Cargo Bikes for Sustainable Last Mile City Logistics

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Abstract. Climate change, increasing urbanization and growing transport volumes are challenges cities nowadays have to face. Especially the large number of parcels due to the growing e-commerce sector which need to be delivered in densely populated urban areas cause several negative impacts like air pollution, noise and congestion – all reducing the quality of life. One way of reducing these negative externalities of logistics activities in urban areas is the use of small and emission-free vehicles. In this paper, we give an insight into the efficient and effective use of cargo bikes for sustainable city logistics based on a number of case studies. We investigate the challenges and opportunities encountered in last mile logistics processes induced by small environmentally friendly vehicles, such as cargo bikes. Several best practice examples are presented to underline the findings and give an overview of the application areas of cargo bikes. The cases undermine that a priori planning allows to successfully implement logistics processes with cargo bikes, optimizing not only ecological and social aspects, but also achieving economic benefits.

1 Introduction

Today cities are confronted with several challenges - like increasing urbanization and growing transport volumes - related to climate change. The European Union has therefore launched the '100 climate-neutral and smart cities' mission, to trigger a development and transformation to climate-neutrality in urban areas (European Commission et al., 2020).

As the transport sector is responsible for about a quarter of all greenhouse gas emissions in the European Union and the urbanization level is about 75% (European Union, 2020; Szmigiera, 2021), more sustainable distribution schemes for logistics activities in cities are important means on the way to a climate-neutral urban future. To achieve this, small alternatively-fueled vehicles, like cargo bikes, seem to be an appropriate mode of transport in urban areas, since they cannot only reduce logistics-related greenhouse gas emissions but also other harmful pollutants like particulate matters or nitrogen oxides. Furthermore, such vehicles can contribute to the mitigation of congestion and noise in

cities. Despite these benefits of cargo bikes as means of transport also some challenges of these vehicles need to be considered when planning to use them for the delivery of goods.
The remainder of the paper is organized as follows. Chapter 2 presents the related work, while Chapter 3 introduces the methodological approach. Benefits and challenges of using cargo bikes for city logistics in general are dealt with in Chapter 4, and Chapter 5 describes related findings based on a number of case studies. Finally, Chapter 6 concludes the paper.

2 Related work and settings

The use of cargo bikes is well-suited for last mile distribution of goods in urban areas, enforced by an increase in e-commerce, high cost of last mile delivery and time pressure. Successfully applying cargo bikes in a logistics environment is strongly related to technological developments. The latter enable efficient and effective planning and implementation, while considering societal needs and environmental requirements. Investigations show that innovative delivery concepts can benefit companies and the quality of life in cities (cf. Arnold et al., 2018).
In a circular economy, the life cycle of products is extended and waste is reduced to a minimum. By efficiently utilizing transport capacities (i.e., avoiding empty trips, reducing traffic), resources can be preserved in last mile city logistics. The circular economy is a model of production and consumption in which existing materials and resources are shared, leased, reused, repaired, refurbished and recycled for as long as possible. Resources and materials are productively (re-)used in order to continue generating added value. The circular economy is in contrast to the traditional, linear economic model (European Parliament, 2015).
For a comprehensive survey of alternative last mile delivery concepts (i.e., all logistics activities related to the delivery of shipments to customers in urban areas), please refer to Boysen et al. (2021). The authors subsume last mile delivery as shipments, starting at a location point (i.e., storage facility) in an urban area, such as a central depot after long-haul transportation, and ending at the final customer's preferred destination point (Boysen et al., 2021).
The successful use of cargo bikes in last mile delivery operations has been investigated by several authors in a theoretical way. Arnold et al. (2018) compare cargo bike systems with other delivery concepts, i.e., vans and self-service concepts, in a simulation study based on the daily distribution activities of a logistics service provider from Antwerp (Belgium). Their results show that, compared to home delivery via vans, cargo bikes can lead to a decrease in external costs, i.e., emissions, noise, and congestion, by 40% per delivery compared to traditional home delivery via vans.
Gruber et al. (2014) observed whether electric cargo bikes were a good alternative for urban freight delivery via courier services. They analysed the potential market for electric

cargo bikes, the organization of the market and the perception of electric cargo bikes by bike and car messengers. According to the authors, electric cargo bikes are well suited for courier shipments and in urban areas, successfully facing problems like congestion and limited access areas due to environmental zones or delivery period restrictions. Their potential market is positioned between bikes and cars in terms of cost, payload and range. The authors further found that the willingness to use electric cargo bikes is determined by factors such as the electric range, the purchase price and the available information.

Enthoven et al. (2020) present a city logistics problem with cargo bikes and parcel lockers. They investigate a two-echelon vehicle routing problem, where trucks transport goods from a single depot either to covering locations, such as parcel lockers, where customers can pick up goods themselves, or to satellite locations, where goods are transferred to zero-emission vehicles (such as cargo bikes) and delivered to final customers. Computational results indicate that customers in the same area are best-served either via cargo-bikes or parcel lockers.

Dybdalen and Ryeng (2021) investigate whether cargo bikes can operate efficiently in northern climates and on winter roads, based on a case study from Trondheim, Norway. The authors observed that while the average velocity was lower for winter trips than for spring trips, despite snow, ice, slush and low temperatures cargo bikes can operate fully feasible on winter roads for urban delivery. Success factors include the design of the cargo bike, durable parts, larger wheels and better illumination, sufficient clothing and good planning, as well as an increase in the amount of bicycle lanes and urban consolidation centres or micro depots.

Assmann et al. (2020) examine different strategies for the location of urban transhipment points and their effect on traffic, carbon footprint, and air quality. The authors conclude that the use of cargo bikes for courier, express, and parcel deliveries in urban areas could reduce greenhouse gas, particulate matter, and nitrogen oxides emissions significantly. The authors point out that cargo bike delivery networks are dominantly seen as a means to improve liveability, e.g., by reducing traffic.

Browne et al. (2011) investigate kilometres travelled in a distribution scheme, related to the space occupied by vehicles performing on-street deliveries, as well as total kerbside time. They find that the space occupied can be reduced through consolidation and the use of smaller vehicles, further reducing the impact of freight operations on traffic congestion. The authors calculate the effect of different distribution systems on road space requirements by assessing the number of operating hours of the vehicles and the vehicle footprint (square meters) in order to derive the total road space and time occupied.

Vasiutina et al. (2021) provide a literature review, investigating the benefits and drawbacks of integrating cargo bikes in urban logistics schemes. The authors examine different methodologies and techniques to evaluate the impact of cargo bikes on the

environment. They present studies confirming the potential of cargo bikes to serve as sustainable substitution for conventional delivery vehicles. Their literature review shows that cargo bikes are best suited for last mile delivery in cities, especially in districts with traffic restrictions and high population density.

3 Methodological approach

To investigate the potential of cargo bike usage for last mile delivery with a special focus on the situation in Austria a mixed-methods approach was chosen:

- An in-depth desk-recherche combined with semi-structured expert interviews with 23 experts from different fields related to sustainable last mile delivery in cities was conducted A content-analysis of all interviews based on Mayring (2010) was applied to gather all relevant statements from the interviews with respect to benefits and challenges of cargo bikes.
- Metaheuristics for specific vehicle routing problems were implemented and tested on real-world problems to find out the impact of transfers between vehicles as well as of bundling goods.
- An Analytic Hierarchy Process was developed and applied to find appropriate locations for hubs in a city to consolidate goods. The perspectives of different stakeholders were integrated in the process as described in more detail in Chapter 5.3.
- A pilot study was conducted in Innsbruck to test the theoretical findings in a practical setting. During four weeks parcels were delivered by cargo bikes in a selected area in the city centre of Innsbruck. The case study was conducted in cooperation with a parcel delivery company which provided the cargo bike drivers with a specific number of parcels (about 150 per day).
- Impact evaluation was based on scenarios modelling the status quo as well as the situation after the implementation. Standard vehicle routing problems were solved for both scenarios and then compared with respect to kilometres driven, number of vehicles required and emissions caused.

Combining the findings by these methods enabled us to draw conclusions from a theoretical as well as a practical point of view.

4 Benefits and challenges of using cargo bikes

While cargo bikes are particularly flexible and fast vehicles in dense urban areas, they possess a comparatively restricted loading capacity and have a potentially limited operating range. Therefore, logistics processes need to be adapted for the use of cargo bikes, which comes along with some additional challenges, such as the selection of the appropriate cargo bike type, the suitability of the products to be transported or the proper delivery routes and radius.

4.1 Benefits of cargo bike usage

Cargo bikes are – as normal bikes – vehicles moved by muscular strength. Even in case of electrically assisted ones which are more appropriate when transporting heavier goods and/or in hilly areas, these vehicles don't cause emissions at the place of use. Besides being emission-free, this type of vehicles is also noiseless and hence a significant improvement in urban traffic which is usually coined by a lot of noise.
Due to their shape, being either two- or three-wheelers, cargo bikes require much less operating space than conventional vehicles or vans. Considering that conventional vehicles might cause congestion, the required space per request is even larger, compared to a cargo bike. The required space per vehicle or per request can be an important key performance indicator for decision makers. The less space is required by vehicles, the more space can be occupied by citizens, used as shared spaces or for greening the cities and regions. This can lead to further social advantages, such as a reduction in conflicts between freight delivery and personal mobility (cf. Browne et al., 2011).
Another advantage of cargo bikes is the flexibility in traffic situations. Depending on the type of the cargo bike additional infrastructure, like bike lanes or one-way streets in both directions, can be used. This also results in cargo bikes being hardly affected by congestion. Hence, a cargo bike can be faster in dense traffic than cars or vans. Thus, the reliability of cargo bikes in freight delivery can be guaranteed and delivery time windows can be respected.
Finding a parking space is also much easier for a cargo bike than for conventional delivery vehicles. In case of broad enough pavements, cargo bikes may even be parked there. Hence, less time has to be wasted for finding an appropriate parking space and situations of delivery vehicles parked in second lane can be avoided.
Eventually, it should be mentioned that for driving a cargo bike no driving license is required. This is especially beneficial nowadays when finding drivers for trucks and vans becomes more and more difficult (Anderluh et al., 2016). In addition, cargo bike riders gain health benefits by moving actively, i.e., using their muscles while riding the bike. Active mobility refers to means of transport that rely on muscle strength, such as cycling. This has a positive impact on health status, it helps to reduce greenhouse gas emissions and thereby counteract climate change (Seel et al., 2022).

4.2 Challenges of cargo bike usage

Cargo bikes as flexible and small vehicles have a limited load capacity and also a limited operating range. These are two drawbacks of such vehicles that need to be considered when planning to integrate them in urban distribution schemes. Additional measures like adapted routing algorithms or the implementation of micro depots within an urban area, which can be used as intermediate storage facilities but also to consolidate deliveries, need to be taken into account to make it a success. Distribution schemes might be

organized in several echelons, to efficiently put cargo bikes into operation (cf. Nolz et al., 2020).
The appropriate cargo bike type needs to be selected for the delivery task at hand. This includes the appropriate size of the bike as well as the load box. Cargo bikes can have two or three wheels, the load box can be located in the front of the bike or at the back. The load box can be dedicated to transport objects as big and heavy as washing machines, or small items such as parcels. In addition, cargo bikes can be purely manual or electrically assisted. In regions, where delivery trips include steep segments, hills or generally long distances, electric cargo bikes are more appropriate.
Further challenges are connected to the topography of the delivery area and the weather conditions. While hilly regions can be solved by using electrically assisted bikes and rainy/snowy weather just requires appropriate equipment for drivers and maintenance for bikes, heat and icy streets are the two situations that remain a challenge in using cargo bikes for delivery (Anderluh et al., 2016).
Some of the mentioned challenges and issues can still be overcome by integrating cargo bikes into a heterogeneous vehicle fleet. In a combined distribution scheme with (electric) vans, cargo bikes can be efficiently used for delivery operations where appropriate, i.e., where their benefits in terms of flexibility and sustainability can be exploited. The disadvantages of cargo bikes regarding the limited driving range or loading capacity can be overcome by applying larger vehicles for the concerned requests / tasks (Anderluh et al., 2017).

5 Best Practices

Benefits and challenges of cargo bikes have to be thoroughly evaluated when planning to integrate these emission-free and flexible vehicles in urban logistics processes. Several case studies show the potential of a significant decrease of transport-related cost caused by freight delivery in urban areas.

5.1 Benefitting from transfers of shipments between vehicles

As mentioned in Section 4.2., cargo bikes are flexible, small vehicles but have a limited load capacity and also a limited operating range. Therefore, it can be beneficial to incorporate transfers of shipments between vehicles for last mile distribution. By these means, opportunities of using cargo bikes are exploited with respect to all aspects of sustainability, namely economic, ecological and social aspects. Details of this distribution scheme are explained as follows.
For logistics activities in inner-city areas, a mixed fleet of cargo bikes and (electric) vans are considered, which are placed at a so-called micro hub in the city centre. Goods can be transported with these vehicles, either from the micro hub or directly from pickup points to delivery points. Deliveries have to occur within (soft) time windows, which are determined by the final customers. In order to respect the time windows and the cargo

bike capacities, while at the same time minimizing total cost, goods can be transferred from one vehicle to another. Therefore, either a spatial-temporal synchronization of the vehicles has to be ensured if goods are directly transferred (on the route), or a temporary storage facility is needed. As a temporary storage facility, the micro hub can be used. However, this implies additional storage cost given a limited storage space in inner-city areas. On the contrary, the direct transfer requires thorough planning, since two vehicles have to meet at the same place and at the same time (please note that some waiting time is allowed, i.e., a few minutes).
Solutions to this problem are generated with respect to total cost, including economic, ecological and social criteria. Economic cost is measured based on the required distance and time for distribution. Ecological cost includes the induced carbon emissions of distribution. Social cost reflects the inconvenience and the threat caused by conventional vehicles in road traffic for human beings. Any traversal of road segments, where vulnerable groups are present is penalized with additional distance or time for delivery. A transfer from a van to a cargo bike could for example be beneficial to reduce social cost. This is especially relevant in areas where vulnerable groups are present, such as schools or homes for elderly people. In contrast to vans, this threat can be alleviated by traversing an area with cargo bikes.
Results of this investigation show that the synchronization between vehicles can be beneficial if a minimum number of requests are transported. Short time windows have an impact on the effects of synchronization. With an increase in the number of requests, the number of transferred requests increases as well. Ecological and economic costs have higher impact on synchronization than social costs, given the cost settings in the study. Especially in a mixed fleet consisting of both cargo bikes and vans, synchronization plays an important role in minimizing ecological cost. Temporary storage of goods can lead to an improvement of total cost if a minimum number of requests have to be completed. Storage pays off in the case of a cargo bike fleet or a mixed fleet (KoopHubs project, 2018).

5.2 Applicability of cargo bikes for parcel delivery in mid-size cities

In the field of parcel delivery in large cities, cargo bikes can already be seen on the streets as an example of city logistics measures. Several best practices can be found in cities like Vienna or Munich, but also mid-size cities can serve as application areas for cargo bike usage in parcel delivery.
A four-week pilot test in summer 2021 in the city of Innsbruck proofed the applicability of cargo bikes in delivering parcels of a logistics service provider to addresses in and around the historic centre of the city. Appropriate parcels with respect to delivery area, size and weight were pre-selected at the depot of the company, brought by a van to an intermediate storage facility near the city centre and then delivered by three different types of cargo bikes to the final customers.

Results of the pilot test showed that even for this small delivery area with about 150 parcels a day 1.5 tons CO_2 emissions could be avoided per year. An additional positive impact lies in the fact that about 570 van-kilometres could be replaced by cargo bikes per year (extrapolated based on the savings of emissions based on the van kilometres saved during the pilot test).

A major challenge in the pilot test was finding an appropriate location for the intermediate storage facility. For the test phase a number of potential locations was named but the only available location (that is, not too expensive and useable during the test phase) was located more than one kilometre away from the delivery area. Therefore, cargo bike drivers had to drive a rather long distance before they could start delivering parcels. Hence, this needs to be improved for a long-term application.

Additional potential for improvements can be found in the selection of the final customers for the cargo bikes. In the pilot phase customers in the historic city centre were chosen, but these were mainly business customers. This fact implies that several parcels had to be delivered each day to specific addresses which is not so appropriate for cargo bikes because they need to return to the intermediate storage facility very often due to the limited load capacity. Hence, a densely populated area with above all private customers ordering usually just a few parcels seems to be more appropriate for implementing a cargo bike delivery (INNS'PAKET project, 2020).

5.3 Appropriate locations for midi hubs

A major challenge of implementing cargo bikes in urban delivery schemes is finding an appropriate location for intermediate storage. Depending on the size of these facilities, they are referred to as micro hubs (size of some hundred square metres) or midi hubs (size of some thousand square metres).

When planning to make the delivery of goods in a large city like Vienna more environmentally friendly, especially parcels could be transported by small emission-free vehicles in the inner-city area. To do this, midi hubs located around the city centre can serve as appropriate means to consolidate parcels for performing the last mile with cargo bikes or small electric vehicles. Due to the fact that in 2019 about 95 million parcels were delivered in Vienna, an increase of 9% compared to 2018 (WKO, 2020), and in addition to this continuous increase, the COVID-19-pandemic further contributes to growing parcel volumes, at least three such midi hubs were assumed to be required to handle the parcel volume in the wider city centre of Vienna.

The first step in finding appropriate locations for midi-hubs was to determine which locations are available. Hence, it needs to be answered, where sufficient free space within the city that can be used as midi hub can be found. After recherche and discussions with city representatives nine potential locations could be identified.

For the evaluation of the nine potential locations for midi hubs an Analytic Hierarchy Process (AHP) was applied. In the AHP quantitative as well as qualitative criteria can be used. Three main criteria were used: costs, environmental and social aspects, and

location-specific characteristics. Each main criterion was further subdivided and then a pairwise comparison of all sub-criteria regarding importance from different stakeholder perspectives was done. Companies, municipality representatives and citizens were asked. The latter group in a workshop, the others in an online survey.
After evaluating the relative importance of the sub-criteria to each other, indicators were defined for each sub-criterion to assess the relative performance of a specific location to all other locations. These results were weighted by using the matrix of relative importance of all criteria which finally results in a ranking of all potential midi hub locations for each stakeholder group (Anderluh et al., 2020).
A rough assessment of the impact of the best-ranked three midi hubs showed an emission reduction potential of up to 25% when delivering all parcels in the wider city centre area in Vienna either with cargo bikes or with small electric vehicles. This result holds even when the companies just use the infrastructure of the hub together but do not cooperate in the last mile delivery.

5.4 The benefits of bundling goods for delivery

As already pointed out in Section 5.3, online shopping is on the rise. During the COVID-19-pandemic, new customer segments, new industries and local shops were opened up on a large scale by connecting to online retail and hence contributing to e-commerce volumes. This leads especially under the current market conditions to a significant increase in the volume of goods traffic.
Although several innovative approaches have already been tested to improve the situation like initiatives for cross-company cooperation between logistics service providers to bundle freight flows, they have so far not been successful due to competition issues. Appeals to individual responsibility for the bundling of orders on the customer side also turn out to be ineffective. In addition, emission-free delivery services are only rarely offered by online shops.
Therefore, a promising option lies in the restructuring of the commissioning process for delivery services. The plan is to establish an independent online platform for the organization of logistics services. Hence, instead of placing decentralized delivery orders through individual dealers, deliveries are centrally coordinated and commissioned by the platform targeting on the interests of society as a whole.
This approach allows to optimize good flows even before the delivery itself by (1) bundling orders according to the spatial distribution of customers and dealers, (2) temporal aggregation of order requests or delivery time windows according to customer requirements and (3) offering sustainable, emission-free delivery services to all suitable customer addresses.
Overall, the spatial and temporal bundling of orders can result in a reduction in delivery frequency and an increase in vehicle utilization. In addition, the increased usage of emission-free small vehicles like cargo bikes for delivery actions can reduce emissions,

mitigate noise and congestion and can finally contribute to an improved quality of life in the city (BündelHeinz project, 2022).

5.5 Logistics concepts as part of Circular Economy

The Circular Economy Research Network of the European University E³UDRES² (Engaged and Entrepreneurial European University as Driver for European Smart and Sustainable Regions) is dedicated to developing and evaluating innovative logistics concepts together with citizens and stakeholders, facilitating the use of cargo bikes, in different European countries. Using cargo bikes for appropriate deliveries in city areas can contribute to emission reduction as well as to increased liveability in cities. Transport resources and capacities can be efficiently used and exploited, thus leading to a decrease in motorized freight traffic.

Novel concepts and approaches in sustainable mobility and in resource efficiency are developed and evaluated. For these concepts economic, ecological and social objectives representing the conflicting perspectives of diverse actors are included. At the same time, new behavioural approaches are proposed instead of solely focusing on technological development. The factors affecting consumer behaviour in the context of the circular economy are economic factors, the fit between needs and offering, information, social factors, and individual consumer preferences (European Environment Agency, 2022). Municipalities, citizens, and private sector companies are connected and supported in how they can achieve the transition towards a circular economy in their region and in their daily life.

The Circular Economy Research Network aims at increasing the understanding of the interdependence between the supply / use of (limited) resources and the fulfilment of demand in urban areas, through better understanding and knowledge of stakeholders' requirements and limitations to facilitate the transformation process from a linear urban economy to a closed-loop sustainable economic system. Decision makers are supported in implementing urban circular economic systems, tailored to the societal challenges of particular regions. Innovative logistics concepts and urban delivery processes performed with cargo bikes are designed to lead to a more socially balanced co-existence in an urban environment. The concepts are developed generically in order to enable their transfer, so that they can be shaped to the specific requirements of individual and diverse regions (E^{3}UDRES^2 project, 2021).

6 Conclusion

Growing urbanization as well as the challenges to reduce climate change increase the necessity of improving delivery processes in urban areas. A promising idea is the integration of small environmentally friendly vehicles like cargo bikes in urban delivery schemes. These vehicles benefit from flexibility, zero-emission and noiselessness but on the other hand are limited in loading capacity and operating range. Hence, the

implementation of such vehicles needs to be thoroughly planned and accompanied by appropriate additional measures and actions.

The results of a number of national and international research projects – some of which are still on-going, point out the potential of cargo bikes as an excellent substitute for, as well as combination with, conventional delivery vehicles in inner-city areas when considering parcel-sized deliveries. Prerequisites for a successful implementation are (1) the commitment of the company to using such delivery vehicles, (2) an additional support by the municipality by setting appropriate conditions and (3) an appropriate integration of cargo bikes in the company's urban delivery scheme by means of suitable vehicle routing algorithms, which consider for example the usage of mixed fleets, synchronization between vehicles to transfer goods or intermediate storage of goods at differently sized hubs. Hence, the challenges of cargo bikes need to be considered in the implementation phase.

The benefits of using cargo bikes in urban delivery can be seen in the reduction of emissions (carbon dioxide, nitrogen oxides and particulate matters) and noise as well as in the reduced number of conventional vehicles required especially in city centers which contributes to less congestion. Hence, the positive impact concerns the climate as well as the wellbeing of citizens and in the long run also the economy.

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