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Operational performance of light electric freight vehicles in the last mile: two Nordic case studies

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Abstract

Purpose – To assess the introduction and performance of light electric freight vehicles (LEFVs), more specifically cargo cycles in major 3PL organizations in at least two Nordic countries.

Design/methodology/approach – Case studies. Interviews. Company data on performance before as well as after the introduction. Study of differing business models as well as operational setups.

Findings – The results from the studied cases show that LEFVs can compete with conventional vans in last mile delivery operations of e-commerce parcels. We account for when this might be the case, during which circumstances and why.

Research limitations/implications – Inherent limitations of the case study approach, specifically on generalization. Future research to include more public–private partnership and multi-actor approach for scalability.

Practical implications – Adding to knowledge on the public sector facilitation necessary to succeed with implementation and identifying cases in which LEFVs might offer efficiency gains over more traditional delivery vehicles.

Originality/value – One novelty is the access to detailed data from before the implementation of new vehicles and the data after the implementation. A fair comparison is made possible by the operational structure, area of delivery, number of customers, customer density, type of packages, and to some extent, the number of packages being quite similar. Additionally, we provide data showing how city hubs can allow cargo cycles to work synergistically with delivery vans. This is valuable information for organizations thinking of trying LEFVs in operations as well as municipalities/local authorities that are interested.

Keywords City logistics, Last mile distribution, LEFVs, Cargo cycles, Cargo bikes, Microhubs

Paper type Research paper

1. Introduction

In urban areas with increasing traffic and limited space leads to conflicting demands for its use. One challenge is finding a balance between creating livable spaces for people and accommodating deliveries and services crucial to the area's functioning. Simply investing in more transportation infrastructure may not solve the issue. Thus, both industry leaders and academics are exploring alternative transportation solutions to mitigate the negative impacts

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of city logistics, with a focus on replacing traditional delivery vehicles with more sustainable options (Zhu *et al.*, 2023). Many cities are experiencing densification and increased urbanization, which intensifies the competition for vacant areas and infrastructure among different road-user groups. Some cities in Europe are moving in the direction of more car-free centers with a focus on vibrant cities and facilities for soft road users (Hedblom *et al.*, 2017). The negative impact of transport is not only focused on climate change but also has developed into a broader perspective including health issues (air quality and noise nuisance), public space occupancy and the attractiveness of cities in general (Hogt *et al.*, 2017). Delivery of goods, on the other hand, has traditionally been adapted to a car-oriented infrastructure, primarily based on distribution solutions using diesel vans and trucks (Arnold *et al.*, 2018).

The number of light commercial vehicles is growing in cities (Hogt *et al.*, 2017). The demand for more goods, fast deliveries and an on-demand economy (Dablanc *et al.*, 2017) in combination with the public sector zero-emission goals results in small deliveries and decreasing average shipment size, which in turn, contributes to an increase in the number of vans (Moolenburgh *et al.*, 2020) and results in vehicles using less of their maximum capacity (Hogt *et al.*, 2017). Increased e-commerce will continue to have a significant effect on in cities and contribute to a growing number of freight vehicles performing transport assignments (Visser *et al.*, 2014; Moolenburgh *et al.*, 2020). The increased demand for goods delivery in cities combined with a greater focus on access restrictions, environmentally friendly and vibrant cities accelerates the need to rethink traditional goods delivery operations. With increased demand for goods comes a corresponding need for space devoted to logistic activities.

The trends observed in cities put the logistics sector in a challenging situation where they are pressured to quickly lower emissions while also reducing their use of space in dense cities. One would expect the density of potential customers within cities to be a benefit for logistics companies, but operations can be hindered by congestion, significantly reducing efficiency. Logistics facilities closer to customer areas can allow the use of LEFVs to navigate dense areas more efficiently, but those facilities are expensive and demand dramatic increases in efficiency to offset costs. This phenomenon has been noticed by other researchers, recently by Buldeo Rai *et al.* (2022. p. 57) and Kin *et al.* (2024, p. 29), and we suggest referring to it as the "densification paradox" for logistics, where a concentration of customers does not necessarily lead to an increase in efficiency.

The aim of the paper is to provide operational insight into the use of cargo cycles using delivery data from two case studies plus interviews, showing under what circumstances they can be a useful complement to vans. The costs of the transshipment facilities were not included in the comparison as the necessary data were not available. Additionally, differences in the case studies in terms of scale, the use of subsidies, local context and the types of goods would make such a comparison of limited use. To use the framework of He (2020), we look at a single tier network for last mile delivery. Results indicate that cargo cycles are best suited to carrying smaller packages in areas that are difficult for larger vehicles to access with a relatively high customer density and a high number of stops. We also address some drawbacks and challenges in using cargo cycles effectively. In the following sections, we present a literature review, followed by the methods used and presentation of case studies. After that the results are presented and the paper closes with discussion, conclusions and future research.

2. Literature review

The last mile is well known to be the most expensive (Goodman, 2005), most complex (European Commission, 2011) and most polluting (Albergel *et al.*, 2006) part of the logistic chain, with estimates suggesting it accounts from 28% (Ranieri *et al.*, 2018) to more than 50%

(Ostermeier *et al.*, 2022) of the cost. Light electric freight vehicles (LEFVs) might be a step in the right direction to these challenges (Moolenburgh *et al.*, 2020). This paper defines LEFVs in accordance with van Amstel *et al.* (2018) *as a* "bike, moped or compact vehicle with electric assistance or drive mechanism, designed for the distribution of goods in public space with limited speed. LEFVs are quiet, agile and emission-free and take up less space than conventional vans and trucks" (van Amstel *et al.*, 2018, p. 4) In several European cities, urban planners are shifting their focus from automobiles to cyclists and pedestrians, which has contributed to cargo cycles becoming an alternative to motorized vehicles for urban freight (Dybdalen and Ryeng, 2021). Electric cargo cycles can play a key role as zero-emission vehicles in dense cities where the focus is on minimizing car use (Assmann *et al.*, 2019). Cargo cycle distribution of packages and small shipments in central urban areas has great potential as cargo cycles are not impeded with the same restrictions related to queuing and parking as vans and trucks are. Cargo cycles often have the option of using bicycle lanes, roads and sidewalks, though the type of infrastructure used and where the cargo cycle parks can be influenced by the available infrastructure and its design. At the same time, the unfettered access of cargo cycles to sidewalks and other pedestrian areas can lead to safety concerns and other externalities, especially if cargo cycles are more widely adopted (Dalla Chiara *et al.*, 2023). So far, these potential safety concerns have yet to materialize as no fatal accidents have been reported for cargo cycles and just a few injuries to riders and the public (van Duin, 2022).

In addition, cargo cycles avoid access restrictions in the form of zero-emission zones, tolls and other climate and environmental measures and can more easily maneuver away from unforeseen detours and closed roads (Sheth *et al.*, 2019; Gruber *et al.*, 2014). In Norway, and to some extent Sweden, bicycles can also ride on one-way streets where this is signed, which further increases the accessibility and flexibility of the cargo cycle compared to vans and trucks. However, cargo cycles are also limited by lower capacity (weight/volume), more limited range due to lower speeds and the added expense of transshipment operations and facilities. Therefore, even if delivery of goods with cargo cycles is considered an attractive solution in compact future cities, cargo cycles will not be suitable for all product segments and for already consolidated goods (Nordby Rundberget *et al.*, 2019) without innovation. Many solutions require the implementation of two echelon vehicle routing problems that ensure the cycles are supplied with goods throughout the day either through mobile or fixed depots, but this adds complexity which adds to costs (Boysen *et al.*, 2021).

The estimated potential for these small vehicles varies from being able to deliver from 10% (Melo and Baptista, 2017) to 25% (Wrighton & Reiter, 2016) of the total number of goods in cities. Wrighton and Reiter's (2016) estimate rises to 50% if private citizens' logistic trips are also included. Melo and Baptista (2017) used a traffic simulation model in AIMSUN 8.1.2 (Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks) to assess whether LEFVs, such as cargo cycles, could achieve better environmental and social results and still obtain the levels of operational and traffic efficiency for the city of Porto (Portugal). Robichet *et al.* (2022) studied DB Schenker's operations in Paris and found that while it was theoretically feasible to distribute as much as 91% of their goods by cargo cycle using a weight limit of 200 kg, the costs would be prohibitive, with access to microhubs being the primary expense driver. Their estimate does not consider the volume of goods.

One of the biggest competitive advantages a cargo bicycle has over a delivery truck is its ability to quickly find parking close to the customer. A recent study conducted by INRIX in 2017 indicates that vehicles spend 9 min on average looking for on-street parking and this significantly adds to traffic congestion and emissions while Dalla Chiara and Goodchild (2020) found cruising for parking accounted for 28% of total trip time in Seattle on average. Trucks circling street blocks until parking is found hampers efficiency, adds to congestion and increases air pollution (Sheth *et al.*, 2019).

Parsmo (2019) performed a lighter version of an LCA on propulsion for the use of cargo cycles in relation to electric and diesel vans. Not surprisingly, from energy efficiency perspective cargo cycles do well. The energy usage per kilometer for propulsion compared to an electric van decreases 7–12 times. In comparison to a diesel van, the decrease is 13–27 times. In both instances the truck was lightly loaded (50–200 kg) (Parsmo, 2019).

In Frankfurt and Utrecht, DHL has piloted a City Hub concept. A van drives into the city with multimodal ready containers that can be easily transshipped from the van to a cargo cycle. According to John Pearson, CEO DHL Express Europe, the cargo cycles offer a range of advantages; bypass congestion and make up to two times as many stops per hour than a van. The total cost of ownership is less than half than a van. But most importantly, there are no emissions (DHL Press release, 2017). In another study, Verlinghieri *et al.* (2021) similar benefits can be found with freight cycles, including lower costs, better maneuverability, less road space occupied and quicker delivery. By reducing delivery distances and times, cargo cycles can increase the efficiency of urban freight. Additionally, these businesses are aware that additional handling expenses in regional hubs can be reduced by employing intelligent procedures like containerization, standardization and automation (van Duin *et al.*, 2022). Van Duin also has an updated scientific literature compilation on the topic of LEFVs. As an example, only one real life case has been found comparing vans to cargo cycles, Browne *et al.* (2011). They thoroughly investigated the case of Gnewt Cargo in London. From the company's standpoint, the LEFV trial was a success in terms of transportation, the environment and finance because using LEFVs reduced total distance traveled and CO2 emissions per parcel delivered by 14 and 55%, respectively. After the project was completed, they made the decision to keep using LEFVs for delivery. This paper tries to improve this gap in previous literature, mentioned by van Duin (2022).

However, it is also clear that cargo cycles can only replace some activities within a transport system and effectively implementing them in cities is reliant on operational, vehicular, infrastructural, workforce, organizational and policy factors and a mixed fleet is likely to be the most efficient (Narayanan and Antoniou, 2022). These different factors can act as enablers or barriers for cargo cycles.

3. Methods and case description

This paper is centered on two case studies introducing cargo cycles in parcel delivery operations from Norway and Sweden, adding cargo cycles in one case and replacing two vans with two cargo cycles in the other case. The case of the city hub for Company A in Norway was the first of its kind to ensure zero emission deliveries within the entire city and offered perspective on the use of cargo cycles in cooperation with vans. The data from Company B provided a unique opportunity to compare cargo cycles and vans in operation. In both cases the data were provided by the companies.

Additionally, to understand the introduction of LEFVs in a wider context and to confirm common themes across the use of LEFVs, interviews with a Swedish cargo cycle producer and a Norwegian logistics company were conducted. The type of data sources used in this article comprises delivery data, interviews, email exchanges, company web sites and company documents as summarized in Table 1. The delivery data for each case study is described in greater depth in sections 4.5 and 4.6.

3.1 Presentation of companies, interviewees and their use of LEFVs

A total of 20 in-depth interviews were conducted with managers and drivers from four different companies operating in last mile distribution on the use of LEFVs. A common interview guide was developed to ensure similar topics were covered during interviews with

Company	Position of interviewee	Company description	Type of data
Company A (Large, experienced company)	Sustainability manager, Land transport Operational leader hub Cargo cyclist	World's leading logistics provider with electric cargo cycle operations in several cities in Norway	Interviews, delivery data
Company B (Large, experienced company)	First Choice and quality manager Country compliance coordinator First Choice senior advisor Operations director, Sweden Network operations Area operations manager, West	Global logistics company with electric cargo cycle operations in the three major cities in Sweden	Interviews, delivery data
Company C (Small company, new entrants)	Founder and formerly responsible for Stockholm region	A Swedish cargo cycle producer and logistics operator	Interviews
Company D (Small company, new entrants)	COO Regional manager/project leader Drivers	Norwegian logistics company using electric mopeds for night deliveries	Interviews

Source(s): Table by authors

Table 1.
Description of interviewees from four companies

the four companies. Each interview lasted between 45 and 60 min and was recorded and subsequently transcribed. The interviews were used to identify common themes and provide insight and context into the delivery data. Email exchanges (approx. 500), company websites (approx. 50) and company documents (approx. 20) provided additional context for operational and strategic decisions behind the use of LEFVs. This also provided needed insights for interpreting the delivery data provided by Companies A and B. An overview of the collected data and the companies involved is available in Table 1.

Company A first introduced the three cargo cycles in their city distribution in Oslo in 2019. The three cargo cycles were loaded and stored at a centrally located microhub comprising of two 20 foot containers. Company A expanded their operations and invested in a city hub at the same location. Around 21 electric vehicles perform last mile deliveries in Oslo city center from this hub, including electric cargo cycles, electric trucks and electric vans. Despite substantial investment in larger electric vehicles, Company A still found the cargo cycles necessary for carrying out efficient last mile logistics for certain areas of the city that were challenging to access for larger vehicles.

For Company B, the Dutch branch of the company began using cargo cycles since its existing routes with low distances and high customer density were seen as especially suitable for a cargo cycle trial. Company B's Swedish branch started using Dutch "long bikes" in 2017 in Stockholm. From the distribution center, the distance to the delivery area was only six kilometers and "by avoiding congestion" the cycles could reach their destination 15 min faster than the vans. The driving force behind the initial implementation has been the global sustainability vision for 2030, which expects last mile deliveries to be zero emission. In Stockholm, Company B replaced three vans with four cycles and in Gothenburg two vans were replaced with two cycles. Company B needed a centrally located hub for supplying goods to the cycles, but it took some more time and steps to get a sensible business out of it, in part because there were only a handful of cargo cycles in operation which limited efficiencies of scale.

As a cycle producer and a cargo cycle operator, Company C has more experience with cargo cycle operations than Companies A and B but is significantly smaller. They also use a variation of cargo cycles, some of which are produced and sold to other companies. Their own electrically assisted cargo cycle has a capacity of 200 kg and up to four cubic meters but was not included in the test cases.

Company D initiated testing of a new type of electric moped in the summer of 2019. The electric moped is a Norwegian produced vehicle on four wheels and is classified as category L6e or L7e by the EU. The LEFV offers a range of 90 km with so-called active distribution, including stops and acceleration. These LEFVs are assumed to be suitable for all routes between 10 and 80 km, which make up 60–80% of Company D's current route structure. The transition to LEFVs will cover about 40% of the more than 1,000 routes in Company D's distribution network. The LEFVs are primarily used in cities and suburban areas across Norway. Prior to investing in LEFVs the operating model of company D was based on each driver using their own private car, which provided little opportunity to standardize sorting and loading of the vehicles.

3.2 Specifications of vehicles in the company use cases

Three vehicle types are present in this study with the following associated vehicle specifications in Table 2.

4. Results

This section presents the results from the in-depth interviews. The data of the people interviewed can be viewed in Table 1. The section ends with the presentation of the route data for the two cases as well as calculations.

4.1 Effects on efficiency

One of the primary advantages offered by LEFVs, and especially cargo bikes, is their ability to avoid traffic and more easily access dense, congested areas of the city. Depending on their type and local regulations, different LEFVs may have different levels of access to enabling infrastructure. For example, in Norway small electric distribution vehicles such as mopeds are not allowed on sidewalks, cannot use cycle infrastructure and must abide by the same

Cargo cycle	
Height, width and length (cm)	160 x 86 x 305
Weight (without trailer)	270 kg total max weight
Load capacity	1 m3 + 1 m3 (200 kg)
Electric motor assistance	250 W, two 0,5 kWh batteries
Diesel van	
Height, width and length (cm)	256 x 242 x 694
Weight	1,270 kg allowed total weight
Load capacity	14 m3
Fuel type	Diesel
Electric moped	
Height, width and length (cm)	186 x 118 x 229
Weight	845 kg
Load capacity	1.2 m3 (240 kg)
Electric motor	3-phase PMAC with up to 48 V 10 kWh battery

Source(s): Table by authors

Table 2. Specifications of the vehicles

delivery windows in pedestrian areas that restrict larger vehicles. Therefore, electric mopeds as used by Company D are not as flexible as cargo cycles when it comes to accessibility in city centers and is why, according to managers at Company A, electric mopeds were not considered for their distribution.

Company B found that the operating window was larger for cargo cycles than for vans, since the cycles reached the delivery area faster and delivered efficiently. Company A invested in electric vans and trucks for last mile distribution from their city hub but continued using cargo bikes for certain routes. According to both drivers and managers, access to areas and infrastructure in the city center was more challenging for conventional distribution vehicles. In addition, the delivery density in the areas surrounding the transshipment hub was well-suited for cargo cycles.

Company D has experienced a substantial improvement in efficiency with the introduction of LEFVs and sees them as well-suited to address their distribution needs. The most obvious is the large number of stops and deliveries of small sized parcels during a shift. A large volume makes every small timesaving related to vehicle functionality a substantial total efficiency improvement. With easy access to parcels, the open solution without doors and flexibility of parking the LEFV showed clear efficiency potential compared to the before situation with private cars. The most important feature of the LEFV is the possibility to load and organize parcels at the front dashboard of the vehicle, which gives easy access to parcels during delivery. Another influencing factor was Company D's ability to standardize loading of vehicles. The loading operation that previously was performed by each driver at their own pace and logic into vehicles of different design was replaced by standardized loading of similarly designed vehicles specially developed for goods delivery purposes. In the case of Company D, which is true for many last mile delivery actors today, volume capacity of the vehicle is not the limitation for efficient deliveries, but rather how many parcels a person can deliver per hour. This means that it is not the carrying capacity of the LEFV that is crucial to obtain efficient deliveries, but rather the duration of work sessions and the effectiveness of the routes.

In terms of lessons, Company B mentions the positive productivity as well as the positive publicity as somewhat of a surprise to them and loading capacity as a downside. Company B still must use sweeper vans (a van that helps) for larger packages. In terms of weather, in Stockholm and Malmö the cyclists are out all day, all year round without facilities. The drivers eat lunch in the city, since there is no transshipment facility, they get a tax-free voucher for 2000 kronor that they pay 600 kronor from their salaries. Financially for Companies A and B, the purchase cost is around 100 k SEK for the cycle (Velove) to compare with around 300 k SEK for a van. Despite the lower vehicle price, employee wages are a more significant obstacle when introducing LEFVs. A certain level of productivity needs to be reached to offset additional costs due transloading processes or reorganizing route structures. While Company B has not experienced any major issues with uptime for their cycles both companies A and C mentioned the importance of maintenance and voiced a concern that the vehicles they used had issues with the constant high loads on the axles and other parts. Company C needed a full-time mechanic for their ten cycles, while Companies A and B used a third party for maintenance.

For efficient use of cargo cycles sorting and the targeted allocation of goods to the cargo cycles are important. Company B sees the nature of the load as important as size and volume must be suitable to the LEFV. The challenge is to find enough small packages to deliver by cargo cycles, which for Company A has a maximum 30 kg per single package. When introducing cargo cycles the sorting and route planning of Company A needed reorganization to make sure that the different vehicle types were used optimally. Goods sorting and allocation at a post code level did not take sufficient account of the vehicle specifications and the drivers experiences were leaned on heavily to better differentiate appropriate routes for the different vehicle types.

However, e-commerce order sizes are on average coming down both in order size and volume. Therefore, according to Company B, a combination of smaller vehicles, like cargo cycles, golf carts and electric small trains together with sweeper vans could really make a difference. But the real benefit for the cargo cycle is the possibility to use all types of infrastructure and get close to the customer, which some of the other smaller electric vehicles cannot. A cyclist from Company A believes that for small package deliveries in the city center cargo cycles are faster than vans, which implies that the distance of the transshipment hub from the city center impacts efficiency.

The cargo cyclist also saw a great advantage in moving to a transshipment facility that serves all the vehicles responsible for last mile distribution in Oslo city center as opposed to using a microhub serving just cargo bikes. The larger hub makes it possible to communicate and perform fine sorting between the drivers of different vehicle types. As everyone at the hub is employed by Company A and not temporary workers, the cyclist experiences that the crew at the hub work as a team with a common goal to empty the hub of packages. The drivers are paid per hour instead of per package, which means that the drivers can allocate goods between vehicles based on what makes most sense from an efficiency and route planning perspective instead of worrying if they have enough packages for the day. The cargo cyclist has experienced an increase in deliveries and weight per day due partly to this evolution.

Other key factors are educating employees in new types of vehicles and usage. For Company B it was a "what can we do with what we have" mindset from the onset in both Stockholm and Gothenburg. Company B used personnel internally and experienced a barrier with getting people to make the switch from vans to cycles. Company B did not want to force anyone and learned that working as a cargo cyclist "requires a special type of mindset."

4.2 Key performance indicators (KPIs) used

Company B measures productivity in various forms, such as energy per stop or fuel efficiency per stop, MJoule per shipment (per parcel), stops per route and stops per on route hour. It is important to put these measurements in context. Not just the number of stops. As mentioned, Company C also focuses on maintenance hours. Since Company C lost a lot of uptime on broken cycles, all other productivity measures became secondary at one point. This has been improved now. For Company B, they could borrow cycles from a third-party supplier if they experienced a break down. The fleet system is not yet installed on the cycles, meaning they are not integrated into the company's global telematics system. If so, Company B can check speed and driving behavior in even more in detail. Company D views delivery efficiency as an important KPI and the only factor that increases their income. Company D sees the need to develop a new internal logic incorporating the time aspect in a better way and describe time as an important part of their business. The utilization of the vehicles is also important, but the focus is rather on how much and what a vehicle should be filled with in order to be used optimally, rather than achieving as high of a utilization rate as possible.

4.3 Corona

More people changed from pick up at service points to home delivery during Corona, which then increases the number of stops per courier. For Company B, pre-Corona, out of all shipments around 40% were to private individuals. Pre-Corona most of these were delivered to a few service points. Now they had to go to multiple homes, which drives costs up and decreases productivity per courier. Also, at drop off, Company B has skipped the digital signature, increasing productivity. This was planned before Corona, but Corona sped this process up. Company B uses power of attorney (BankID), less signing but more pictures as proof of delivery and app-based verifications. This is to get permission to put parcels outside the door, especially for houses. This has been a global decision. Company B does not think that customers will revert back post-corona, home deliveries will still be popular and the new ways of permission and less interaction is here to stay. *"We were thinking of doing this anyway, but Corona sped up this process."* LEFVs operate better in an environment with frequent delivery stops rather than a few stops with many parcels. Company D also experienced a significant increase in volume of parcels for home deliveries, which in turn, entailed a greater degree of volume variations. Corona also led to the need for Company D to establish different attendance times at the exchange terminals to maintain social distancing, which delayed exchanges and resulted in reduced utilization of the distribution window.

4.4 Public authority

Company B knows that many cities are looking into creating zero emission or environmental zones, "Gamla stan" in Stockholm as an example. *"Will it even be possible to drive in a city center with a carbon vehicle in the future?"*. For Company B's cargo cycle projects, the local authorities have not been very involved. However, the use of cargo cycles received a great deal of attention in media, fairs and at universities, which surprised them. *"Cargo cycles are nothing new, but the novelty is that a big company is using them."* Company C believes that public authorities can contribute by continuing to build bike lanes, creating low emission zones, implementing congestion charges, lowering the speed limit in city centers and investigating regulations for increased battery sizes. Company D requests support measures that are adapted to LEFVs, as existing support schemes in Norway apply to electric vans and vehicles that require fast charging. There are no similar schemes for LEFVs and vehicles that do not use fast chargers.

Company D and Company A see the need to establish a terminal close to the city center to manage the transition to LEFVs in urban distribution. The terminals have critical functions such as storage and charging of vehicles, unloading, fine sorting and preloading of vehicles. Vacant areas in cities are a scarce resource and there is a need for public facilitation to find suitable locations and support the transition to LEFV's financially.

4.5 Presentation of route data for Company A

Route data for three cargo cycles and eight vans operating out of a city hub were shared by the delivery company from three two-week periods in September and December 2021 and March 2022. The collected data included information on aspects such as delivery weights, volume and number of packages (see Table 3). Driver reports recording vehicle kilometers were also collected for 2021. Though these reports do not overlap directly with the time periods from the route data, they can still be considered relevant as the route structure for the hub did not change significantly during this period.

Table 3. Data from company A's eight electric vans and three cargo cycles

Averages	Rounds	Number of deliveries	Volume (m3)	Number of packages	Average kilometers	Total weight (kg)	Package weight	Delivery weight
Cycles	3.0	37.9	2.2	64.7	23.4	320.8	5.0	8.4
Vans	1.5	43.2	3.7	102.6	52.8	492.6	4.8	11.0

Source(s): Courtesy of Company A and B

In the case of this city hub, the drivers had areas of the city that were considered their primary responsibility, but the volumes were high enough that no single vehicle could manage the area alone so there was overlap between delivery routes in the city center. The proximity of multiple routes created the possibility for vehicles to swap packages at the hub in accordance with what drivers considered most efficient based on their experience. Factors that affect the decision to exchange packages include access restrictions, weight, proximity to other deliveries (clustering) or capacity issues as a result of large daily variations in the number of packages to be delivered to a specific area.

The result of the active exchange of packages was that the cargo cycle's delivery load was characterized by being lighter, with fewer packages, to areas with less ability to consolidate packages. In practice, this meant that vans would be more likely to deliver to shopping centers while cargo cycles delivered to single stores or offices. As a concrete example, during the analysis period, 89% of deliveries to dentists in the center of Oslo were performed by cargo cycles. The differing roles of the two vehicles can be seen in the data as a higher number of packages delivered by vans (59%) without a correspondingly large increase in the number of deliveries (14%). A delivery is not equivalent to a stop, so multiple deliveries might be registered at a single customer if they receive goods from different retailers.

The proximity of the hub to the delivery area allowed both cycles and vans to return to the hub to replenish goods as needed. This was especially important for the cycles to compensate for their lower capacity, and we see that they took on average three trips back to the hub to collect more goods. In interviews some drivers mentioned they would take as many as five trips back and forth to the hub during a day, sometimes delivering shipments weighing over 100 kg to areas close to the hub but difficult to reach for larger vehicles.

4.6 Presentation of route data for Company B

In contrast to data from Company A, the data from Company B allows a more direct comparison between cargo cycles and vans as they were used on the same route delivering the same type of goods. Company B is a post and parcel company, which suits LEFVs particularly well since the shipments come in smaller packages and volumes and the operations are conducted within networks of high customer density (van Amstel *et al.*, 2018). In practice, this meant that Company B's cargo cycles were able to complete their deliveries without needing to return to a hub to replenish goods. The cycles start their operations in the morning from a parking space in the garage of a major shopping mall and deliver in an area of a radius of about 1 kilometer. The cycles are also stored here over night. See Table 4 for weight distribution of the parcels from Company B.

The company has supplied us with data for three years, 2018, 2019 and 2020. For the first two years, they performed the deliveries using conventional diesel distribution vans (mainly Mercedes Sprinter). For 2020, the distribution vehicles were switched to cargo cycles with removable mini containers (Velove). These data sample are for the month of September for

Route	Envelope 0–3 [kg]	Small 4–6 [kg]	Medium 6–10 [kg]	Large >10 [kg]	Approximate average weight per parcel	Total number of deliveries [st]
Van 1	31	8	3	5	2.6	47
	66%	17%	6%	11%		
Van 2	37	7	9	2	2.5	55
	67%	13%	16%	4%		

Note(s): Note that more than half are parcels
Source(s): Courtesy of Company B

Table 4. Approximate weight distribution of parcels for the delivery area of Company B from 2019

each year. September is a month that, according to the person responsible for data collection at the company, is "normal" in terms of volumes. The cycles made on average 70 stops per route with a customer density of approximately three stops per kilometer. Operationally, the delivery area is the same for the three years and the number of customers in the same range. However, the vans start their operations at the distribution center outside the city close to the airport. To account for this, adjustments to the data have been made. Using Google maps, the distance between the distribution center to the parking space in the shopping mall was calculated and the distance and time of travel (return trip) was subtracted from the van data. See the following sections for numbers.

4.7 Calculations of data

In this section, we present the calculations of the data from the case studies. But let us first explain Company B's Table 5 more in detail and relate this to Company A. The main key performance indicators used by Company B are SPR, SPROH and kilometers driven. SPR is short for stops per route and SPROH is short for stops per on route hour, meaning how many stops the driver makes per hour during active/productive working time. With these three KPIs one can calculate various important performance measures, and these are used by the companies to assess the productivity of employees and various vehicles. As seen from the interviews they also use energy used per shipment (parcel). Performing a similar calculation for Company A's data provides a SPROH of 6.3 for cycles and 7.2 for vans. This assumes six hours spent on route, for Company A, to account for lunch, breaks and time the drivers spend sorting goods in the morning. Company B gets presorted packages.

4.7.1 Customer "density"/route efficiency and average weight of parcels. By dividing the number of stops with driven kilometers in the city center, we would get a proxy of customer density. This is not an exact number, since a vehicle driving less "unnecessary" kilometers would also seem to operate in a more customer dense area, even though that is not the case. For Company B, the vans the customer density is between 1.9 and 2.8 stops per kilometer and for the cargo cycles the customer density is 3.4 stops/customers per kilometer since the cargo cycles are more route efficient.

For the average weight of the parcels, it is clear that Company B has smaller packages 2.5–2.6 kg (2019 data) than 4.8–5 kg for Company A, where Company B has a lot more envelopes. The average weight per parcel for cargo cycles at Company B in 2020 can be expected to be even lower since they used a sweeper van for the heavy packages.

4.7.2 Corona effects. The researchers have been told by Company B that the customer density, number of parcels and working times has remained stable over these years. For 2020 and the COVID-19 epidemic, the volumes for September where "quite normal" for the year (Interviewee at Nordic operator, 2021). "If anything, the restrictions during 2020 due to the Covid-19 pandemic were at times quite stringent, the driver could not always use elevators and such which impeded productivity, so possibly the productivity numbers are a bit low". This suggests that while the negative impacts of Corona were relatively limited, the productivity numbers for cargo cycles (measured in September 2020) could be on the lower side.

4.7.3 Distance, time and productivity. As mentioned, to be able to compare the vehicle data for Company B, we need to subtract the distance and time spent driving into and away from the city for the vans. The distance between the shopping mall and the Distribution center at the airport is 21 km and they spend 21 min one way since the average speed is 100 km/h according to Google maps, a highway with 110 km/h max speed and slower in the very beginning and end of that leg. That means that 42 kilometers and 42 min of their trip and workday should be subtracted before we make the performance calculations.

Table 5. Data from delivery area of Company B for 2018, 2019 and 2020

2018 – van PUD date	PUD route	SPR	SPORH	Km	2019 – van PUD date	PUD route	SPR	SPORH	Km	2020 – cargo cycle PUD date	PUD route	SPR	SPORH	Km
2018-09-03	Van 1	62	10.67	80	2019-09-02	Van 2	83	9.88	69	2020-08-31	Cargo cycle	86	11.85	25
2018-09-04	Van 1	68	10.56	74	2019-09-03	Van 2	69	9.5	50	2020-09-01	Cargo cycle	75	10.52	27
2018-09-05	Van 1	64	10.16	74	2019-09-04	Van 2	67	8.9	70	2020-09-02	Cargo cycle	87	12.55	25
2018-09-06	Van 1	62	10.02	78	2019-09-05	Van 2	73	9.42	x	2020-09-03	Cargo cycle	85	12.06	30
2018-09-07	Van 1	71	11.11	82	2019-09-06	Van 2	71	9.01	78	2020-09-04	Cargo cycle	82	13.36	22
2018-09-10	Van 1	52	9.72	81	2019-09-09	Van 2	73	9.21	68	2020-09-07	Cargo cycle	86	12.84	23
2018-09-11	Van 1	68	10.32	81	2019-09-11	Van 2	78	10.37	68	2020-09-08	Cargo cycle	71	11.7	25
2018-09-12	Van 1	62	10.9	74	2019-09-12	Van 2	61	8.52	78	2020-09-09	Cargo cycle	75	11.9	24
2018-09-13	Van 1	61	10.34	83	2019-09-13	Van 2	77	11.96	71	2020-09-10	Cargo cycle	76	12.08	21
2018-09-17	Van 1	66	10.7	74	2019-09-16	Van 2	68	9.25	65	2020-09-11	Cargo cycle	80	12.1	27
2018-09-18	Van 1	66	10.3	82	2019-09-17	Van 2	70	9.47	75	2020-09-14	Cargo cycle	75	13.94	17
2018-09-19	Van 1	74	11.13	73	2019-09-18	Van 2	75	9.86	71	2020-09-15	Cargo cycle	72	13.07	15
2018-09-20	Van 1	68	10.13	78	2019-09-19	Van 2	75	10.11	71	2020-09-16	Cargo cycle	75	15.09	20
2018-09-21	Van 1	60	10.34	66	2019-09-20	Van 2	70	9.41	73	2020-09-17	Cargo cycle	72	14.55	20
2018-09-24	Van 1	60	10.08	72	2019-09-23	Van 2	72	9.5	71	2020-09-18	Cargo cycle	72	16.63	17
2018-09-25	Van 1	71	10.01	81	2019-09-24	Van 2	72	9.7	73	2020-09-21	Cargo cycle	76	12.46	28
2018-09-26	Van 1	66	10.2	83	2019-09-25	Van 2	73	9.86	69	2020-09-22	Cargo cycle	77	11.81	23
2018-09-27	Van 1	38	9.92	66	2019-09-26	Van 2	72	10.54	69	2020-09-23	Cargo cycle	72	11.96	28
2018-09-28	Van 1	69	10.83	71	2019-09-27	Van 2	69	9.4	71	2020-09-24	Cargo cycle	74	11.71	24
										2020-09-25	Cargo cycle	69	12.95	20
Average		*63.,6*	*10.4*	*76*	*Average*		*72*	*9.66*	*70*	*Average*		*76,9*	*12.61*	*23*
		Total		*1.453*				*Total*	*1.259*			*Total*		*461*

Note(s): PUD: pickups and delivery, SPR: stops per route and SPORH: stops per on route hour
Source(s): Courtesy of Company B, retrieved 2021

The most fitting KPI in the data from a productivity point of view is SPORH, meaning that the number of stops performed on average every hour of the working day. The productivity calculations were performed using the average of SPORH in September each year, 2018 and 2019 for vans and 2020 for cargo cycles.

Before making a fair comparison of these years, we need to consider the longer distance and time the vans are driving in the morning to and from the city center from the airport. From the above, the distance and time it takes between the airport and the city center times two is 42 km and 42 min, and 42 min is 8.75% of an eight-hour workday (42/480), which means that if the drivers of the vans would have started from the same place they would be almost 10% more efficient (100/(100–8.75) = 1,095). The average "new" SPORH for the vans would then be 10.6 (9,66x1,1) and 11.44 (10,4x1,1), respectively. The span of the productivity improvement for the cargo cycles would then in turn be 10–19% (12.6/11.44–12.6/10.6).

Another interesting result of this exercise is that we get a difference in total kilometers traveled by the vans and the cargo cycles. In this case, the cargo cycle drives 23 km in a day in September and the vans between 30 and 34 km, which is 23–32% less kilometers traveled. According to an employee in charge of operations for the European market, the above numbers are also in line with their own average estimates for cargo cycle operations, though there was a degree of local variation. They found a SPORH of 12 in their estimates, whereas we found 12.6 in our estimates.

Interestingly, Company A's cargo cycles have a similar daily km of 23.4, but their vans drive a much higher 52.8 km on average. This is likely attributable to the geography and infrastructure of the city in which they are based. A tunnel allows vehicles to cross the city at relatively high speeds to reach delivery areas, whereas the bikes are able to take a more direct route. As discussed previously, vans and cycles are also used differently to capitalize on their relative advantages. In Company As evaluation, it would be less efficient to use a van for the routes that the cargo cycles take despite their lower capacity and speed.

5. Conclusion

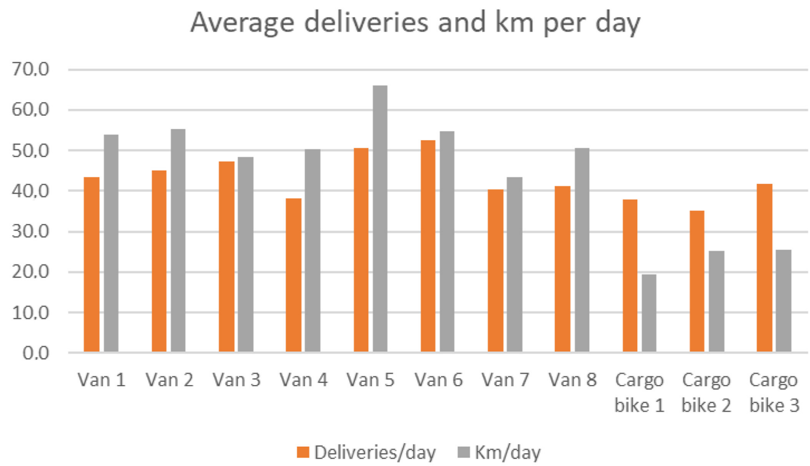
For LEFVs to be seen as viable by LSPs they need to be considered the most efficient option. We see that companies are adapting to the new landscape within urban logistics by developing new KPIs to better understand the efficiency of these vehicles. Measures such as stops per route and joules per shipment introduce a time and energy component to measuring efficiency. This is in contrast to the long-haul logistics industry which focuses more on ton kilometers (tkm) and vehicle kilometers (vkm), as vehicles are likely to "cube out" or "weigh out" whereas in last mile distribution vehicles will often "time out". Meaning that for parcels, oftentimes the driver's workday is the limiting factor, not the weight or the volume of goods. The energy component stems from the vision/targets of the companies as well as a correlation between reduction in energy and cost savings.

The limitations of tkm and vkm for measuring the efficiency of lighter vehicles are illustrated in a report from a Swedish government agency (Trafa, 2023, Figure 1 and 2, page 13), which compared light goods vehicles (LGVs) with heavy goods vehicles in Sweden. They found that the LGVs moved 3% of the total freight tonnes and 2% of the total tkm in Sweden, but 70% of the mileage. LGVs also caused 50% of the NOx, about 50% of the particle matter, and 30% of the CO_2. LGVs mostly operate in cities.

Similar to the findings from Browne *et al.* (2011), our case studies showed that cargo cycles drive fewer km than vans for similar routes. For Company B, the cargo cycles traveled between 23 and 32% fewer kms than vans in the delivery area, compared with 20% less in

Source(s): Photos: Howard Weir (author) and Wikimedia Commons for the van (courtesy of Wikimedia Commons)

Figure 1. Examples of light electric freight vehicles (LEFVs) and a van commonly used for distribution (white labeled)



Source(s): Figure by authors

Figure 2. Route data providing average deliveries and traveled kilometers for eight electric vans and three cargo cycles

Browne *et al.*'s (2011) study. For Company A the difference was more extreme, with the cargo cycles traveling 44% fewer km on average.

After the initial journey from the terminal is controlled for, cargo cycles from Company B travel fewer kilometers than vans. Since the delivery area is the same and the cargo cycle delivers to more customers, the only plausible explanation is that the cycles have better access by avoiding traffic and using various forms of infrastructure such as roads, bike lanes and pedestrian walkways, as was frequently mentioned as a benefit in interviews. The cycles do not have to cruise for parking, can take short cuts and are not affected by one-way streets or traffic to the same extent as vans. Driving speeds in cities are generally low for both bikes and vans and many last mile operators spend more time per customer outside the vehicle delivering parcels by walking than driving (Dalla Chiara *et al.*, 2023). Being able to use multiple forms of infrastructure leads to performance enhancements as the courier gets closer to the customer, faster and walks less.

One of the major differences between the two case studies looked at is that Company B directly replaced van routes with cargo cycles, whereas Company A incorporated them as part of a mixed fleet operating out of a larger city hub. The cooperation between the cargo cycles and vans makes it more challenging to isolate the performance of either the vans or the bikes, as they were reliant on each other and acted in cooperation to deliver as many goods as possible. Company A's cargo cycles also carried substantially more weight and volume than Company B's, though still not as much as the delivery vans. Proximity to the city hub and the ability to replenish goods throughout the day were reported to mitigate the limitations of cargo cycles related to capacity, allowing the cargo cycles to deliver greater volumes and weights.

Interestingly, the Browne *et al.* (2011) study also showed results related to distance traveled per parcel that we could not replicate with our available data. The total distance traveled per parcel was higher for cargo cycles in the Browne *et al.* (2011) study and the authors explain this by the limited load of the cargo cycles compared to vans as well as strict time requirements on some deliveries leading to less efficient routes.

The interviews confirmed the findings from literature; the running costs of cargo cycles are about half compared to vans and the purchasing costs are around a third. But in many instances the operational setups require some form of transshipment facility, which can be costly. Apart from the extra handling, hubs located centrally in cities are expensive and makes the creation of a profitable business model for cargo cycles challenging. While cargo cycles are less expensive to purchase and operate in terms of fuel/energy, maintenance issues remain a concern. In our case studies, and especially for Company A, the cargo cycles reportedly experienced significant challenges related to maintenance and parts availability.

Our work also supports previous research on bicycles traveling faster than cars in cities [1] by showing data that cargo cycles seem to mimic this pattern in relation to vans in city centers. It seems that cargo cycles deliver more efficiently than vans (measured by number of deliveries), at least with a customer density/route efficiency of over 2–3 customers per driven kilometer and for packages preferably of weights no larger than 5 kilos on average. Cargo cycles not only occupy less space, measured as fewer square meters per time unit but also drive fewer kilometers in total than vans.

A clear limitation of our study is that the additional costs related to the operation of hubs are not explicitly considered. Perhaps looking into a simpler form of a "terminal", microhub or meeting points for transloading between vehicles is a way forward, to use infrastructure that is available at least some of the time in a day. Like parking lots in centrally located malls or gas stations that most likely are looking into new business models for the use of their space. The Department of Transportation in New York City are currently testing a version of this, dedicating curb side for delivery operations, see NYC DOT (2023).

Many cities have begun to enact restrictions on the movement of vehicles in an effort to combat issues related to congestion, local pollution and safety. Doing so also encourages the use of LEFVs, making them comparably more efficient than larger vehicles. Cities will need to consider how access to dense areas is maintained while creating pressure to use light vehicles such as cargo cycles, electric mopeds or looking further into the future, autonomous delivery vehicles.

Introducing cargo cycles into logistic systems creates both costs and benefits that are split between different actors. The logistics companies bear the extra cost of transshipment facilities and maintenance for instance, while cities and inhabitants benefit from less vehicle movement, less pollution and less congestion. As seen from the data from Company A, vans perform better than cargo cycles where the parcels are about double the size on average and the customers are further apart compared to Company B. The limited cargo space and larger parcels add several replenishment trips for Company A's case.

Also, in Company B's 2020 data, where the operational efficiency is measured in a 1:1 replacement of vans with cargo cycles, still some of the heavy parcels are delivered by a sweeper van.

Conventional diesel vans will slowly be replaced by electric vans, and these will be the preferred solution for most parcel delivery companies as they require fewer changes in how logistic systems are organized. However, swapping out fossil vehicles with electric ones does not address problems related to congestion, parking, safety or particle emissions from tires and brakes (not to mention the resources necessary for vehicle production). Research suggests (Melo and Baptista, 2017; Wrighton and Reiter, 2016) that between 10 and 50% of logistics activities (including private logistics) can be carried out by LEFVs, which could significantly reduce the negative impacts of logistics.

Cargo cycles offer a number of benefits but also carry some serious drawbacks. While cargo cycles and other LEFVs have the potential to deliver a higher proportion of goods, a number of barriers have so far hindered their transition from niche to mainstream. If LEFVs are adopted more widely, issues such as competition for space on sidewalks and bike lanes as well as regulation addressing the use of infrastructure for LEFVs could become more prevalent.

6. Future research

This work examines the use of LEFVs through two case studies. One in which the performance of cargo cycles is examined in relation to their cooperation with vans operating in the same area and a second case study, which offers a more direct comparison as cargo cycles are used to replace van routes in a specific area. Both studies show that cargo cycles can be competitive with vans if they are able to leverage the relative advantages they have through use of well placed, cost-efficient and organized transshipment points.

The paper adds valuable information for organizations that are thinking of trying LEFVs in operations as well as municipalities/local authorities that are interested in implementing more sustainable last mile deliveries. It is also important to mention that with the advent of AI in combination with automation other types of LEFVs are on the horizon, for instance slow moving side-walk delivery robots in suburbs where the competition for space is lower.

From the interviews, we know that the results can be very context dependent, and it would be of interest to understand how factors such as customer density/route efficiency, business models, package size, topography and congestion levels impact the efficiency of LEFVs.

Note

1. https://www.forbes.com/sites/carltonreid/2018/11/07/data-from-millions-of-smartphone-journeys-proves-cyclists-faster-in-cities-than-cars-and-motorbikes/?sh=27c866bc3794

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