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Integrating establishments in an agent-based modeling framework for urban parcel shipments on the first and last mile

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Abstract

In recent decades, there has been a substantial increase in courier, express, and parcel (CEP) shipments. 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, freight demand models are used. 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 first model prototype is developed and integrated into the existing parcel demand model logiTopp. All integrated modules are based on open data sources and expert interviews with CEP service providers. The framework simulates on a parcel level over a simulation period of one week and is made available as an open-source project. 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 establishments' 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

1. 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, further stressing urban road infrastructure and intensifying emissions exposure. Studies forecast a continuation of the steady growth of parcel volumes due to further growth in e-commerce activities [5] and a

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general shift towards higher-value but smaller-volume goods (see [9] based on empirical data provided by the Bureau of Transportation Statistics and the U.S. Commodity Flow Survey from 2012). Therefore, establishments can resort more often to the services of CEPSPs instead of being forced to use dedicated freight forwarders. Hence, along with the trend of urbanization, transportation effects caused by CEP shipments are expected to intensify.

To examine the effects of urban freight movements and to evaluate possible alternative concepts in terms of more sustainable city logistics, freight demand models are used. Fostering more detailed studies of complex freight transport systems, microscopic, agent-based modeling approaches are suggested. Although there has been great progress in the development of agent-based urban freight demand models in the past two decades, the overall CEP segment has been insufficiently addressed. One of the first such models is *GoodTrip* [6], enabling the assessment of supply chain interactions to evaluate the impact of urban freight transport. However, the commodity-based approach focuses on freight movements in general without further considering households as receivers or CEPSPs as carriers, similar to other approaches. Hunt and Stefan [8] propose a trip-based model simulating freight movements to establishments, but also without explicitly considering CEPSPs as carriers. Roorda et al. [17] present the commodity-based conceptual modeling framework *FREMIS*, which allows the explicit consideration of CEP shipments. However, it is a framework only and not implemented.

Nevertheless, several recent models incorporate CEPSPs explicitly in their models. Sakai et al. [18] propose the commodity-based modeling framework *SimMobility Freight*. While several transport service types are incorporated, the authors focus on freight relationships between establishments and ignore households as receiving agents. Moreover, parcel shipments are modeled incidentally while focusing on freight in general. Based on their rich empirical foundation, *CRISTAL* [20] and *MASS-GT* [7] form similar approaches. However, *CRISTAL* only considers parcel shipments produced by private households, while establishments' parcel demand is neglected. *MASS-GT*, similarly to most other approaches such as the application of Llorca and Moeckel [12] in *MATSim* [19], simulates CEP shipments based on weight commodity flows rather than the number of parcels, which is, in the CEP segment, the more decisive factor for tour formation. To the authors' knowledge, *logiTopp* [16] is the only urban freight model that simulates on the level of single parcels. However, the model is currently limited to households as recipients.

The literature shows that microscopic, agent-based freight demand models have started to consider CEP shipments only recently. If so, besides few exceptions, CEP shipments to households are focused. Still, shipments to and from establishments remain mainly disregarded, even though those shipments account for nearly 40 % of the overall CEP market, e.g., in Germany [5]. Moreover, 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, 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 period of one week is necessary to reflect differences between weekdays and weekends, i.e., Saturdays, and the consideration of repeated unsuccessful delivery attempts.

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. 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 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 present results gathered in expert interviews with CEPSPs and introduce the private household parcel model *logiTopp*. Second, we explain the model concept and its first prototype implementation in *logiTopp*. Third, we apply the integrated modeling framework and show the simulation results. Finally, we elaborate on the specifics of CEP shipments to and from establishments and give a conclusion.

2. Modelling Framework for establishments' parcel delivery and pick-up

Based on the literature review and expert interviews with CEPSPs, we developed an integrated microscopic, agent-based modeling framework for explicitly simulating CEP shipments to and from establishments within *logiTopp*. Before presenting the framework in this chapter, relevant results of the expert interviews are introduced, followed by a brief introduction to the current *logiTopp* framework.

2.1. Expert interviews with CEPSPs

To better understand the structural patterns of parcel deliveries to and pick-ups from establishments, four expert interviews with leading German CEPSPs, namely DHL, Hermes, UPS, and FedEx, were conducted in spring 2022. 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. We will only focus on aspects relevant to this study and refer to Barthelmes et al. [2] for additional details.

A key finding from the interviews is that retail establishments, but also other commercial facilities, experience a peak in parcel pick-ups at the beginning of the week, driven by individuals' increased e-commerce activity over the weekends. From the middle of the week, the peak decreases to a constant proportion for the rest of the week. Parcels are also sent out on Saturdays, though the volume is much lower due to the weekend rest of many establishments. This initial spike in pick-ups results in a corresponding rise in deliveries to households mid-week. In contrast, according to the interviews, establishments show a constant ordering behavior. Hence, they receive parcels evenly throughout the week, except for reduced volumes on Saturdays. The distributions of establishments' parcel deliveries and pick-ups and household parcel deliveries obtained in the expert interviews are shown in Table 1.

Table 1: Distribution of parcel quantities throughout the week obtained from expert interviews

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sum
Parcel pick-up from establishments	23%	21%	18%	16%	17%	5%	100%
Parcel delivery to establishments	19%	19%	19%	19%	19%	5%	100%
Parcel delivery to private households	10%	25%	25%	20%	10%	10%	100%

In contrast to households, establishments primarily enter into contracts with CEPSPs, ensuring their regular parcel shipments are transported at specified times and prices. According to the interviewees, these contracts are less formal than typical agreements. However, they still create a relationship with a CEPSP, also indicated by an establishment survey in Berlin, Germany [21]. Another relevant finding is that establishments' outgoing parcels are usually picked up in separate tours, while deliveries are combined with those for private households. Additionally, the interviewees revealed that their drivers typically ignore the tour optimization software provided. Experienced drivers, in particular, assume that they know their delivery area implicitly better and don't give credit to optimization software. This may explain the reported delivery success rate of about 100% for establishments, as drivers typically adapt their routes based on the expected recipients' availability.

2.2. Existing last-mile private household parcel demand model logiTopp

Our work is based on the agent-based private parcel model *logiTopp* [16], which is an extension of the agent-based travel demand model *mobiTopp* [13]. Hence, it allows interaction with private travel demand. *logiTopp* already fulfills many required preconditions to reflect establishments' CEP shipments that have been defined in the previous section. First, its simulation period is one week, allowing to consider fluctuations in shipped parcel quantities during a week, as indicated in Table 1. Second, *logiTopp* uses parcels as the smallest logistical unit rather than general good flows, ensuring the ability to simulate alternative shipment solutions with small-volume transport vehicles reliably.

Third, *logiTopp* is available as an open source project on GitHub [11], making it suitable to adapt and ensuring its transferability in future applications.

However, currently, *logiTopp* only considers private parcel recipients that are served by CEPSPs. Therefore, in the following, we extend *logiTopp* by CEP shipments to and from establishments and present the newly integrated modeling framework. *logiTopp*'s model structure is aligned with *mobiTopp* and, hence, consists of a long-term and short-term module. In the long-term module, the weekly private parcel demand is modeled for each agent in *mobiTopp*'s population. 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 across all possible delivery days. For this, inverse transform sampling is applied. 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 [4]. The tours are finally processed considering the chosen delivery types.

2.3. 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 modeling 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 1 illustrates the extended modeling framework.

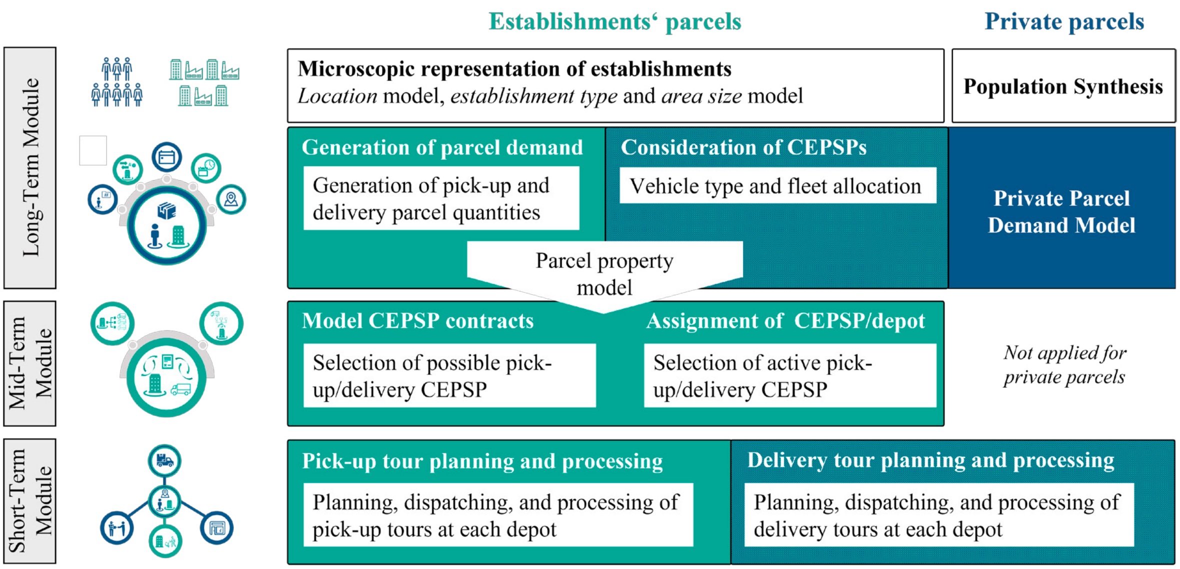

Fig. 1: Modeling framework for establishments' delivered and picked-up parcels and its integration into logiTopp

Analogous to the population synthesis, the model extension is based on a microscopic representation of all establishments within the study area. This includes the depiction of each establishment's geographical location, its sector classification, and area size. All this information is gathered from the open data source *OpenStreetMap (OSM)* [14]. Hereby, we extract establishment objects from OSM based on relevant feature variables using 'Osmosis'. 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*. All objects undergo geographical preprocessing using *ArcGIS*. Hereby, establishments are allocated to their corresponding travel analysis zone (TAZ) in the respective modeling framework. 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. [1] for further details of the method and its application.

Within the *long-term module*, the transport demand side required by establishments is added. In contrast to the current version of *logiTopp*, 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. Aiming at an open-source approach, we use literature-based data presented in the study of Thaller et al. [21]. Based on a representative survey among 431 establishments in Berlin, Germany, in 2018, the study provides information about the annual distribution of delivered and picked-up parcel quantities per sector. For the parcel generation models, we replicate these distributions and apply them to all establishments, resulting in two ordered vectors for each sector, one for delivered and one for picked-up parcel quantities. The vectors are broken down into weekly quantities and are aligned with the overall CEP market evolution based on [5]. 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. Further details on the parcel generation model for establishments are given in Barthelmes et al. [1].

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. However, with the development of this framework, an additional parcel property model is added, determining a parcel's size out of the four classes *S, M, L,* and *XL*. The model is based on empirical observation and is necessary to account in more detail for the appropriate transport capacity as establishments typically send or receive more parcels than private people. For further details, we refer to Barthelmes et al. [3]

The implementation of the transport supply side is adapted from the current version of *logiTopp* that 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/from establishments.

Newly integrated into *logiTopp* 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 on which day. For private parcels, the distinct CEPSP is chosen based on market shares. The delivery day choice is adapted from an even distribution to the distribution presented in Table 1. However, the expert interviews showed that establishments typically have contracts with one or more CEPSPs, restricting the possible choice set of CEPSPs for each establishment. Therefore, we integrate a two-stage CEPSP contract model, determining the number and set of possible CEPSPs able to deliver or pick up parcels to/from each establishment.

Similarly to the procedure described for the parcel generation model, the number of possible CEPSPs with whom an establishment can have a relationship is determined based on a replication of sector-wise distributions of potential contract partners provided in [21]. 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. [10]. 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 Table 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 principle logic of *logiTopp*'s tour planning and processing is adopted. However, according to the expert interviews, tour planning is often less optimized and based on the drivers' implicit knowledge. Hence, instead of the existing optimization procedure, we develop and integrate an allocation heuristic for parcels to tours based on travel times between TAZs. In contrast to the existing route-first cluster-second procedure, the heuristic considers an explicit locality criterion to ensure that a driver first includes all parcels of a TAZ in his tour and, if capacity is still available, includes parcels from the next closest TAZ. The heuristic accounts for a delivery success rate of 100% for establishments. However, the modeling framework also considers parcels 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. All extensions are integrated into the modeling framework *logiTopp* and made available as an open-source project on GitHub [11].

3. 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 17 km in north-south direction and 19 km in west-east direction. Within the *logiTopp* model, about 300,000 agents are depicted in the population synthesis. 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 [15]. For each CEPSP's distribution center, a fleet is integrated containing solely 3.5 t light-commercial vehicles (LCV) that carry up to 150 parcels. The fleet size is aligned with real fleet sizes provided by local CEPSPs and according to their market shares.

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 [5].

Moreover, we also checked for the geographical distribution of parcel shipments, which showed reasonable results, e.g., with a higher parcel density in retail or residential areas. 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 aligns with empirical data provided by Thaller et al. [21]. However, the distinct constitution of choice sets cannot be validated as no data is available.

Selected results of the simulation of the short-term module over one week are presented in Figures 2 to 4. They are based on one simulation run. No disaggregated comparative calibration data is available for the study area, so the results are tested for internal plausibility and interpreted below. According to the extended modeling framework, contracts between CEPSPs and establishments as well as distinct pick-up tours are considered in the simulation. Moreover, the simulation results are based on the newly developed parcel-to-tour allocation heuristic reflecting the drivers' implicit knowledge about their service area.

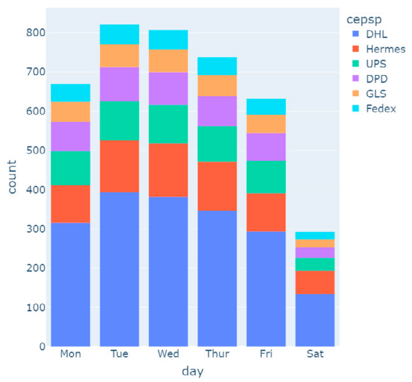

Fig. 2: a) number of tours

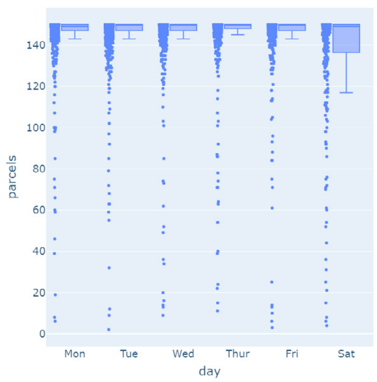

Fig. 3: b) parcels per tour

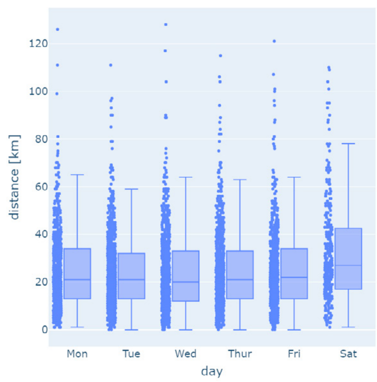

Fig. 4: c) distance per tour

Fig. 2 to 4: Simulation results: a) number of tours over a week by CEPSP, b) distribution of parcels per tour, c) distribution of tour distance

Figure 2 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 Table 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 reduced parcels needing to be transported. 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, Mondays are the first day of the simulation, and, hence, no parcels are considered that failed the delivery attempt to a household. The distribution of tours among different CEPSPs meets the corresponding market shares.

Moreover, Figure 3 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 LCV. On Saturdays, greater variations are observed. 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. However, the number of parcels is only one indicator of a tour's loading degree. Due to different parcel size classes, also the available transport capacity in terms of volume is considered, further limiting the maximum parcel number per vehicle in some cases.

In Figure 4, the distance in kilometers traveled in each tour is depicted. Although the number of tours varies between the weekdays, the distribution of traveled distance per tour on weekdays stays stable, with a median distance of about 22 km. The distance increases on Saturdays when much fewer parcels are picked up or delivered, resulting from a less dense distribution of parcel demand and, hence, more extended tours. The simulated distance per tour is considerably small explainable by the comparatively small study area. 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. Unfortunately, the interviewees couldn't provide tour length parameters for tours within the urban area of the study area, preventing a further validation of the simulated average tour length.

We further analyze the effect of the integration of delivery and pick-up of establishments' parcels on the model results compared to when only the delivery to households was considered. For this purpose, 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 establishments' 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 establishments compared to households, a higher concentration of stops occurs. Overall, 60 % more parcels are delivered/picked up per stop, while the number of stops per tour is 33 % lower. The total mileage increases due to the larger number of tours. However, per tour, the mileage decreases slightly. 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. As pick-up tours only apply to establishments, a comparison to the private parcel model cannot be made.

Moreover, we investigate the effect of establishment-specific characteristics, namely the consideration of contracts, distinct pick-up tours for establishments' parcels, and the depiction of drivers' implicit knowledge in the tour planning, on the overall simulation results of the integrated model. 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. Contracts lead to a concentration of establishments' parcels on fewer CEPSPs. Consequently, each CEPSP faces denser parcel demand patterns, leading to more efficient tours.

Table 2: Comparison of relative changes in tour characteristics between integrated model and different model specifications

	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 %

Surprisingly, the *consideration of distinct pick-up tours* only slightly increases the overall tour number. However, the number of stops per tour increases as pick-up and delivery cannot be done simultaneously, explaining why the number of parcels per stop decreases with separate tours. Moreover, distinct pick-up tours increase the total mileage per tour. Based on this finding, from a transportation perspective, mixed tours should be preferred 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. Also, the mileage per tour slightly decreases. 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 a TAZ and its nearest TAZs. However, a more detailed review of different tour planning procedures is necessary as these modeling decisions greatly influence the simulation results.

4. 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. In this study, we developed a first prototype of 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. It is integrated into the existing modeling framework *logiTopp*, allowing for a comprehensive analysis of the transport-related effects caused by the overall CEP market.

Applying the modeling framework to the example of Karlsruhe, Germany, shows reasonable results. 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 shipments 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 significantly throughout the week.

Still, further research is needed to generate a well-funded empirical database of establishments' parcel shipments and tour characteristics of CEPSPs to better calibrate the model. Furthermore, the prototype model's functionality could be enhanced with more detailed data. Generally, more simulation runs with different starting random numbers need to be performed to further validate the results. 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.

5. Acknowledgments

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