Optimization of Last Mile Parcel Consolidation From an Economic and Ecological Perspective

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Extended Abstract

Summary. Consolidation of parcels in urban areas has the potential to improve ecological sustainability. The purpose of this paper is to evaluate the economic viability and environmental impact of a micro-consolidation concept including cargo bike delivery within time windows. Methodologically, a Fleet Size and Mix Vehicle Routing Problem with Time Windows (FSMVRPTW) is designed to simulate last mile delivery routes, a sensitivity analysis is conducted and CO_2 emissions are calculated based on EN 16258. This work proves that the implementation of a micro-consolidation concept leads to benefits for the environment, but also to additional costs of more than 3 € per parcel in the presented case study. Therefore, the underlying work provides guidance of how to minimize these costs by identifying the most effective levers for operational improvement.

1. Introduction

Congested city centers and the wish of consumers for fast and flexible delivery are challenges of last mile operations. Moreover, the current parcel delivery structure with a variety of Parcel Logistics Service Providers (PLSP) is presumably not the most environmentally sustainable solution. Huge potential of consolidation on the last mile across the PLSPs to increase sustainability is not taken into account.

Pooling parcel deliveries from different PLSPs through a micro-consolidation center (MCC) in combination with cargo bikes deliveries within customer defined time windows is one consolidation concept that could lead to a more efficient, customer-friendly and sustainable parcel supply chain and at the same time relieve the urban traffic situation.

The aim of this work is to evaluate the economic and ecological sustainability impact of the mentioned concept and identify the main drivers. In order to reach this aim, a mathematical optimization model is built, enriched and validated with data of a field study and then performed on the example of a B2C parcel delivery case in a Berlin-Charlottenburg neighborhood as part of the research project „Kiezbote".

2. Prior Work

Urban consolidation can be realized using Urban Consolidation Centers (UCC) and/or Micro Consolidation Centers (MCC). UCCs are defined as logistics facilities located *relatively close* to the delivery area (Browne et al. 2005), for example aimed for a city or urban district. Whereas MCCs are located *very close* to the assigned target group and result in a very decentralized distribution structure suitable for cargo bike delivery (Assmann and Trojahn 2018). While the sustainability effects of UCCs are broadly discussed in the literature (e.g. Allen et al. 2012), MCCs have not been sufficiently explored so far. Browne et al. (2011) conducted a pilot using a MCC in London with the result that CO_2 emissions on the last mile could be reduced by 54% per parcel delivered, however, the financial results are not available due to commercial confidentiality. Sheth et al. (2019) focus only on the financial aspect of cargo bike delivery in time windows in dense urban areas. They find out that cargo bikes can be more cost effective for deliveries close to the distribution center, what emphasizes a MCC implementation. Melo and Baptista (2017) analyze the impact of consolidated cargo bike deliveries on urban logistics with the result that CO_2 emissions can be reduced by over 70%.

New consumer requirements like time window delivery are rarely considered in prior studies in the field of last mile consolidation and eco-friendly transportation as the initial overview has shown. Most of the prior work is only estimating or simulating routes in a simplistic way. With our work, we evaluate the ecological impact *and* the economic viability of receiver-centric urban last mile consolidation including delivery with cargo bikes by solving a detailed routing problem.

3. Methodology

3.1 Last Mile Vehicle Routing and Sensitivity Analysis

To simulate last mile delivery routes close to reality we design a *Fleet Size and Mix Vehicle Routing Problem with Time Windows* (FSMVRPTW), also referred to as *Heterogeneous Vehicle Routing Problem with Vehicle Dependent Routing Costs including a Time Window* (HVRPDTW) (Liu and Shen 1999; Bräysy et al. 2008). With this kind of model, a delivery with different vehicle types as well as different capacities and velocities can be simulated. Because of its more complex characteristics it belongs to the "rich" CVRPs, that are close to practical distribution problems (Baldacci, Battarra, and Vigo 2008). In contrast to the basic CVRP with cost focus, the presented model aims to find a fleet composition and a corresponding routing plan that minimizes the total time to serve all customers in the given time windows. To achieve economic sustainability, we calculate for every time window the most resource-efficient fleet composition.

The calculated vehicle routing serves as a basis for determining the required vehicle fleet, the delivery staff and the associated variable costs of the last mile delivery concept. For simulating realistic delivery conditions, we propose to use a range of stochastic parameters, such as changing parcel amounts during the week and time windows per day. In addition, the calculation of different scenarios (e.g. different parcel amount estimations) helps to validate the sensitivity of the fleet composition. This sensitivity analysis helps to predict the costs per parcel depending external conditions. Next to the described variable cost components, a share of fixed costs (e.g. the warehouse rent) needs to be included.

3.2 CO_2 Emissions Calculation

The performed vehicle routing allows determining the ecological sustainability based on transport emissions of the delivery concept. Due to obtain a holistic picture of the incurred emissions, we propose a well-to-wheel emission calculation that considers direct emissions created by the fuel consumption of the transport services (tank-to-wheel) and indirect emissions caused by the production of power and fuels, the manufacturing of vehicles and construction of streets and maintenance of the transport network (well-to-tank) (Schmied and Knörr 2012). We propose the standard EN 16258 "Methodology for calculation and declaration of energy consumption and greenhouse gas emissions of transport services" for the calculation. For measuring the sustainability impact, the traditional parcel transports of multiple parcel delivery services beginning from the final distribution center needs to be modeled in addition.

4. Case Study: Consolidated Parcel Delivery in Berlin

4.1 Description and Data Collection

The presented methodology has been applied to an urban last mile consolidation case in a Berlin-Charlottenburg neighborhood with 15,000 inhabitants as part of the research project "Kiezbote". Within this project a MCC has been operated to deliver parcels with different types of electrical cargo bikes within four time windows per day from Monday to Friday and two on Saturday. This case study has been generated as preperation for the "Kiezbote" operations with the help of secondary data and industry experts of the project consortium. Some data like the bike speeds and capacities could precisely be determined whereas a set of estimates and assumptions regarding the later real operation were necessary to solve the FSMVRPTW with an appropriate data set. The distribution of parcels across the week and the daily time windows as well as parcel volumes and handover times per parcel were stochastically simulated to cover uncertainties. The baseline scenario estimates in average 100 parcels per day, three minutes of handover time per household, ten minutes of bike loading time at the hub per trip and a parcel volume of 0.06 m^3. For the calculations, we wrote the model in Python and used Gurobi as a solver.

4.2 Results

Applying the FSMVRPTW to the collected data illustrates for every simulated time window the economically most sustainable bike fleet. This calculation proved for the baseline scenario a fundamental feasibility of the delivery with only two deliverer and two cargo bikes. It also showed that stochastic demand peaks could bring the delivery service occasionally to the limits. Apart from the costs for delivery personnel and the leased cargo bikes, the total costs also consider different types of fixed costs, including the micro hub rent and equipment, software and hardware depreciations, insurance fee, and personnel costs for hub handling, operations planning, and administration. Large daily parcel amounts significantly exceeding 200 parcels would let jump up the fixed costs due to more required warehouse space and equipment. In total, the last mile delivery concept can be operated at costs per package of around 3.40 € for a daily amount of 100 parcels. Cost drivers are particularly labor costs, followed by the micro hub rent and operational costs for the cargo bikes.

The results of a sensitivity analysis presented in Figure 1 show that even smaller variations of individual input parameters of the FSMVRPTW can have considerable effects on the resource requirements. It demonstrates that the daily amount of parcels, the length of the given delivery time windows and the average service time per customer have the largest impact on the economic performance. Further experiments have shown that best- and worst-case scenarios (by varying multiple parameters) for an amount of 100 parcels lead to even higher sensitivities.

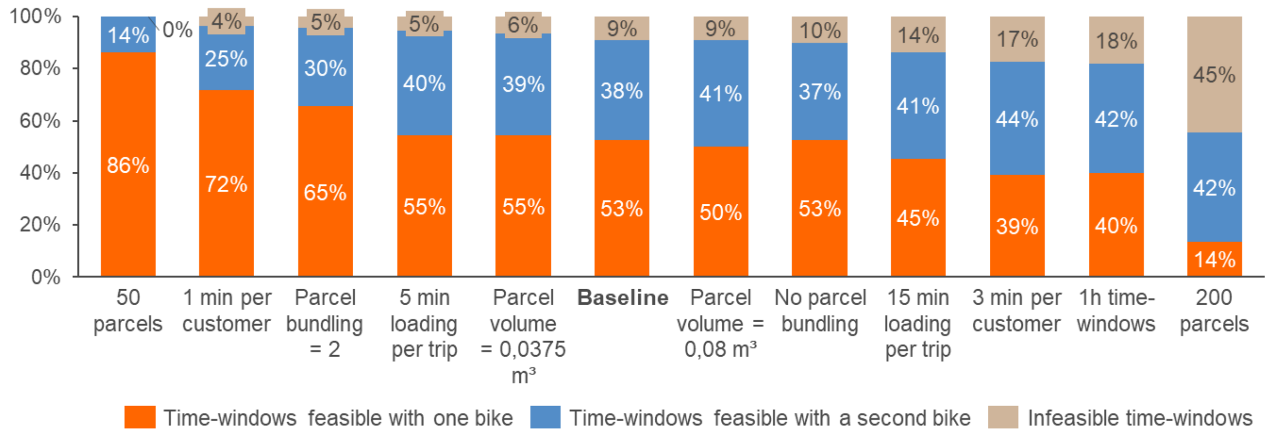

Figure 1. Share of feasible delivery time windows per scenario

To compare the sustainability of this concept with the traditional parcel delivery, the transport emissions of both variants have been calculated based on the standard EN 16258, like outlined in section 3.2. The relevant well-to-wheel CO_2 emission factors refer to the HBEFA data base (HBEFA 2020) and result in 182.3 g CO_2e/km for standard delivery vans and 15.6 g CO_2e/km for the cargo bikes. Emissions caused by energy consumptions in the micro hub are not considered. The distance between the distribution centers, mostly located near the city boarders of Berlin, and the MCC claims a high share of almost 80% of the transport emissions but cannot be prevented with this concept. The CO_2 emissions of the parcel delivery process to the end customers on the last mile can be reduced by almost 60% compared to the conventional 3.5t-diesel-vehicles.

5. Discussion and Implications

The results have shown that the customer-friendly MCC cargo bike delivery concept can be operated at costs per package of more than 3 € for a daily amount of 100 parcels. The sensitivity analysis, conducted with varying input parameters indicates that particularly the daily amount of parcels has a substantial impact on the economic performance. The results of the $C0_2$

emissions calculation confirm findings of prior work and showed that significant emission savings on the last mile delivery process could be reached, even with time window delivery. In order to obtain these ecological benefits, additional costs are caused that could be covered either by PLSP due to consolidation savings, online retailers due to customer service, city administrations due to less congested streets or parcel recipients who can flexibly choose the parcel arrival times. Public-private partnerships and subsidies for sustainable last mile consolidation can help to align the interests of public and private actors and achieve higher efficiency.

The results underlie some limitations. The size and total freight activities in the urban area served could have limiting effects on the environmental benefits. In addition to that, more real-world data could improve the model. Further efforts could also be made to improve the robustness of the optimization with the help of a very large number of calculation runs simulating the highly uncertain conditions. Further investigations could be made to enhance the concept, e.g. with other sustainable vehicle types or a broader range of services like parcel return collection. Also, the location decision of MCCs could be more researched in future. Advanced research should also be made regarding a sustainable delivery structure through all upstream supply chain stages, e.g. the transports from the regional distribution center to the MCC. Empirical studies on the acceptance of the service could provide profound insights for a widespread use.

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