the simulation period. The number of tours is sharply linked with the number of parcels that need to be transported per day, as depicted in Figure 1, which is comprehensible. With over 800 tours, the maximum number is achieved on Tuesdays when many parcels are picked-up from establishments and delivered to households. The number of tours decreases during the week according to the reduction in parcels needed to be transported and is on Saturdays about one-third of the tours on Tuesdays. Mondays form an exception. On this day, the highest number of parcels is picked-up at establishments assuming a greater tour number, although, on Mondays, only few parcels are delivered to private recipients. As parcel pick-ups concentrate only on establishments, this phenomenon could be attributed to a more efficient pick-up tour planning due to fewer pick-up points with higher parcel quantities than private agents. Moreover, on Mondays, no parcels are considered that failed the delivery attempt to a household as it is the first day of the simulation. The distribution of tours among different CEPSPs is in-line with the corresponding market shares.

Moreover, Figure 5 illustrates the number of parcels per tour. The median values coincide with the distributions' maximum and minimum and match the maximum number of 150 parcels per vehicle. On Saturdays, the number of parcels per tour shows greater variation. On this day, fewer customers are served, leading to a less dense distribution of delivery and pick-up points. Tours can become longer, and fewer parcels may be transported to obey the maximum tour duration.

In Figure 6, the distance in kilometers (km) traveled in each tour is depicted, while Figure 7 shows the corresponding duration in minutes. Although the number of tours varies between the weekdays, the distribution of traveled distance per tour stays stable during the weekdays with a

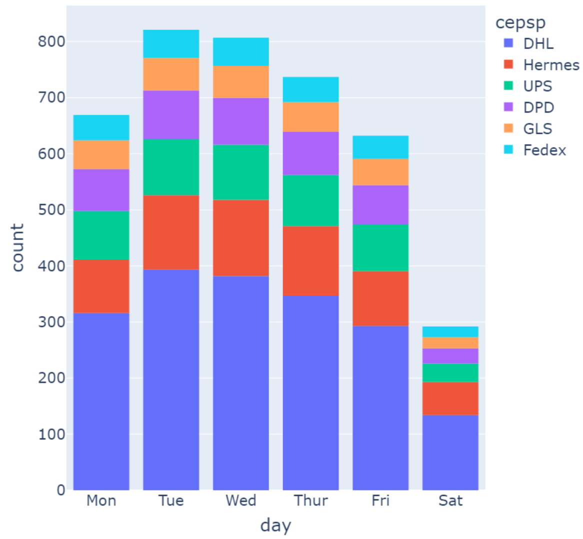

FIGURE 4: a) number of tours

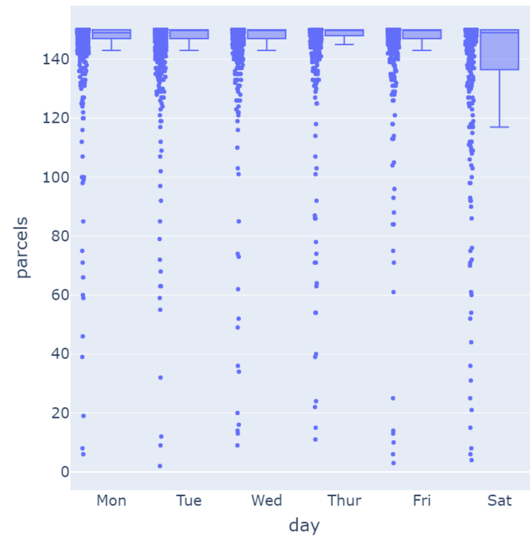

FIGURE 5: b) parcels per tour

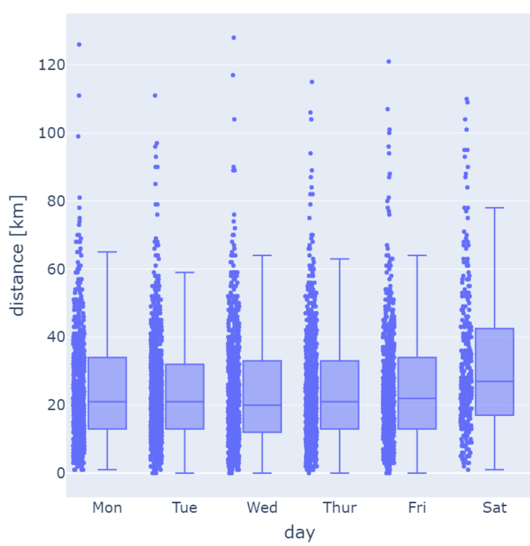

FIGURE 6: c) distance per tour

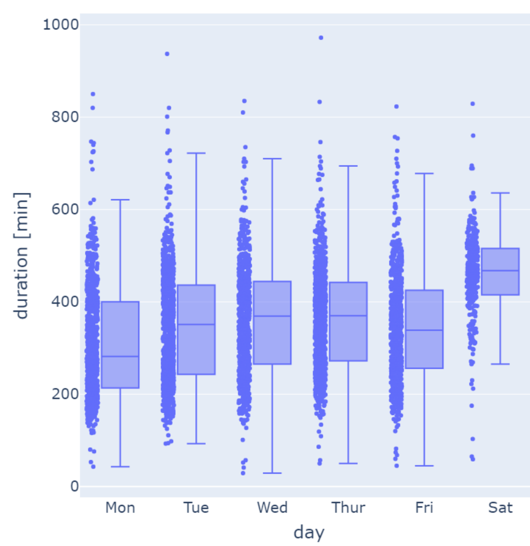

FIGURE 7: d) duration per tour

Fig. 4 to 7: Analysis of *logiTopp* simulation: a) number of tours over week by CEPSP, b) distribution of parcels per tour, c) distribution of tour distance (6), d) distribution of tour duration (7).

median distance of about 22km. The distance increases on Saturdays when much fewer parcels are picked-up or delivered, resulting in a less dense distribution of transport demand and hence, more extended tours. According to the duration of tours, similar results are observed. However, the increase on Saturdays is much stronger. Facing the lowest parcel density on this day and consequently relatively more geographically diverse stops, this is expected. The simulated distance per

	Private Parcel Model	Integrated Model: Effect of		
	vs. Integrated Model	contracts	distinct pick-up tours	tour allocation heuristic
tours	179.29%	-0.30%	1.24%	-16.12%
stops	84.11%	-20.17%	5.60%	-0.20%
stops/tour	-32.88%	-19.80%	4.42%	13.71%
parcels	196.30%	0.00%	-0.05%	-0.15%
parcels/tour	8.02%	0.30%	-1.30%	13.75%
parcels/stop	60.94%	16.78%	-5.98%	0.04%
deliveries	76.78%	-0.01%	-0.08%	-0.26%
deliveries/tour	-35.55%	0.30%	-1.33%	13.66%
deliveries/stop	-3.98%	16.78%	-6.02%	-0.06%
pick-ups		0.00%	0.00%	0.00%
pick-ups/tour		0.30%	-1.25%	13.88%
pick-ups/stop		16.78%	-5.94%	0.20%
distance [km]	167.46%	-1.50%	12.45%	-16.62%
distance [km]/tour	-2.49%	-1.19%	11.36%	-0.43%
duration [min]	117.38%	-13.72%	8.13%	-2.25%
duration [min]/tour	-20.75%	-13.38%	6.98%	11.94%

TABLE 2: Comparison of relative changes in tour characteristics between integrated model results and i) only private household parcel model as well as ii) scenario variations of the integrated model

tour is considerably small. The comparatively small study area can explain this effect. All CEPSPs typically service a greater area which would increase the distance traveled per tour. However, focusing on the urban area of Karlsruhe leads to dense demand points and, consequently, shorter distances between stops. Moreover, the distribution center of DHL, the major CEPSP in Germany, is located centrally in Karlsruhe. So, access and egress to and from this distribution center is also short.

We further analyze the effect of the integration of delivery and pick-up of establishment parcels on the model results compared to when only the delivery to households was considered. Therefore, we compare both simulation runs regarding selected tour metrics and show the relative deviations between the simulation results of the integrated model compared to the model reflecting only private parcels in the first column of Table 2.

The integration of establishment parcels nearly triples the number of transported parcels. However, the number of tours increases slightly less. This is because almost 8% more parcels are transported on each tour than when only private parcels are delivered. Due to the higher average parcel volumes of an establishment compared to households, a higher concentration of stops occurs. Overall, 60% more parcels are delivered/picked-up per stop compared to only private parcels, while the number of stops per tour is 33% lower. The total mileage and tour duration increase due to the larger number of tours. However, per tour, the mileage decreases slightly while the duration decreases considerably due to the reduction of the number of stops per tour. These results indicate that disregarding establishments in urban CEP movement models massively underestimates the number of CEP tours and, consequently, the overall mileage traveled. As certain tour metrics do not scale linearly with the overall parcel demand, models are required to simulate these effects.

Moreover, we investigate the effect of establishment-specific characteristics, namely the consideration of contracts between CEPSPs and establishments, the consideration of distinct pick-up tours for establishments parcels, and the depiction of drivers' implicit knowledge in the tour planning by applying the tour allocation heuristic, on the overall simulation results. In three scenarios, we compare - ceteris paribus - the simulation results when a) no contracts are applied, b) no separate parcel pick-up tours are applied, but parcel pick-ups are integrated with delivery tours, and c) route-first cluster-second optimization is applied for tour planning. The results are shown on the right of Table 2 as relative deviations towards the presented integrated model.

Since the scenarios leave the overall parcel quantities untouched, the number of delivered and picked-up parcels remains constant. Slight fluctuations are observed for delivered parcels due to varying delivery success rates of private parcels.

While the *consideration of contracts* has a negligible impact on the overall number of tours, it leads to a remarkable consolidation of stops. The number of stops per tour reduces by about 20%, and the number of parcels per stop, whether for delivery or pick-up tours, increases compared to when no contracts are modeled. Due to fewer stops per tour, each tour lasts, on average, shorter. Contracts lead to a concentration of establishment parcels on fewer CEPSPs. Consequently, each CEPSP faces denser parcel demand patterns leading to more efficient tours.

Surprisingly, the *consideration of distinct pick-up tours* rather than mixed delivery and pick-up tours only slightly increases the overall tour number. However, the stops per tour increase as pick-up and delivery cannot be done simultaneously, explaining why the number of parcels per stop decreases with separate tours. However, distinct pick-up tours increase the total mileage and duration traveled per tour, which the higher number of stops per tour may cause. Based on this finding, from a transportation perspective, mixed tours should be used to reduce the overall mileage traveled. However, for CEPSPs, distinct pick-up tours are more suitable for operational reasons.

The tour allocation heuristic for *considering the drivers' implicit knowledge* reduces the overall number of tours by 16% while increasing the number of stops per tour. According to other metrics, this is mainly driven by a generally higher number of picked-up and delivered parcels per tour. While the mileage per tour slightly decreases, the duration per tour rises by about 12% caused by more stops. The heuristic proposes a more efficient tour planning than the route-first cluster-second approach based on the stronger focus of parcel-to-tour allocations within TAZs and nearest TAZs. However, a more detailed review of different tour planning procedures is necessary as these modeling decisions greatly influence the simulation results.

CONCLUSION

Parcel shipments to and from establishments comprise much of the total parcel volume in the CEP market. Establishments order online, and many parcels from online orders are also dispatched from establishments. Nevertheless, existing freight demand models often do not consider these shipments explicitly. However, in this study, we could develop a feasible, modular, open-source, and agent-based modeling framework for parcel shipments to and from establishments. Although data availability of establishments' parcel shipments poses challenges when developing such a framework, the model can simulate the disaggregated level of parcels over a simulation period of one week. The approach is based on open data and is further integrated into the existing modeling framework *logiTopp* comprising parcel deliveries to households. This allows for a comprehensive analysis of the transport-related effects caused by the CEP market.

Applying the modeling framework to the example of Karlsruhe, Germany, shows overall reasonable results. Although restrictions in the data granularity apply, parcel quantities and their geographical distribution delivered to and picked-up from establishments are realistically reflected. The simulation results emphasize the necessity of considering establishments' parcels in such models. If only deliveries to private households are considered, the overall number of tours and hence, the transport-related effects of CEP shipment are massively underestimated. Further, the results indicate that existing model approaches for household deliveries cannot be applied to establishments without restrictions. Specifics of this segment, such as carrier contracts between CEPSPs and establishments or distinct pick-up tours, must be respected, as these influence key tour metrics. Moreover, the study stresses the requirement of a simulation period of one week as tour numbers vary greatly throughout the week.

Although the results appear generally reasonable, further research is needed to generate a well-funded empirical database of establishments' parcel shipments and tour characteristics of CEPSPs to calibrate the model with observed data and further enhance model functionality. Moreover, the study could identify a noticeable influence of the selected tour planning algorithm on the key tour metrics. Therefore, an in-depth analysis of several algorithms is necessary, along with comparing tour planning procedures used by CEPSPs.

AUTHOR CONTRIBUTION STATEMENT

The authors confirm contribution to the paper as follows: study conception and design: L. Barthelmes, M.E. Görgülü, J. Kübler, M. Kagerbauer, P. Vortisch; analysis of results: J. Kübler, L. Barthelmes; interpretation of results: L. Barthelmes, J. Kübler, M.E. Görgülü; model concept: L. Barthelmes, M.E. Görgülü, J. Kübler; model implementation: J. Kübler; draft manuscript preparation: L. Barthelmes, M.E. Görgülü, J. Kübler. All authors reviewed the results and approved the final version of the manuscript.

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