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# Traffic impact on last mile parcel delivery with cargo bikes

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## Abstract

In the course of global warming, low-emission last mile delivery concepts are being discussed as alternatives to conventional concepts. Complementing the logistical perspective, this study evaluates the impact of surrounding traffic on parcel delivery with cargo bikes. We propose a scenario-based methodological approach including an agent-based, multimodal simulation analysis. The approach includes the identification of infrastructural potential for cargo bike route shortcuts as well as effects of provider-joint collaboration. Key findings from a use case in the city of Hamburg, Germany, show similar traffic impact on delivery with cargo bikes and vans according to simulation KPIs such as time loss and mean speed. However, significantly lower $CO_2$ emissions for cargo bike scenarios are observed as well as considerable synergy effects in collaboration scenarios.

*Keywords:* parcel delivery; last mile; cargo bikes; traffic impact; SUMO; white label logistics

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## 1. Introduction

Due to growing cities and thus urban traffic volumes, last mile delivery is gaining importance as part of the operational logistics planning horizon. According to Gevaers et al. (2014), last mile is regarded as one of the more expensive, least efficient and most polluting sections of the entire logistics chain. In terms of parcel delivery, last mile operations are usually covered by vans for capacity reasons, even in large cities. As they are prone to traffic implications and conventional vans have relevant $CO_2$ emissions, alternatives are being discussed.

As part of the real-world laboratory (RealLabHH, 2021) last mile parcel delivery with cargo bikes was tested in the city center of Hamburg, Germany. Since cargo bikes are more flexible and sometimes can use different parts of the infrastructure, they could be less affected by traffic-related impacts (e.g. traffic jams) on tour duration and reduce

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$CO_2$ emissions. On the other hand, they have a limited parcel capacity and lower maximum speed. Our work analyses these effects by means of agent-based microscopic simulation with SUMO (Lopez, et al., 2018).

Even though the concept of last mile delivery with cargo bikes has already been extensively studied, many studies focus on the aspect of logistical tour planning. The main contribution of this study is the consideration of surrounding traffic in different intensities and its impact on parcel delivery on an operational level. This is of great importance for urban parcel delivery operations and allows a deeper understanding of the correlation between traffic and different delivery concepts. Moreover, the study identifies traffic and network-related circumstances under which cargo bike delivery could be a feasible option for urban parcel delivery. Lastly, provider-joint operation is analyzed in regards to further synergy potentials.

## 2. Literature

Many studies evaluated the potential of cargo bikes for delivery concepts. Cairns and Sloman (2019) provide a summary of cargo bike simulation studies and real-world examples. Caggiani et al. (2020) and Leyerer et al. (2020) focus on the mathematical optimization and decision support systems. In regards of provider-joint delivery operations, Elbert and Friedrich (2020) conclude in a simulation study that full cooperation between service providers is promising from both an environmental and financial point of view.

Microscopic simulators allow detailed modelling of urban traffic (Codeca, et al., 2015). Some studies combined microscopic simulations with cargo bike delivery: Llorca and Moeckel (2021) reported that delivery duration increases with higher share of cargo bikes. Also, cargo bikes and feeder vans added extra distance compared to conventional delivery, but this effect decreased with higher share of cargo bikes. Melo and Baptista (2017) note that additional driving time is compensated by fuel savings.

Few studies analyze surrounding traffic in addition to logistical aspects of cargo bike delivery. Melo and Baptista (2017) considered traffic flows from surveys for the city of Porto. While replacing up to 10 % of vans with cargo bikes led to better traffic performance, higher shares increased delays in the network significantly. The advantages of bike routing in an urban environment are mentioned in several references: Logistic efficiency gains of cargo bikes can be explained by easier parking, shortcuts and driving through one-way streets according to BIEK (2017). Cairns and Sloman (2019) list case studies which show that cargo bikes may be able to undertake shorter, faster routes. Llorca and Moeckel (2021) note that cargo bikes are smaller, so they can ride on narrow streets more easily.

## 3. Methodology

Four different scenarios were defined as shown in Table 1 to compare cargo bike delivery to conventional parcel delivery and evaluate the effects of collaboration.

Table 1: Definition of scenarios including delivery vehicles and collaboration between service providers

| Scenario | Delivery mode | No. of vans/bikes | Collaboration |
|---|---|---|---|
| Van | Van delivery | 3/0 | No |
| Bike | Feeder vans and cargo bikes | 3/9 | No |
| Van collaboration | Van delivery | 3/0 | Yes |
| Bike collaboration | Feeder vans and cargo bikes | 3/9 | Yes |

In the bike scenario, a micro depot is supplied by feeder vans entering the simulation area from the entry point. Next, cargo bikes deliver parcels from the micro depot to end customer locations on the last mile. In the two van scenarios, vans enter the investigation area, distribute parcels to customers and leave the investigation area. In contrast to the bike scenario, there is no turnover at the micro depot. Moreover, the non-collaborative scenarios assume three competing parcel service providers, whereas the collaboration scenarios merge them to one large joint provider.

Customer locations were given by three sets of randomly picked edges in the delivery area representing three service providers. The number of delivered parcels and customer locations were chosen according to values from BIEK (2017). The number of parcels $n$ per location was drawn from the discrete probabilities given in Table 2.

Delivery vehicles stopped for a duration of $60\ s + n \cdot 60\ s$ at each customer location. For (un-)loading at the micro depot, a duration of 5 s per parcel was assumed. Vehicle parameters were derived from real world vehicles deployed by the service providers in the RealLabHH project. We assumed a maximum speed of 25 km/h for cargo bikes and a maximum parcel capacity of 200 for delivery vans and 60 for cargo bikes.

Table 2: Probabilities for different number of parcels per customer location

| Number of parcels | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Probability | 0.7 | 0.1 | 0.08 | 0.07 | 0.03 | 0.02 |

The microscopic software simulation package SUMO was chosen for this study as it enables multimodal and agent-based mobility analyses with a focus on urban areas. Since cargo bikes, vans and parcels are modelled as individual simulation agents, traffic implications such as congestions can be measured and evaluated at a detailed, individual level. Furthermore, SUMO allows to model bicycle infrastructure (Grigoropoulos, et al., 2019). This is needed to study the aforementioned advantages of bikes in urban areas.

Travel times between customer locations and depot were computed prior to simulation with a SUMO built-in routing functionality called duarouter. The resulting capacitated vehicle routing problem (CVRP) was solved with OR-Tools (Google, 2022). Without collaboration, one CVRP had to be solved for each of the three service providers. With collaboration, the three separate demand sets were pooled which resulted in a single but larger CVRP. In a last step, custom Python scripts created simulation input files (delivery trips, stops, setup files) depending on the scenario and CVRP solution.

### *3.1. Surrounding traffic*

Every scenario was realized in three different intensities of surrounding traffic to study the impact of traffic on delivery. We created this traffic with SUMO randomTrips. This script generates trips by assigning cars and bikes randomly chosen source and destination edges in the network. The time period between two consecutive trips defines the traffic intensity. Highest intensity as given in Table 3 was chosen so that the network could still handle the traffic flow without severe congestion for a sample of random seeds.

Table 3: Traffic intensities for random passenger car and bike trips

| Traffic intensity | High | Medium | Low |
|---|---|---|---|
| Passenger car period | 1.2 s | 1.5 s | 2 s |
| Bike period | 2.83 s | 3.55 s | 4.73 s |

As a further measure to avoid unrealistic traffic congestions, we excluded random seeds where mean time loss over all vehicles (delivery and surrounding traffic) exceeded 900 s, which is roughly twice the mean time loss at high traffic intensity of valid simulation runs. To reach a steady state, delivery vehicles entered the simulation after one hour of initial random traffic and left the simulation while random traffic was still ongoing.

For each traffic intensity (low/medium/high), a scenario was varied with 10 random demand seeds and with at least 10 random traffic seeds for each demand. More specifically, random traffic was varied through a loop of simulations until mean delivery duration stabilized over all simulation runs of a specific demand. Thus, we performed at least 300 simulations for each scenario.

## 4. Proof of concept

In order to proof the methodology described above, it was applied to a part of the very center of Hamburg, Germany. This urban area is characterized by high traffic intensity and dense population. For this reason, a total number of 163 parcels delivered to 98 locations was assumed according to tour classification “A” from BIEK (2017). The heart-shaped simulation area around the micro depot can be seen in Figure 1. The location of the micro depot is the same as in the real-world laboratory RealLabHH (2021).

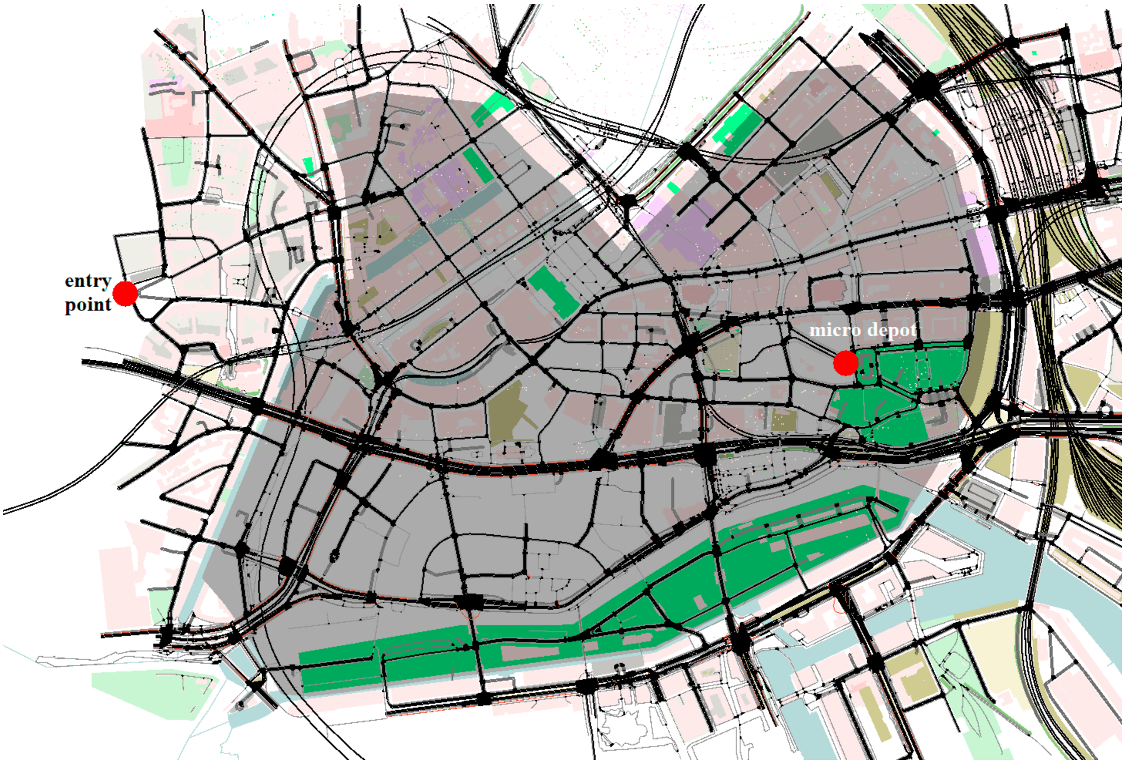

Figure 1: Heart-shaped delivery area (grey) and characteristic locations (red)

The network was imported from OpenStreetMap (OpenStreetMap, 2022) and converted into a SUMO network using a built-in SUMO functionality called *netconvert*. During conversion the option *netconvert --osm.bike-access* was applied to fix edge permissions for bikes. Finally, we corrected the network manually at crossings and connections to get a reasonable traffic flow.

### *4.1. Network routing analysis*

The street networks of bikes and vans are not completely overlapping, e.g. due to bike lanes or main streets without bike permission. This suggests that cargo bikes can take shortcuts in some cases. To identify the potential of shorter cargo bike routes, an N-to-N routing analysis between all possible customer locations in the delivery area was performed by means of the SUMO tool duarouter. The length of cargo bike and van routes was computed for each origin-destination pair (OD-pair).

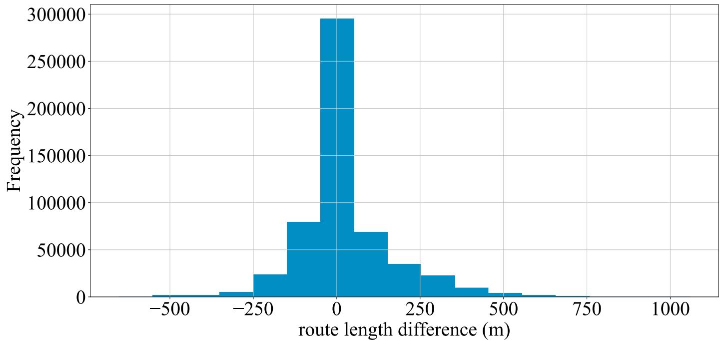

Figure 2: Shortcut potential of cargo bikes (positive values shorter for bike)

Differences in route length are plotted in Figure 2 as a histogram for each OD-pair. They vary between –653 m and +1059 m, where positive values mean shorter routes for bikes. The majority of tours have a similar length which is shown by the peak around 0 ±50 m route length difference. Roughly 30 % of the route lengths are exactly the same with bike and van. For around 40 % of the OD-pairs, bike routes are shorter. For the remaining 30 % OD-pairs, van routes are shorter (possibly due to left- or U-turns by bikes at complex intersections). On average, bike routes are 24 m shorter or 3 % compared to van tours, showing limited potential for shortcuts of cargo bike tours within the given infrastructure.

### *4.2. Time loss and travel speed*

As a next step, simulation runs were performed with SUMO version 1.12 for all four scenarios in order to analyze the impact of surrounding traffic on last mile delivery with cargo bikes. Two central KPIs in the context of traffic impact are time loss and travel speed. According to SUMO simulation output definition, time loss refers to the time lost due to driving below the ideal speed. For example, slowdowns due to intersections or congestions etc. will incur time loss, whereas scheduled stops do not count (DLR and others, 2022). The travel speed was calculated on the basis of the accumulated route length and tour duration without stopping time. The two non-collaborating scenarios “bike” and “van” are depicted in Figure 3.

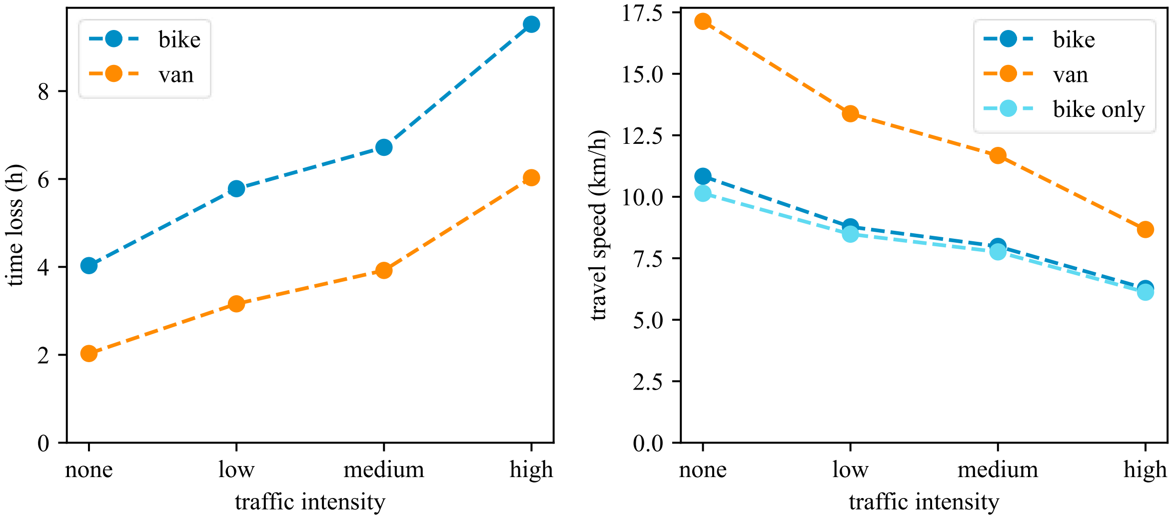

Figure 3: (a) Accumulated time loss; (b) travel speed for van and bike scenarios

Figure 3a shows a generally higher time loss in the bike scenario, independent of traffic intensity. This is expected as tour length is 15 % higher in the bike scenario. The higher tour length can be explained as follows: First, the bike scenarios include additional feeder tours by vans in order to supply the micro depot. Second, the cargo bikes have lower parcel capacities. For this reason, cargo bikes have more but shorter routes and each route has to start and end at the micro depot. This increases route length compared to fewer and longer routes starting directly from the entry point by vans. Since longer tours correlate with a higher probability of encountering congestions and intersections, higher time losses can be observed for the bike scenario. Furthermore, time loss significantly rises when intensifying surrounding traffic – both for bikes and vans.

Vehicle travel speeds are generally higher in the van scenario as shown in Figure 3b. With low traffic, vans can make use of their higher maximum speed. With increasing traffic intensity, the travel speeds of van and bike delivery slightly align and maximum vehicle speed has lower impact. Also, cargo bikes might be able to use different routes in the network and bypass highly congested areas. Overall, cargo bikes cannot reach the travel speed of vans even with high traffic. As the bike scenario involves both feeder vans supplying the micro depot and delivery bikes, Figure 3b additionally depicts the travel speed of delivery bikes within the bike scenario. The according curve shows that the alignment of travel speed between the two scenarios can be explained by the cargo bikes. The feeder vans slightly rise the average speed level of the bike scenario at low traffic but this effect decreases with higher traffic intensities.

### *4.3. Tour duration and collaboration*

Figure 4 shows the accumulated tour duration of all four scenarios. It can be seen that delivery by cargo bikes takes generally longer. This is justified by more kilometers traveled and reduced travel speeds as described above. Moreover, the bike scenarios have an additional turnover at the micro depot which accounts for an additional stop time of 80 minutes in total.

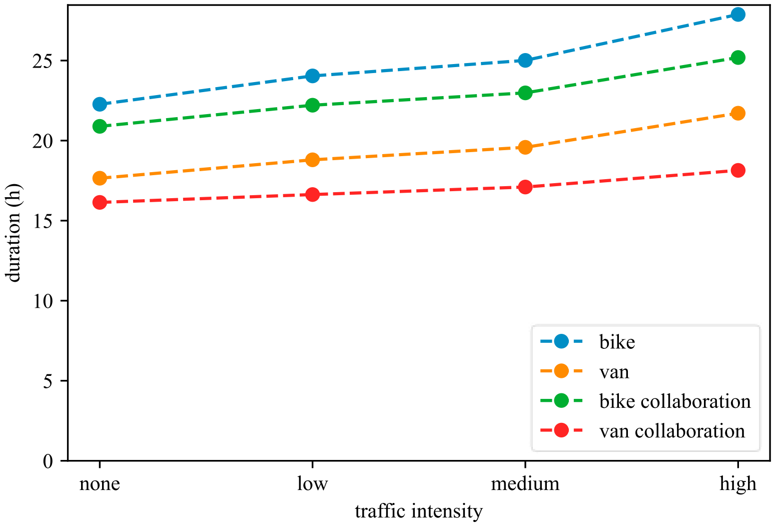

Figure 4: Accumulated tour duration per scenario

A further comparison of the beforementioned scenarios bike and van with their collaboration counterparts shows a significant reduction of tour durations in case of joint operation. This can be explained by synergy effects of collaborative tour planning, as no longer three different providers operate independently, but one large white-label provider operates jointly. Merging the demand allows to create tours with higher stop density which is beneficial for logistic efficiency. Due to far larger capacities, the collaborative van scenario can be identified as the best option in terms of tour duration. Furthermore, collaborative bike delivery narrows the gap to conventional van delivery in terms of delivery duration in comparison to separate bike delivery.

### *4.4. $CO_2$ emissions during driving*

CO2 emissions during driving were estimated for delivery vans with the light-duty vehicle (LDV) model used for delivery vehicles in SUMO (DLR and other, 2022) and based on HBEFA version 3 (HBEFA, 2022). They are significantly lower with cargo bikes as shown in Table 4. Furthermore, emissions naturally rise with higher traffic intensity. As no emissions were assumed for driving with electric cargo bikes, the small digits within the bike scenarios can be explained by the feeder vans. Depending on the source of energy, additional CO2 emissions for cargo bikes might apply.

Table 4: Accumulated $CO_2$ emissions during driving in kg

| Scenario/traffic | None | Low | Medium | High |
|---|---|---|---|---|
| Van | 130 | 138 | 143 | 157 |
| Bike | 15 | 18 | 19 | 21 |
| Van collaboration | 118 | 121 | 124 | 131 |
| Bike collaboration | 16 | 18 | 19 | 21 |

## 5. Discussion and future work

Since cargo bikes are more flexible than vans and can use different parts of the infrastructure, we assumed they could be less affected by traffic-related impacts. While this applies to travel speed, this could not be confirmed by accumulated tour duration where both cargo bikes and vans are affected in a similar way from increasing traffic intensity. Even though a network-related shortcut potential of cargo bikes was identified, the potential is limited and it does not necessarily represent the routes taken by the vehicles in the simulation. Our results show that cargo bikes have systematic disadvantages compared to vans due to reduced vehicle capacity and the additional turnover at the micro depot. In terms of collaboration between parcel service providers, new business concepts could aim at the identified benefits.

The limitations of this study are as follows: As all results are specific to the chosen infrastructure, outcome could vary given different infrastructure and traffic settings. Moreover, as described in section 3.1, the results are based on random variations of freight demand and surrounding traffic. This accounts for natural variations and it avoids picking a single demand or traffic seed which might benefit a specific scenario. However, both surrounding traffic and parcel demand are purely random and not based on counting data or demand modelling respectively. Another limitation is that we solely assumed tours to end customers (B2C). In a real-world environment, B2C parcels are often transported with B2B parcels on a tour, which might affect results.

We conclude that last mile delivery with cargo bikes implicates a high reduction potential in CO2 emissions at the expense of tour duration. In general, cargo bike delivery could be feasible for dense urban areas with good bike infrastructure and well-located micro depots. Looking beyond cargo bikes, electric vans could be an alternative for high load volumes, since they have similar logistic advantages as conventional vans and can be operated without emissions during driving. To support further research, we introduced a scenario-based methodology which is based on open source tools and transferable to other investigation areas. Next steps will be to consider a more realistic freight demand in the parcel segment. Also, the impact of parcel deliveries on surrounding traffic (e.g. on-street parking) can be examined. Furthermore, deployment planning can be integrated for evaluating the operability of tours and further deepen the understanding on how sustainable last-mile delivery concepts can succeed.

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