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Cargo bike simulation in urban hub strategies: the GLEAM use case for Rotterdam

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Abstract

This study presents an extension of an existing urban freight simulation model, with a cycling network model for the evaluation of city logistic policy scenarios involving cargo bikes. The purpose of the simulation is to provide indicators for the evaluation of bottlenecks in the bike lane infrastructure and from cargo bike parking on sidewalks. Simulation of cargo bike flows requires an explicit route choice behavior for cargo bike drivers, and sufficient detail in the zonal network connectors to have an accurate representation of trip ends. This paper presents the simulation results from the urban freight model with the integrated cycling network assignment. Two cargo bike network configurations were analyzed: single carrier hubs and open shared use for micro hubs. The results confirm a strong and varied impact on the emergence of bottle necks in the cycling network and the pressure of cargo bike parking in the city center.

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Keywords: City logistics; Cargo bikes; Micro-hubs; Simulation; Bicycle network assignment; Rotterdam

1. Introduction

Metropolitan areas have been focusing for a long time on active modes for more sustainable mobility. To defragmentize the B2C last-mile delivery streams, micro hubs are introduced as a possible solution as they can increase the consolidation of inner-city deliveries (Aljohani & Thompson, 2016). As per the definition of the Urban Freight

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Lab (2020), micro hubs are “logistics facilities inside the urban area boundaries where goods are bundled, which serve a limited number of destinations within a bounded spatial range and allow a mode shift to low (or zero) emission vehicles or soft transportation modes (e.g., walking) for last yard deliveries”. Micro-hubs are also an important component in ‘proximity logistics’: the development of logistics facilities in high-demand areas, which are essentially urban, dense and mixed-use (Buldeo Rai et al., 2022).

In Rotterdam and The Hague, the bicycle mode is promoted with better facilities and infrastructure. In the total mobility pattern (small) freight transport is addressed as well, supporting smart solutions like cargo-bikes or similar services. In this context it is relevant to analyze both the potential and impact of these cargo bike services on the local network. The GLEAM project use cases will be developed on the deployment of cargo bikes and micro hubs in the city. These use cases will consider logical city logistic services and business models that utilize cargo bikes for zero emission deliveries. Rotterdam will use inputs from recent projects such as Tour de Force (Government of The Netherlands, 2025), Living Labs (van Duin, et al., 2022), HARMONY (de Bok et al., 2024), existing stakeholder groups (Logistiek010) and new initiatives (HUB strategy for Rotterdam), to formulate promising scenarios.

However, the city of Rotterdam has a strong growing number of cyclists, and is facing overcrowding on cycle lanes, and over-utilization of bicycle parking in pedestrian areas. There is a need to be able to analyze the impacts of a micro-hub and cargo bike solution on the network performance, and pressure on urban space. In existing urban freight simulators, it is difficult to calculate the required indicators for this.

In this study we update the available urban freight simulation model, MASS-GT, and we extend it with a cycling network model for the evaluation of city logistic policy scenarios involving this mode. This network model offers good insights into the accessibility of destinations for cargo-bikes to evaluate the potential for these services, and direct demand can be quantified. The model is applied to a cargo bike and micro hub case study to explore the impacts of different scenarios on bottlenecks in the network and the parking pressure on public space.

2. Literature

An important factor for the success of micro hub implementation is the need to have public policy support (Kim and Bhath, 2019; Urban Freight Lab, 2020). Having clear and sound empirical indicators to evaluate urban freight policies, can help to provide important arguments to support more sustainable urban freight solutions. But in reality, the available data on urban freight demand is scarce and fragmented. Simulation models of urban freight demand can facilitate indicators that can produce relevant information for the evaluation of different scenarios of micro hub implementation.

Existing studies show the importance of simulation in the design of bike lane networks. Yang et al. (2024) used simulation of parcel demand to study the bike lane network design for urban deliveries in NYC. The study evaluates the connectivity of carriers to neighborhoods but does not consider micro hubs as depots for efficient last yard deliveries by bike. The growth of cargo bike deliveries requires continuous improvements to the design of cargo bike networks (Gruber, 2024). Llorca and Moeckel (2021) also used an agent-based simulator to study the efficiency of parcel deliveries using a network of distribution centers and micro depots (2021).

An important motivation to use cargo bikes for urban deliveries is the ease of parking (Gruber, 2024). The other side of the same coin is an increasing pressure on urban space due to sidewalk parking of urban freight vehicles. Public planners need to have access to reliable estimates of impacts of proposed solutions in order to make an informed trade-off in addressing urban planning issues. Cargo bike parking in public spaces is one of them.

3. Methodology

3.1. Simulation approach

In our approach we use an agent-based urban freight model, to simulate parcel demand and parcel delivery tours, similar to Llorca and Moeckel (2021) and Yang et al. (2024). The simulator we used is MASS-GT, a multi-agent urban freight transport demand model to simulate the decision-making of freight agents on the level of individual firms and individual freight shipments (de Bok et al, 2025). The model was developed in the project HARMONY as the Tactical Freight Simulator (TFS). It allows policymakers to quantify the effects of future scenarios on the freight transport

system. The model distinguishes three main segments of urban commercial vehicle movements: Freight Shipments, Parcels, and Services. It calculates a comprehensive set of KPIs, including accessibility and emissions on the car network. A missing element is the simulation of network impacts of use of cargo bicycles on the cycling network. The number of cargo bicycle tours and vehicle kilometers can be estimated but network assignment is missing, not allowing the identification of bottle necks in the network.

In this study an improved approach is developed to integrate and update the available tools to develop a cycling network model for the evaluation of city logistics policy scenarios involving this mode. The tabular overview below specifies all sources used in the simulation of parcel demand, the scheduling of parcel deliveries, and the cargo bike scenarios. For details on the parcel demand and parcel scheduling modules see the methodological publication of de Bok et al. (2025). Additional cycling networks from the traffic model of the metropolitan area of The Hague and Rotterdam were used to set-up the bike and cargo bike assignment module. The model also calculates relevant KPI's based on the bicycle assignment results, such as the bottlenecks and parking pressure indicators discussed later in this article.

Table 1: Sources of data used for parcel demand modelling and cycling assignment.

Data source	Description [# or dimensions, granularity]	Use in MASS-GT
Traffic model of the metropolitan area	- Zonal socio-economic data [Employment and population, 6625 TAZ] - Car Networks [158 thousand links] - Cycling network [527 thousand links]	- Employment by economic sector, and number of households by zone. - Network assignment (LCV+HGV) - Cycling network assignment
MPN household travel survey (Hoogendoorn-Lanser et al, 2015)	Online orderings by individuals [6750 surveys; individuals]	Calibration of parcel demand by households
Monitoring statistics about the parcel market (ACM, 2020)	Parcel market statistics (historic trend) [B2B and C2C; study area]	Parcel market size by B2C and B2B segment, market shares of CEP companies
Open Street Map (OSM)	Location parcel depots for CEP couriers [29 depots; address]	Simulation of parcel demand for delivery per parcel depots

3.2. Bicycle assignment modelling

The existing traffic assignment model does include a module for bicycle assignment, but it is underspecified to represent realistic routing choice behavior for cargo bikes. It poses two challenges. First, the model does not include a user-class that represents the route preference behavior for cargo bikes, taking into account the larger size (width) of the vehicle, different speeds and turn penalties. Second, the zonal network connectors are not detailed enough to represent the micro-routing on the first/last yard of the journey.

Route choice for cargo bikes is different from conventional cyclists due to the weight and size of the vehicle. In order to have a reliable estimate of the bike lane use by cargo bikes, the routing preferences need to capture this particular preference. The bicycle assignment model considers three conventional classes of cyclists and a new class for cargo bikes. The regular cyclists optimise travel time, distance or a combination of both (see equation 1 to 3). One important factor in the route preference of cargo bikes is a strong preference for short travel times as cargo bikes are used for commercial operations. The most important differentiations between the cargo bike user class and regular cyclists, is the larger size of cargo bikes on the network. Routes are preferred with asphalt and wider bike lanes. Cargo bike drivers prefer to avoid cobble stone streets, also common in the Netherlands, and traffic lights (see equation 4).

Let a route r be a set of consecutive links a . Where l_a =link length, v_{at} =link speed at time period t , rt_a = link road type impedance, m_a = link road material impedance and tl_a = link traffic light time. The four user classes each try to minimize the following generalized cost function:

1. DIST: Route distance minimisation:

$$C_{dist} = \sum_{a \in r} l_a \quad (1)$$

2. TIME: Route time minimisation:

$$C_{time} = \sum_{a \in r} l_a * v_{at} \quad (2)$$

3. COMB: Route distance and time minimisation (50-50 weights)

$$C_{comb} = 0.5 * \sum_{a \in r} l_a * v_{at} + 0.5 * \sum_{a \in r} l_a \quad (3)$$

4. CABI: Route time minimisation accounting for road characteristics (including road type, surface material and traffic lights)

$$C_{cabi} = \sum_{a \in r} l_a * v_{at} * rt_a * m_a + tl_a \quad (4)$$

Figure 1 shows the difference in route choice between cargo bike drivers and cyclists that prefer short routes, or quick routes. As can be seen, the cargo bike route follows mostly the quick route, but where it can, e.g. near the trip end at the left, the cargo bike follows the grey, asphalt paved bike lines, instead of the green stone paved streets.

To get a better estimate of the cargo bike routing and parking at the final destination, it is necessary to have more detail in the modelling of the trip ends. Although the traffic analysis zones from the model are very detailed for traffic assignment, most zones are still too large and wide to represent local micro-routes of bicycle route choice behavior on smaller streets and roads. Therefore, to have a better prediction of the trip ends of the cargo bikes, a procedure is implemented with multipoint access on the network in order to have a more detailed and realistic spread over the network of cargo bike trips. The procedure utilizes a micro-node layer, originally developed for a street level traffic intensity map for the municipality of Rotterdam, which contains information on the urban functions at each node (ANTEA Group, 2024). Depending on whether the parcel deliveries are B2B or B2C the trip ends are assigned to the most likely micro-node.

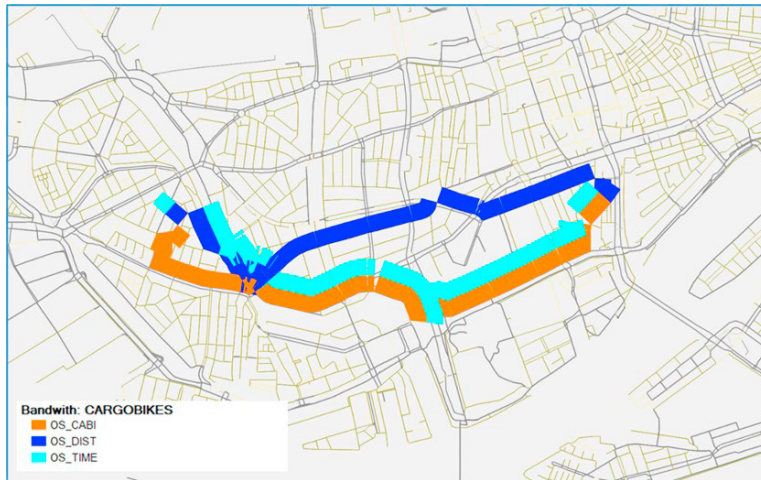


Figure 1: Cargo bike route choice (orange), relative to shortest route (dark blue) and quickest route (light blue).

4. Use case

This bicycle assignment model, with separate user-class for cargo bikes, will provide improved insights into the use of the bike-lane network and the distribution of bicycle trip ends, in particular for cargo delivery bikes in the city center. In the use case we compare the business-as-usual scenario to two scenarios of a cargo bike and micro-hub network in the city center of Rotterdam. In the reference use case, over seven thousand parcels are delivered to the micro-hub catchment area, with a total of 44 simulated delivery routes, with a total of 960 vehicle kilometers. These 44 routes are operated by the 6 parcel carriers that are active in the study area.

Similar to the study by Llorca and Moeckel (2021) we include micro-hubs in the operations of the cargo bike scenarios. The micro-hubs add a delivery leg for the last yard. The parcels are delivered to the micro-hub in consolidated transport (small trucks). Cargo bikes are used for the last yard delivery. For the operations of micro-hubs, we study both a scenario in which the hubs are operated by each carrier individually, and a scenario of shared operations (white label).

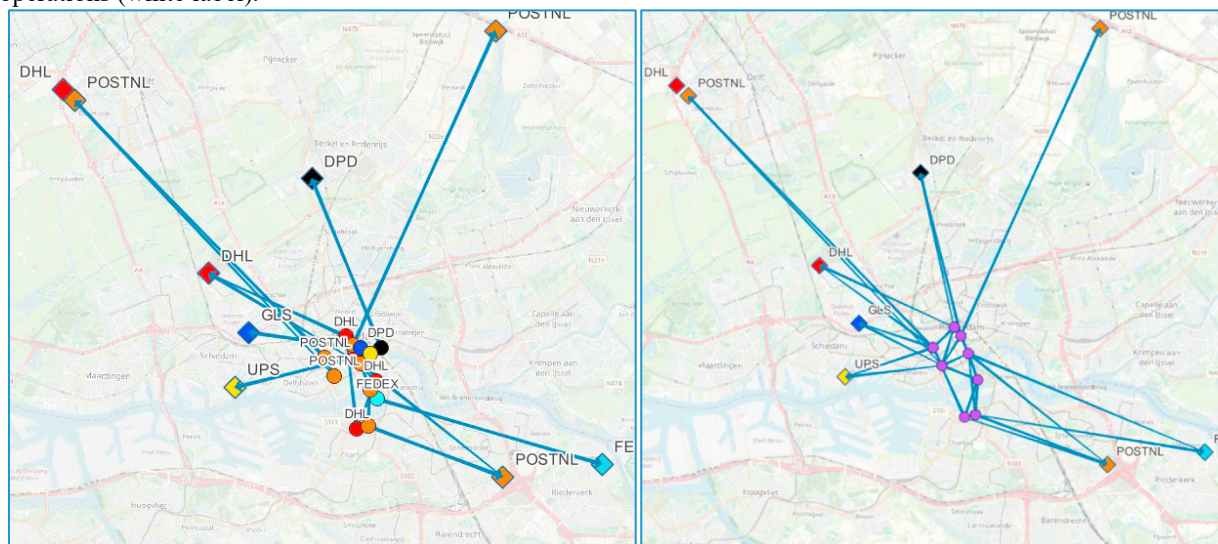


Figure 2: Cargo bike networks in the use case. With single carrier hubs (left) and shared 'open' hubs (right).

5. Simulation results

The cargo bike and micro-hub network scenarios were simulated to assess the impact on the bicycle network and urban space. The simulations allow the evaluation of the impacts of different cargo bike scenarios on two important indicators: bottlenecks in the cycling network and heatmaps of cargo bike parking.

The parcel demand and delivery tours in the reference situation are simulated with MASS-GT, the freight demand model. These simulated delivery tours are input for the bicycle assignment. The cargo bike delivery tours start from the corresponding micro hub and visit several zones to make the final delivery until the capacity of the cargo bike is reached (the capacity is assumed to be 13 parcels/bike). The figure illustrates the simulated delivery routes. There is a very sharp difference in the number of delivery tours generated when carriers operate together or share the micro hub facilities.

Figure 3 shows the results for the cycling assignment. It shows the intensities of the regular cycling traffic on the network, and the additional cargo bike traffic in the two scenarios. In the busiest parts of the network, around the Central Station, or the Erasmus University, cycling intensities of 3 to 5 thousand cyclists per day are common. The cargo bike flows will add another user group to the bike lane network. The results show distinctive cycling patterns between the scenarios. Single carrier scenarios show notably higher cargo bike movement intensities. In this scenario, each carrier delivers only their dedicated deliveries and thus they have a much lower delivery density: in other words, they make much longer delivery tours to do a delivery round of a fixed maximum number of parcels. In the shared carrier hubs, the tours are much more efficient and are operated from a central hub in the delivery area, and there are much less bottlenecks from cargo bike traffic flowing through the whole network.

To identify bottlenecks in the bike lanes network, the locations are identified that have high usage of cargo bikes, and regular cyclists. Bottlenecks are defined as links with high usage of both cargo bikes and other cyclists. We applied an arbitrary independent threshold value of at least 400 regular cyclists passing by and 30 cargo bikes. The results are visualized in Figure 4. This shows that the network configuration of micro hubs and its operation also affect the creation of bottlenecks. One mayor difference between the scenarios is that in the single carrier configuration, the

higher intensities on the network also create more potential bottlenecks. In the single carrier scenario, in almost all major corridors including the water crossings, there is an indication of potential bottlenecks.

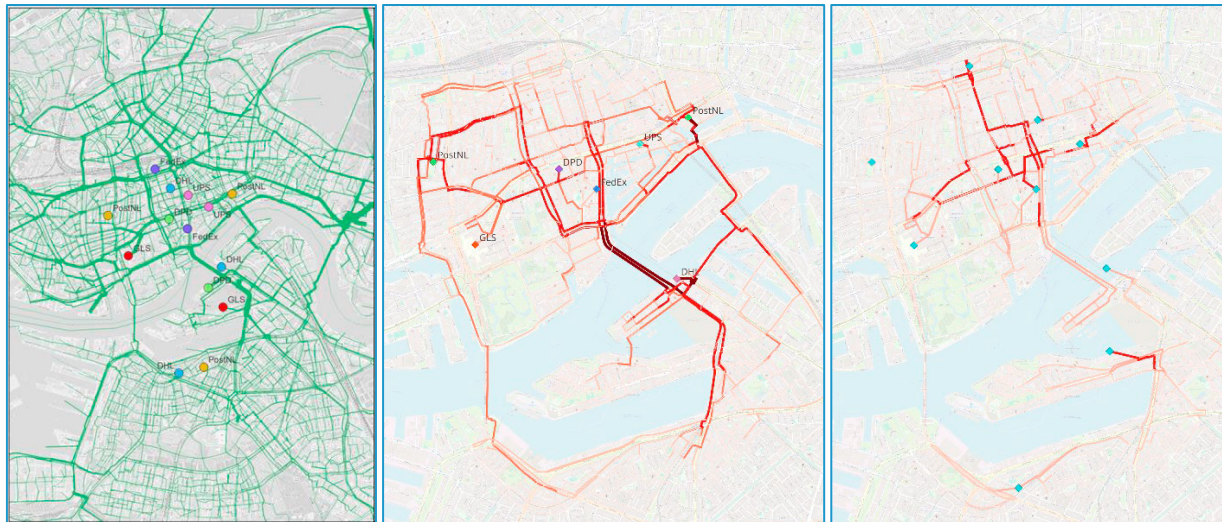


Figure 3: Bicycle intensities on the cycle network in Rotterdam: regular cyclists (left), cargo bikes in the single carrier scenario (middle) and shared 'open' hubs scenario (right).

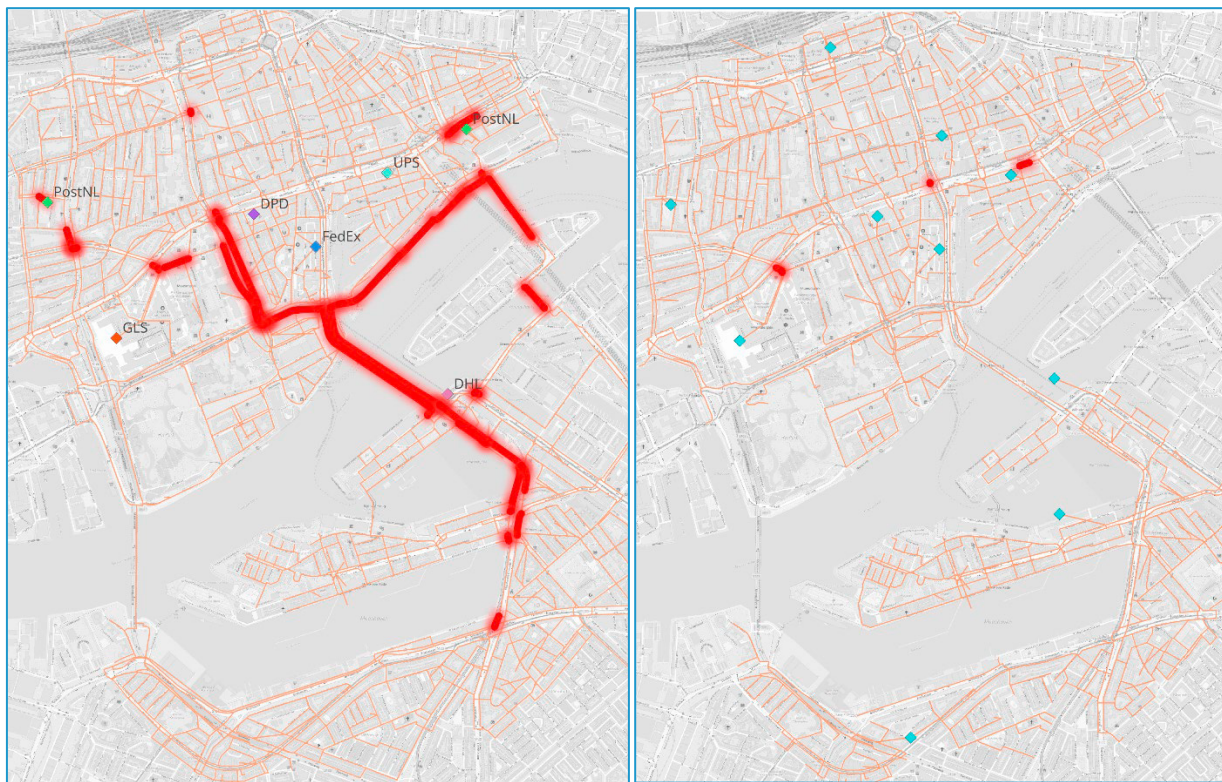


Figure 4: Bottlenecks for cargo bikes and regular cyclists on the cycle network in the single carrier scenario (left) and shared 'open' hubs scenario (right).

Pressure from cargo bike parking can be measured by the number of cargo bikes parking per zone. The tour scheduling model assumes that cargo bikes can stop at any delivery location. This seems justified as in practice delivery bikes are parked anywhere on the curbside or at any other part of the paved urban environment. A heat map indicator for the cargo bike parking pressure is calculated from the simulated delivery patterns. Figure 5 shows the intensity of cargo bike parking for parcel deliveries. Some observations can be made. First, the hubs pop out as hot spots with many cargo bike stops: these dominate the illustration of hot spots. This is logical as each cargo bike tour ends at the micro hub. The highest intensity of cargo bike stops is around 142, for one of the shared micro hubs in the collaboration scenario. The single carrier hubs scenario lead to delivery tours with fewer deliveries per stop. Consequently, more stops are made to make all deliveries in a cargo bike tour. This translates into more stops and increased parking pressure across neighborhoods. In operation this will also be experienced, as cargo bikes from multiple carriers will visit the same addresses. This will also create more pressure from cargo bike parking on the sidewalks. The heatmap can give a quantitative estimate of this impact. When it is combined with other layers, for instance with sidewalk width, or pedestrian intensities, it can be identified where the bottlenecks in cargo bike parking are expected to occur, to identify potential mitigation measures.

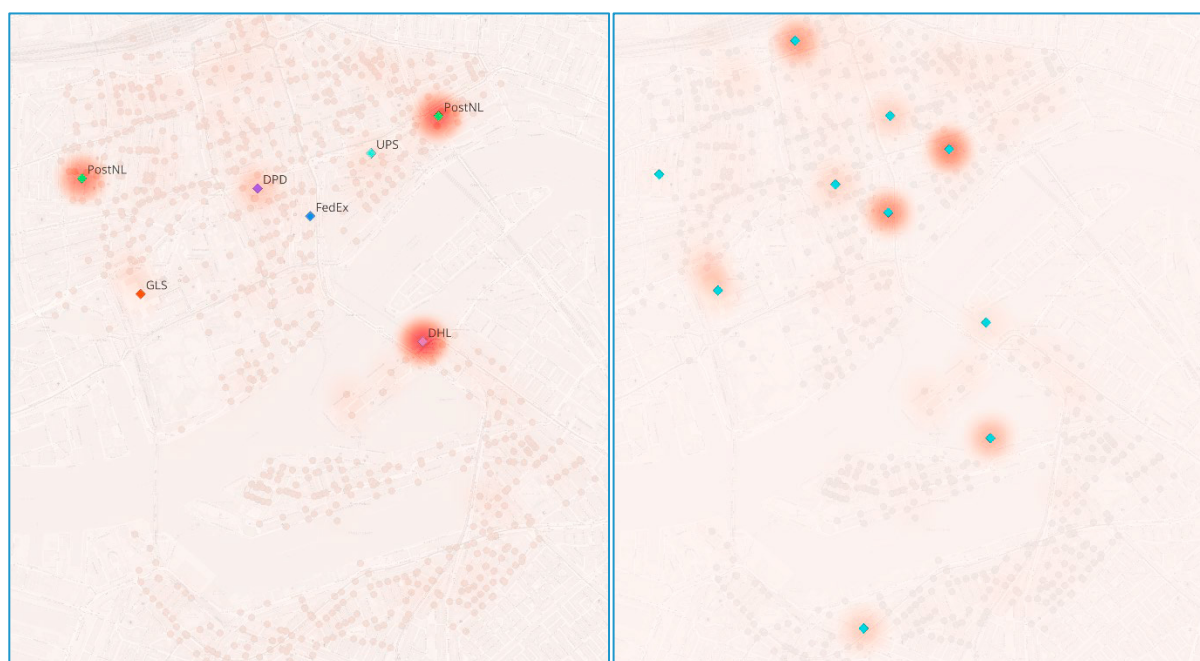


Figure 5: Example of cargo bike parking heatmap in the single carrier hubs (left) and shared 'open' hubs (right).

6. Conclusions and discussion

This study presents an extension of an existing urban freight simulation model, with a cycling network model for the evaluation of city logistics policy scenarios involving cargo bikes. The simulation of cargo bike flows requires an explicit route choice behavior for cargo bike drivers, and sufficient detail in zonal network connectors to have an accurate representation of trip ends.

The simulation results are presented from two different scenarios for cargo bikes and micro hubs in the city center of Rotterdam. The paper presents the integration of the urban freight model with a cycling network assignment that includes cargo bikes as a dedicated user class with distinctive route preferences. This allows the presentation of bottleneck indicators and cargo bike parking pressure heatmap.

The simulation results for the two scenarios show distinctive impacts of hub implementation in the city center of Rotterdam. The outcomes allow detailed analysis of bottlenecks in the network, and the local pressure on sidewalk

parking. This information will be used to evaluate the scenarios described in the paper, and to define the city's location strategies on logistic cargo-hubs development.

Such information is relevant to city planners and is useful to make an impact assessment of urban freight plans. By comparing network cargo bike flows with the flow of other cyclists, or with car traffic, potential bottlenecks, or future conflict intersections can be identified in the planning stage. Parking pressure information could be used with information layers in the urban environment, such as pavement width, pedestrian density or other relevant indicators.

The research presented makes some important assumptions that can be explored in further research. One of such assumptions is the assumed route choice behavior of cargo bikes in equation 4. This is based on our assumed importance of travel time, distance and road type design, but the lack of empirical proof on the route preferences of cargo bikes is a shortcoming. In future research the cargo bike routing preference can be further calibrated and validated with supporting data. The study assumes a fixed capacity of 13 parcels per cargo bike. It is worth investigating if a higher capacity could be assumed, either by using larger cargo bikes, or by parcel selection strategies. Another critical aspect of the identification of bottleneck identification in cycling network is the assessment of the capacity of bike lanes. Such fundamental research is available for single bike lanes (Wierbos et al., 2019) but as the cycling network is a mixed network of routes via single bike lanes or via mixed urban streets, it is difficult to establish a quantitative capacity standard for the cycling network.

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