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Modeling Relations Between Companies and CEP Service Providers in an Agent-Based Demand Model using Open-Source Data

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Abstract

Growing e-commerce activities cause an equally rapid rise in demand for courier, express, and parcel (CEP) transportation, resulting in increased emissions and substantial strain on the road infrastructure, especially in urban areas. Therefore, transportation planners investigate the potential of alternative concepts for parcel and freight transport. Commonly freight demand models are used, however, current models for CEP-based transportation typically focus on private parcel demand. In this paper, we extend the integrated agent-based model logiTopp of last-mile parcel delivery and private travel demand by introducing company agents and, consequently, first-mile deliveries. We present a concept for modeling (the number of) relations between companies and carriers, as these relations highly influence the resulting travel demand in the survey area. Along with implementation techniques, we provide a greedy algorithm to estimate these carrier relations, which takes carrier market shares, customer parcel demand, and carrier capacity into account. All developed model components are solely based on open-source data.

Keywords: Type your keywords here, separated by semicolons ; agent-based; urban freight; travel demand; last-mile delivery; carrier contract; carrier selection

1. Introduction

With the steady increase in parcel volumes, which is mainly driven by the growing importance of e-commerce activities, one can observe an equally rapid expansion of parcel shipments by courier, express, and parcel service providers (CEPSPs). Especially in urban areas, the hereby-induced traffic intensifies the already existing space conflicts and the emission of greenhouse gases and other pollutants, diminishing the quality of living in cities. Hence, transportation planners analyze the potential of establishing alternative delivery concepts to reduce the transportation-related impacts caused by parcel shipments. For this purpose, freight demand models are commonly used, which can

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be aggregated or disaggregated. Although the latter requires a vast amount of data that is often not easy to obtain, disaggregated approaches have the power to map relevant relationships, while aggregated models either map less accurately or not at all. In the recent past, disaggregated freight demand models such as MASS-GT [3], MATSim Freight [19] or SimMobility Freight [18] have become an established tool.

Still, when focusing on CEP-based parcel shipment to and from companies - in the following also called consumed (delivery) and produced (pick-up) -, an analysis of current state-of-the-art freight demand models shows that relationships between companies and CEPSP are often neglected, and parcel shipments are performed by a randomly assigned carrier. However, Barthelmes et al. [1] have found in expert interviews with leading CEPSPs that contracts play a relevant role in the case of commercial customers 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 while minimizing the dependence on just one CEPSP. Nevertheless, some agent-based approaches exist addressing and modeling the relationships between companies and CEPSPs.

Cavalcante and Roorda [4] present the conceptual agent-based model FREMIS for modeling freight market interactions. They model producers and receivers and the commodity shipments between them. These shipments are bundled into contracts and they explore game theory approaches to determine equilibrium points in the market's commodity flow matrix. FREMIS applies a carrier selection model which incorporates carrier reputation and past experiences. A stated preference survey in the study region is suggested to obtain the data required to calibrate the model.

Sakai et al. [18] present SimMobility Freight, an extension of the agent-based travel demand model SimMobility, for evaluating logistics solutions. They break down annual commodity quantities into 'commodity contracts' between producing and consuming companies to specify contract size, shipment size, and frequency. They also apply a carrier selection model in case the producer's or consumer's fleets do not have enough capacity for all shipments. They assign randomly picked surplus shipments to third-party carriers. The carriers are selected by applying a multinomial logit model, which accounts for the supplier-carrier distance, the shipping volume, and carrier capacity.

Both approaches focus on modeling contract relations between companies; their carrier selection models do not impose contractual binding between producer and carrier. Moreover, they do not limit the number of carriers per company as observed in practice. This, however, is crucial when estimating the impact of company-carrier relations - either contractual or non-contractual - on the travel demand i.e. the resulting vehicle trips in the survey area. Whether the weekly parcel quantity of a company is served by two carriers or six has a huge influence on the number of redundant trips to that company. Hence over- or underestimating a company's number of carrier relations can lead to over- or underestimating the resulting travel demand and traffic load of the road network. FREMIS further requires microscopic survey data, which is scarcely provided as open-data and expensive to buy or collect on your own.

2. Data

Overcoming the lack of accurate data is a critical challenge in microscopic freight demand modeling. This kind of data is commonly considered highly confidential, hence research on freight data is limited. We approach the issue by merging data from the literature and OpenStreetMap (OSM) [13].

Although parcel consumption derived from companies accounts for one-third of the CEP market [2], it got mainly neglected in research contrary to private households' parcel demand. By rolling out an empirical survey in Berlin, Thaller et al. [20] analyzed the parcel consumption and production behavior of commercial recipients and their relations to CEPSPs. They addressed business establishments (including retail, gastronomy, and services) and administration facilities (e.g., research institutions, associations, and public administration units) while providing sector distributions based on primary data from 431 companies. For our survey area, which is serviced by the six major CEPSPs, namely DHL (48%), Hermes (16%), UPS (12%), DPD (10%), GLS (7%), and FedEx (6%), the corresponding market shares based on parcel volumes are provided by national market reports [14]. We learned from expert interviews that CEPSPs, which emerged from different markets and conditions, usually focus either on the private or the commercial sector. This implies that there are different market share distributions for both sectors. However, to the best of the authors' knowledge, no such detailed data is provided publicly. We aim to collect additional data to reproduce sector-specific market shares in the future. In this paper, we apply the overall national market shares as an approximation.

To model carrier contracts between companies and CEPSPs, a microscopic representation of all companies within a study area is necessary. Aiming at a transferable approach that can be easily replicated in other study areas, we developed a method based on the open data source OpenStreetMap (OSM) [13]. Based on the procedure described by Klinkhardt et al. [9], we first analyzed all feature variables available in OSM and elaborated relevant filters to identify company objects in OSM using 'Osmosis'. In total, after a partly manual pre-processing of the extracted data, 7,037 objects could be classified as companies within the designated survey area. Furthermore, based on their feature variables' values, all extracted objects are classified with their branch category according to the standardized NACE classification [5]. Moreover, a higher-level sector-based classification, namely *gastronomy*, *retail*, *leisure*, *service*, *industry*, and *administration*, was introduced, enabling a utilization with other data sources used in the study at hand.

To obtain a reliable representation of the companies, the extracted objects were compared with the sector distribution of the official registry and up-sampled according to the sectors. As an example, we extracted 1,944 *retail* objects from OSM, but in the official registry, 2,376 objects are reported. Hence, 432 missing objects were drawn from the OSM objects. By that, the objects were adapted sector-wise, resulting in a synthetic company data set representing the total number and sector distribution given by the official registry.

3. Methodology

3.1. Agent-Based Travel and Freight Demand Modeling Framework

For our research, we use and further develop the agent-based travel demand modeling framework *mobiTopp* [11, 12, 10] and its extension *logiTopp*. *mobiTopp* provides the means to model the private travel demand of a population and consists of two separate modules. The long-term module generates a synthetic population of individual person agents and their households and assigns each agent a workplace or educational site, a set of mobility tools like a driver's license, as well as an activity schedule for one week [6]. Decisions taken in the long-term module stay constant for the simulation period of one week. The short-term module simulates the planned activities and the intermediate trips for all agents simultaneously. This includes modeling the choice of destination and mode of transportation for each trip.

The extension *logiTopp* [16, 15, 10] allows to model the travel demand of last-mile parcel deliveries and its interactions with private travel demand. To model parcel deliveries, CEPSPs (carriers) and delivery agents were introduced as new agent entities. The agent-based approach of *mobiTopp* allows for modeling agent-agent interactions between private and delivery agents. The minimal shipping entity considered in *logiTopp* are parcels that can be grouped into deliveries. Information on a sub-parcel level, like the packaging of individual items, is out of the scope of the travel demand simulation of *logiTopp* as all underlying surveys were conducted on parcel level.

Before simulating the last-mile deliveries of parcels, the synthetic population's weekly demand for parcel deliveries must be determined. To do so, a parcel demand model (as shown in Figure 1) is applied to each private agent to determine the number of parcels they will receive during one week. Additionally, various parcel attributes are defined including the arrival day, a delivery type (home, workplace, and parcel locker deliveries), a CEPSP that delivers the parcel, and one of its depots where the parcel is stored before delivery. Reiffer et al. [17] developed a negative binomial generalized linear model based on a survey about e-commerce behavior, taking the socio-demographic attributes of a person into account to estimate the number of parcels they receive in one week. Based on the same survey, a multinomial logit model was developed to estimate the choice of delivery location (home, workplace, parcel locker). These models can be used to forecast the parcel demand of the population for different scenarios like the COVID-19 pandemic.

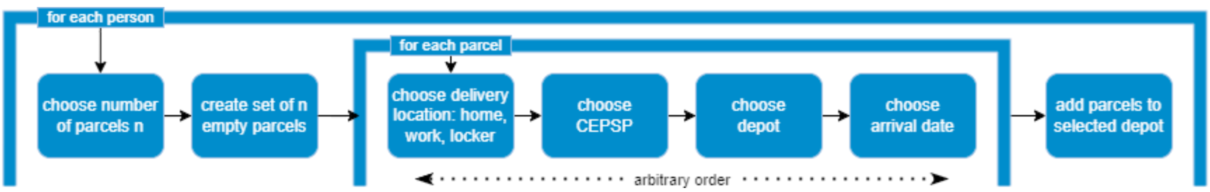

Fig. 1: *logiTopp*'s parcel demand model for private parcels fully taking place in the long-term module

In this way, the parcel demand and all parcel attributes are determined before the simulation of deliveries and travel demand. Private and delivery agents are simulated simultaneously during the short-term module, allowing for agent-agent interactions. As this paper focuses on modeling carrier contracts between companies and CEPSPs, we will omit the details of the last-mile delivery simulation process, which are already discussed in previous papers [16, 7].

3.2. Concept

For this paper, we further extended and developed the *logiTopp* module by introducing companies as an additional type of agent. Each company agent represents a single establishment at a specific site (i.e. geo-coordinate) with a branch category (NACE classification [5]), a sector (retail, hospitality, service, industry, administration, and leisure) as well as a building type. In contrast to private agents, companies can both receive (consume) and send (produce) parcels. Hence, this extension also introduces first-mile parcel deliveries from the producer to a CEPSP depot from where parcels are shipped into the world, thus leaving the scope of the simulated area.

Analogous to the parcel demand of private agents, an estimated weekly parcel demand is required for each company. Additionally to the estimated number of consumed (received) parcels, the number of produced parcels (shipped via CEPSP) must also be determined. The presented extension of *logiTopp* provides the means to model both the shipment of parcels via CEPSPs into the world outside of the simulated area as well as shipments directly to the recipient (company or private person) within the survey area using their own fleet. However, in order to investigate carrier contracts (or company-CEPSP relations in general), this paper will focus on company-CEP shipments in either direction. In the context of the logIKTram research project [8], a parcel quantity model for businesses was developed, the details of which will be the subject of future papers.

Private persons usually have only little influence on which CEPSP will deliver their parcels. Company customers, however, have contracts with one or more CEPSPs to ensure they can ship their produced parcels in time and for a specific price. Parcel deliveries to companies are usually not bound by contracts. However, Thaller et al. [20] observed varying numbers of CEPSPs for delivery of consumed parcels for different sectors as described in Section 2. Even though there may not be a formal contract, the findings still suggest a relationship between companies and CEPSP. Otherwise, companies would be serviced by any CEPSP at random. Furthermore, CEPSPs have different market shares in the private and commercial sector: e.g. a CEPSP that primarily focuses on private parcel deliveries can have a high market share in the private sector but a low market share in the commercial sector.

In this paper, we define carrier relations as follows: Each company agent has two fixed numbers of partners: one for receiving (consumed parcels) and one for shipping (produced parcels). These numbers are individual for each company agent and are based on the observed distributions by Thaller et al. [20]. The number of relations remains the same during the simulated period of one week. So each company has two sets of carrier relations (for receiving and shipping), and each set is a subset (with the respective size described above) of the full set of CEPSPs available in the survey area.

Due to the lack of microscopic survey data about carrier contracts and delivery relations, aggregated open-source data was used to model and calibrate the number of relations for each individual company. Thaller et al. [20] provides distributions for the sectors *service*, *retail*, *gastronomy*, and *administration*. The sectors *industry* and *leisure* were not included in their survey, therefore we assumed the average of the statistical key figures of the provided sectors. The market shares of the different CEPSPs are considered as presented in Section 2.

To model a company with e.g., n_s carrier contracts for shipping, n_s CEPSPs can be drawn from the set of all CEPSPs; not uniformly at random but rather weighted by market share in sector s. Additionally, the parcel quantity of the company at hand should be accounted for since companies with, e.g., a higher production volume also make a larger contribution to the market shares of the selected carriers. Effectively, only one of the carriers gets to process a given parcel, which creates a discrepancy between the estimated market share based on the chosen carriers (which is calibrated to match the actual market shares from the literature) and the effective market shares based on actually assigned parcels. Therefore, the CEPSPs' estimated capacity - their ability to process the assigned parcels - should also be considered as well when determining their CEPSP relations.

After determining the weekly number of produced and consumed parcels for each company as well as their CEPSP relations, further parcel attributes have to be defined for each individual parcel similar to the parcel demand model for private agents [16, 17]. The attributes arrival day (for shipping this means the day of production), CEPSP, and depot also apply to company agents and can be reused. However, the delivery type (home, workplace, parcel locker) is omitted; all company parcels are assumed to be delivered or picked up directly at the company site. Furthermore, a shipment size (small, medium, large) attribute is introduced.

The model determining the CEPSP that will deliver a given company parcel differs from the model for private parcels. The CEPSP of a private parcel is drawn from the full set of available CEPSPs weighted by market share of the private sector. For company parcels, this choice set is reduced to their individual set of related carriers. The carrier relation model described above takes an estimated capacity of the CEPSPs into account since the actual capacity at the time of shipment cannot be known beforehand. The actual parcel assignment to one of the carriers, however, must weight them according to their actual capacity to avoid overbooking and to achieve a realistic distribution matching the market share statistics in the short-term module. Unfortunately, it is only known during the delivery simulation and, thus, after the long-term module. The two decisions: 'carrier relation selection' and 'effective carrier selection' must take place at different time scales i.e. the long- and the short-term module, respectively. To be able to incorporate the actual capacity into this decision, the general structure of *logiTopp*'s parcel demand model has to be adapted.

4. Implementation

4.1. Incorporating Lazy Decisions

The current implementation of the parcel demand model in *logiTopp* assumes that all parcel attributes are determined in the long-term module and, thus, before the delivery simulation (see Section 3.1). However, it can be useful to determine certain attributes - like carrier relations or the desired delivery type of private parcels - dynamically during the short-term module to take the current state of the agents and their workload into account. Hence, the model should be able to handle parcels for which some attributes are yet undetermined at the beginning of the simulation; they will be computed dynamically at a later point during the simulation. In the following, parcels with such undetermined attributes will be called 'partially defined parcels'.

To achieve this, we refactor the structure of *logiTopp*'s parcel demand model by introducing lazy evaluation of attribute decision models. The refactored process is shown in Figure 2. The evaluation method of a model step to determine some parcel attribute *T* is called *select(*agent, *parcel): T*. It takes references to the company agent and the parcel to be shipped and returns a value of the respective attribute *T*. Attributes without lazy evaluation can be computed instantly by applying the *select* method with those parameters directly in the long-term module.

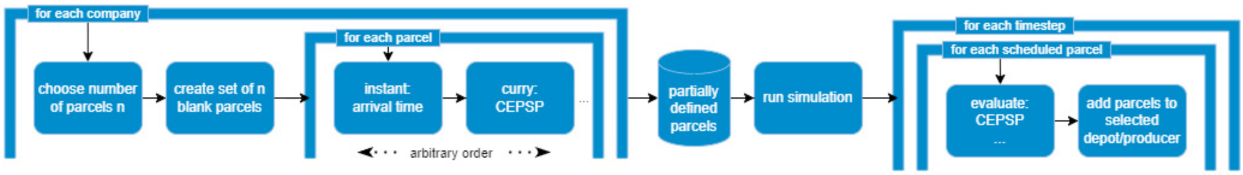

Fig. 2: The refactored parcel demand model for company parcels (cf. Figure 1): the long-term module (left for-loop) produces partially defined parcels (here with an exemplary lazy attribute: CEPSP); the missing attributes are determined dynamically in the short-term module (right for-loop)

For attribute decisions with lazy evaluation, however, we treat the evaluation method *select(*agent, *parcel)* as a function object and curry it with the two parameters: *agent* and *parcel*. This produces a curried function *curried_select* without arguments: *curried_select() := select.apply(*agent, *parcel)*. This curried function is stored in the partially defined parcel object to be evaluated later. In this way, the evaluation method is not applied in the long-term module but during the delivery simulation in the short-term module. The parcel- and agent-object references used for currying allows the evaluation method to access the current state of the parcel, the agent, and by reference also its related carriers at the time it is evaluated in the short-term module.

This means that parcels are only partially defined until all lazy attributes have been evaluated. A parcel may remain partially defined until it arrives in a depot (delivery) or is produced by the company (pick-up). At that point, all attributes need to be evaluated for the parcel to be processed further by the last-mile delivery model. Thus, the arrival date attribute must not be lazy as it defines the time in the simulation when a parcel's lazy attributes are evaluated.

Since the depot from where a parcel will be delivered might not yet be evaluated at the beginning of the short-term module, all partially defined parcels are temporarily stored in a virtual depot. This virtual depot manages a schedule containing the arrival dates of all contained partially defined parcels. Before each time step in the short-term module (*mobiTopp* uses 1 min steps), the schedule is checked for parcels due to arrive. All scheduled parcels are finalized by evaluating all their lazy attributes. Now that all attributes, including the depot, are determined. The now fully defined parcels can be moved to their respective depots or companies and processed further by the respective CEPSP.

4.2. Modeling Carrier Relations

The carrier relations of a company are selected in the long-term module after the parcel demand model has generated the partially defined parcels. Hence the parcel quantities of weekly production and consumption of each company are known. As described in Section 3.2, the selection of carrier relations should incorporate these demand quantities, the carriers' real market shares, and their capacity.

For this, we apply the greedy algorithm described in Algorithm 1. It keeps track of $weights \in [0, 1]$ as well as assigned parcel *amounts* for all carriers. Initially, the *weights* are set to the respective actual market shares of the CEPSPs and the estimated parcel *amounts* are set to 0. Then all companies are processed sequentially and their carrier relations are selected greedily.

As a first step, the number of relations n of a company agent a is drawn from the distribution (*distr*) matching the company's sector. Next, n CEPSPs are drawn from the full set of carriers C using their current *weights*. The estimated parcel *amounts* of the selected carriers can then be updated to include the *demand* of company agent a. In the short-term module, however, only one of the n related carriers is selected for each parcel. As described in Section 3.2, their capacity can be used to assign each of the n CEPSPs a relative share of company a's demand. Here we use the overall vehicle capacity of the CEPSPs' fleets to approximate their effective capacity during the delivery simulation. The *total* parcel amount is also increased by company a's parcel demand.

The updated *amounts* estimate the number of parcels the respective CEPSPs will process in the short-term module and therefore represent the estimated simulated market shares. Updating the *amounts*, however, may create a gap between the actual market shares and the estimated market shares. To counteract this gap, the *weights* of all carriers are updated for the next iteration. To do so, the difference between carrier c's *share* and c's current estimated *amount* divided by the current *total* is computed. If this difference is negative, the CEPSP c has currently surpassed its actual market share and should not receive further parcels in this iteration. Therefore, its weight is set to 0. Through the iterations, it is possible (and likely) that the CEPSP c's estimated market share will shift below the actual market share, so it is again available as a potential carrier for companies in later iterations.

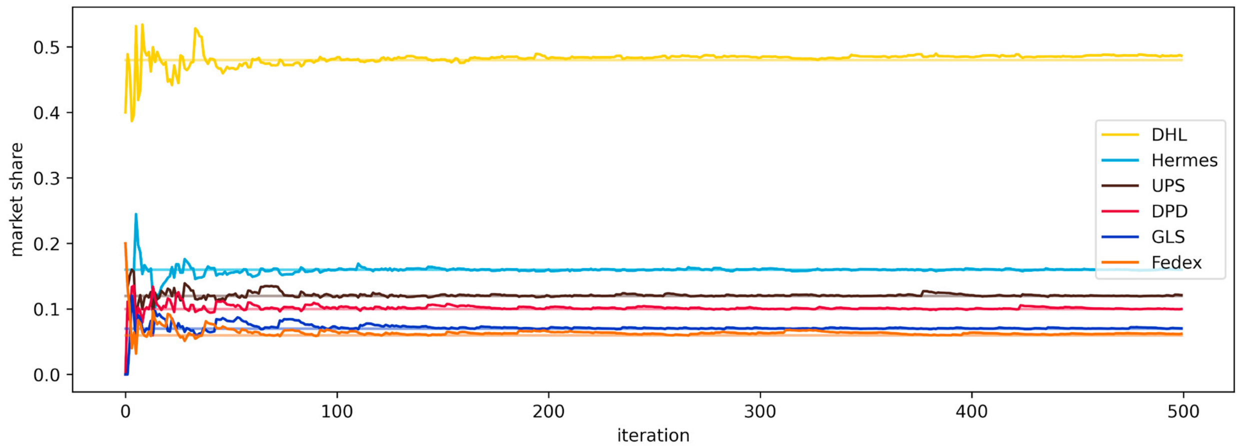

Fig. 3: First 500 iterations (of 15,366) of the greedy algorithm: the estimated market shares converge against the actual market shares (marked as transparent horizontal lines in the respective colors)

If the parcel demand per company is bounded, this greedy algorithm will eventually converge against the given actual market shares (see Figure 3). The presented algorithm can be applied both for selecting pick-up and delivery relations by providing the according distributions and parcel demands. Its run-time is in $O(|A| \cdot |C|)$ where the number of CEPSPs is significantly smaller than the number of companies and can be assumed to be constant.

Algorithm 1 A greedy algorithm for modeling carrier relations of companies

```
procedure SELECTRELATIONS(C: set of carriers, distr: #relations distributions by sector, A: set of company agents)
    total ← 0
    amounts ← ⟨c ↦ 0 | c ∈ C⟩
    weights ← ⟨c ↦ c.share | c ∈ C⟩                       ▷ initialize weights map with actual shares
    for all a ∈ A do
        n ← drawRandom(distr[a.sector])                     ▷ draw number of relations n for a
        P ← drawWeighted(n, weights)                        ▷ draw n carriers (weighted)
        capacitySum ← ∑_{p∈P} p.capacity
        for all p ∈ P do            ▷ add demand of a to selected carrier p scaled by relative capacity
            amounts[p] ← amounts[p] + (p.capacity / capacitySum · a.demand)
        end for
        total ← total + a.demand                            ▷ update total assigned demand
        for all c ∈ C do                 ▷ update weights as diff. of actual and expected share
            weights ← max(0, c.share − amounts[c] / total)
        end for
    end for
end procedure
```

4.3. Dynamic Carrier Selection

The delivery process is simulated in the short-term module. When the arrival time of a (partially defined) parcel is reached, its lazy attributes are evaluated. One of those lazy attributes is the carrier that will deliver (or pick up) the parcel to (from) the recipient. This CEPSP is selected from the previously determined contract partners. At the time of arrival, the current workload and remaining capacity of the partner CEPSPs can be evaluated. Therefore, we use the total sum of the vehicle capacities in the CEPSP's fleet and subtract the number of assigned parcel deliveries and requested pick-ups. The resulting remaining capacity can be used to determine the utility of the corresponding CEPSP.

After determining the utilities of all related carriers, a discrete choice model (e.g. multinomial logit) can be applied. Currently, a plain weighted random draw is used, where the utility function consists merely of the remaining capacity.

5. Results and Discussion

We applied our model to the study area of Karlsruhe, Germany. Karlsruhe is a city in the South-West of Germany with a population of just over 300,000 inhabitants. A total amount of 147,833 consumed parcels and 231,298 produced parcels were generated for 15,366 simulated company agents. The area is serviced by six different CEPSPs, of which one has three depots (DHL) while the others each have one.

We evaluate the long-term module by comparing the number of generated carrier relations (see 4.2) by sector with the distributions provided by Thaller et al. [20]. As shown in Figure 4 on the left (consumed parcels) and the middle (produced parcels), the results match the expected distributions for all sectors except for one: the long-term module does not generate a company with nine carrier relations for consumed parcels. This is because the model only contains eight possible relation partners; currently, each of the eight depots is considered an independent carrier. The estimated market shares produced by the relation selection model in the long-term module converge against the actual market shares given by [14] as shown in Figure 3.

Finally, we evaluate the effective market shares that result from the short-term module as shown in Figure 4 on the right. The results show that our model currently overestimates the market share of DHL, which is the only CEPSP with three depots and, at the same time, the one with the highest market share. The current implementation tends to disfavor those carriers with market shares even smaller than the individual depots of DHL in this example.

In future work, we aim to overcome this bias by grouping depots of the same CEPSP company and treating them as a single carrier. Moreover, dynamic carrier selection (see 4.3) in the short-term module is currently a provisional model that only incorporates the current carrier capacity. The model can be extended to a multinomial logit model with a more complex utility function in the future to include e.g. a previous selection bias.

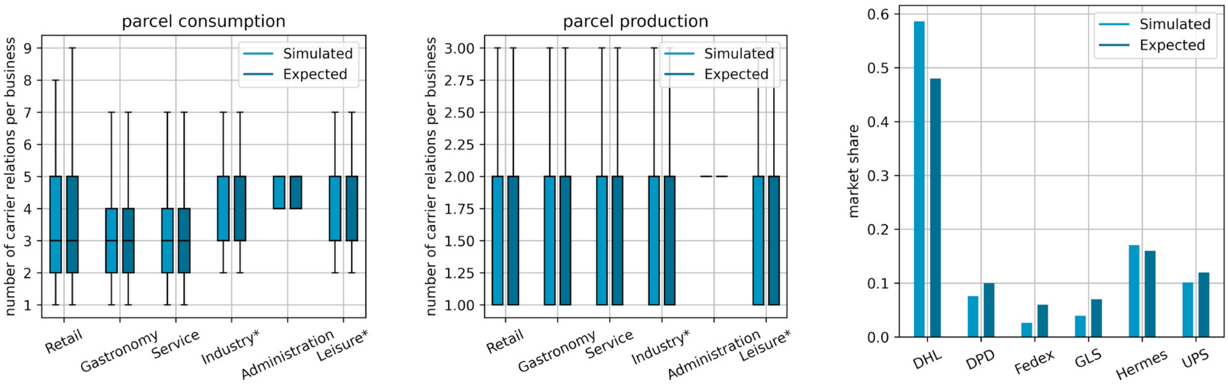

Fig. 4: Comparison of the simulated and the expected results: the distribution of the number of carrier relations (long-term module) by sector for consumed parcels on the left, for produced parcels in the middle, and effective market shares (short-term module) on the right

6. Conclusion

In this paper, we presented a concept for modeling general microscopic carrier relations between companies and CEP service providers. It provides the means to model carrier contracts for shipping produced parcels as well as the non-contractual relations for receiving parcels, which can both be observed in practice.

We extended the *logiTopp* framework by introducing company agents and presented how it can be refactored to implement our concept by using lazy evaluation. Our model was applied to a large model of a region in the South-West of Germany for evaluation. All model components are based on open-source data like OpenStreetMap, national market reports, or published research.

The presented iterative, greedy algorithm for matching carrier relations with given market shares shows good results as the modeled market shares quickly converge against the actual shares. The presented provisional decision model for determining a parcel's effective carrier shows promising results but still has room for improvement. Though, it is possible to reproduce observed carrier relations in large agent-based models by only using open-source data.

However, some approximations and assumptions had to be made due to the lack of available data. A more detailed evaluation of market shares of CEPSPs, more comprehensive OSM data regarding companies and a national company survey would further increase the accuracy of our model. Moreover, after obtaining this additional data, we plan to analyze the effects of the modeled relations in more detail. Especially the influence on the planned delivery tours and the resulting overall traffic could be determined by comparing model results with and without modeled relations.

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