7 Delivery robots as a solution for the last mile in the city?

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1. INTRODUCTION

Urban freight transport is assuming an increasingly important role in the field of urban mobility as well as in urban transport policy, as e-commerce is booming: with the advance of digitalization, goods are increasingly being ordered via the internet, with a resulting sharp increase in delivery transport volumes (cf. Muschkiet/Schückhaus 2019: 358; German Federal Government 2019: 44f.). New sustainable solutions and concepts are therefore needed in urban logistics, with the last mile in particular posing a major challenge due to a lack of bundling and the great effort involved (cf. Gerdes/Heinemann 2019: 399; Buthe et al. 2018: 30; Lierow/Wisotzky 2019). At the same time, new delivery media are emerging, such as delivery robots (cf. Baum et al. 2019: 2455; Jennings/Figliozzi 2019: 317), which are seen as having great potential for the last mile.

To date, the development and use of delivery robots have been driven above all by logistics companies and technology developers, without consideration of the municipal perspective. This raises the question of whether and to what extent delivery robots are at all compatible with urban public spaces. This is all the more important since public space is already under increasing strain due to new forms of mobility, adaptation to climate change, rising population figures in cities and the resulting pressure of use. Conflicts of use and interest are inevitable in particular when automated delivery robots are on the move on pavements or in pedestrian zones (cf. Buthe et al. 2018: 121). In view of the necessary transformation of public space from being a transit space to an area with quality of stay, the diverse implications of delivery robots are therefore discussed and options for (transport) policy and planning identified.

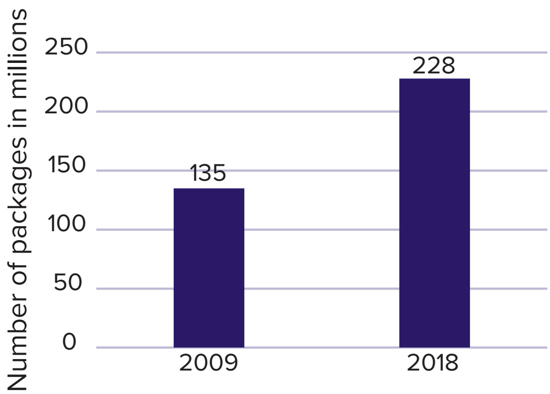
2. E-COMMERCE AND DELIVERY TRAFFIC ON THE RISE

Online trade – also known as “e-commerce” or “distance trade” – is booming. But delivery offers in stationary trade have likewise led to steady market growth for courier, express and parcel (CEP) services in recent years. In Austria, for example, the number of parcels delivered increased by around 69% between 2009 and 2018, and the corresponding global figure more than doubled between 2014 and 2018 alone. Similar developments can also be seen in Germany (cf. BIEK 2020: 11). Forecasts are predicting a further increase in the number of parcels delivered both in Austria and worldwide (cf. Umundum 2020: 151; Buchholz 2019). E-commerce sales volumes in Austria also recorded a significant increase of 21% in recent years, between 2015 and 2019, with an online share of total retail sales in Austria of currently already more than 5% (Fig. 1; cf. WIFO 2019: 15).

As a result of increasing delivery traffic, the need for action by cities and municipalities to proactively develop strategies and concepts for municipal freight transport, but also to plan and implement appropriate measures, is likewise increasing (cf. Schönberg et al. 2018: 4): since very many end users are served in urban freight transport, this results in a high number of small individual deliveries, which in turn leads to high mileages (cf. Vienna Business Agency 2016: 5). The result is an increase in particulate pollution and in CO_2 and noise emissions (cf. Muschkiet/Schückhaus 2019: 366), but above all conflicts in public space that are manifested in many ways as competition for space, personal endangerment, but also “commercialization of public space”.

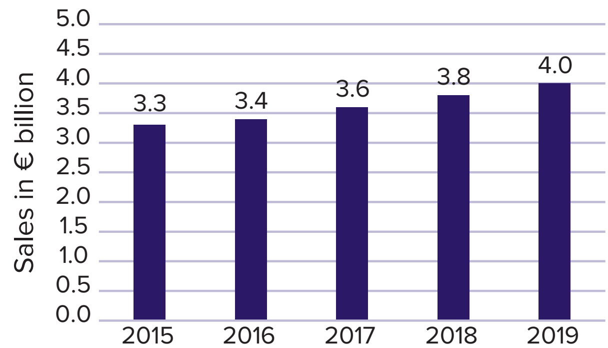
In view of the predicted increase in the volume of consignments – in Austria, for example, the number of parcels delivered is expected to increase by around 14% in 2020 over the figure for 2018 – the cost-intensive last mile will continue to gain significance, with all the negative effects on public space (cf. Leerkamp 2017: 12; Umundum 2020: 151).

Figure 1: Development of the Austrian parcel market in millions of units, 2009 to 2018



Source: Umundum (2020: 151)

Figure 2: Development of e-commerce sales in Austria, 2015 to 2019



Source: WIFO (2019: 15)

3. NEW DELIVERY CONCEPTS FOR THE LAST MILE

The last mile, i.e. the final stage of delivery of goods to the customer's premises, is still one of the most pressing problems in urban freight transport: the degree of utilization of transport carriers in supply and disposal decreases with proximity to the destination, and bundling becomes increasingly difficult over the last link of the supply chain (cf. Just 2018: 5; open4innovation 2019). More than 50% of costs in parcel delivery are incurred in the last mile (cf. Schnedlitz et al. 2013: 251; Schocke 2019). Particularly outside the effective delivery window, i.e. when the probability of the recipient being at home decreases, efficiency is even lower due to the need for multiple trips.

New logistics concepts are being implemented in the area of conflict between commercial efficiency on the one hand and the demands by municipalities for traffic avoidance and displacement and environmentally compatible delivery on the other: these concepts should help to achieve bundling effects, increase the "stop factor" in end-customer business and reduce transport requirements (Buthe et al. 2018: 30). A promising logistics concept is delivery to collection points – so-called city hubs – in the urban core zone by a small number of large lorries from the periphery. From there, the parcels are delivered over the last mile either directly to the customers or to micro-depots and parcel boxes. Various vehicle and drive concepts or delivery by (e-)cargo bike are suitable for covering the last mile (cf. Wittenbrink et al. 2016: 79f.; Leerkamp 2019: 21; Gerdes/Heinemann 2019: 406).

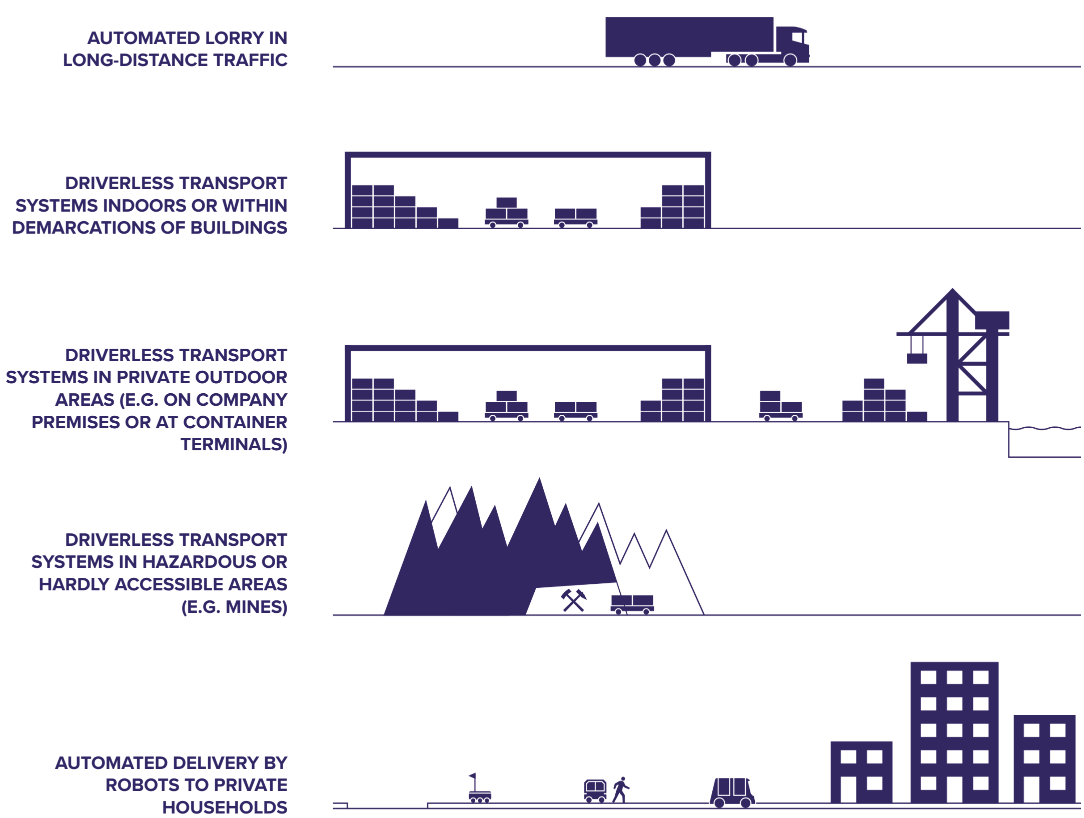
Automation and digitalization, and the delivery concepts based on these, are driving innovation (cf. Umundum 2020: 157). In addition to delivery drones, tests have recently been carried out with electric delivery robots – so-called automated "delivery bots" – in the USA for example, but also in Europe. Last-mile delivery is often seen as one of the first areas of application for automated driving, as these robots travel at low speeds and in a perhaps simple operational design domain (ODD), for example on pavements in a residential area on the outskirts of a city (cf. Soteropoulos et al. 2020; Mitteregger et al. 2022; Leitner et al. 2018: 22).

4. OPERATING CONCEPTS OF AUTOMATED VEHICLES IN LOGISTICS

Automated vehicles are by no means new to the field of logistics: they have already been used for a long time, especially in internal logistics. These vehicles have been used to transport goods in production and logistics systems since the 1950s, mainly for transport without a driver (1) indoors or within the demarcations of buildings, (2) in private outdoor areas, e.g. on company premises or at container terminals, and (3) in hazardous or barely accessible areas (cf. Flämig 2015: 378; Hörl et al. 2019: 35; Paddeu et al. 2019: 9ff.; Hofer et al. 2018: 11ff.).

Today transport within company premises is still the typical domain of automated driving in logistics, e.g. in the autonomous yard logistics of Austrian Post, and is subject to specific framework conditions in terms of infrastructure and processes (cf. Clausen 2017: 16; Muschkiet/Schückhaus 2019: 374; Umundum 2020: 156). As a result of progress in automation and digitalization, increasing attention is now also being given to applications in distribution logistics. In addition to automated lorries in long-distance transport (e.g. platooning – although some tests in this field have been discontinued, e.g. by Daimler; cf. Daimler 2019) and automated delivery concepts with goods delivered by drones, the use of delivery robots in the public spaces of cities and municipalities is now also being tested (cf. Baum et al. 2019: 2457; Howell et al. 2020: 36; Schröder et al. 2018: 7; Hofer et al. 2018: 14ff.). Figure 3 gives an overview of the operational concepts of automated vehicles in the field of logistics.

Figure 3: Overview of different delivery robots



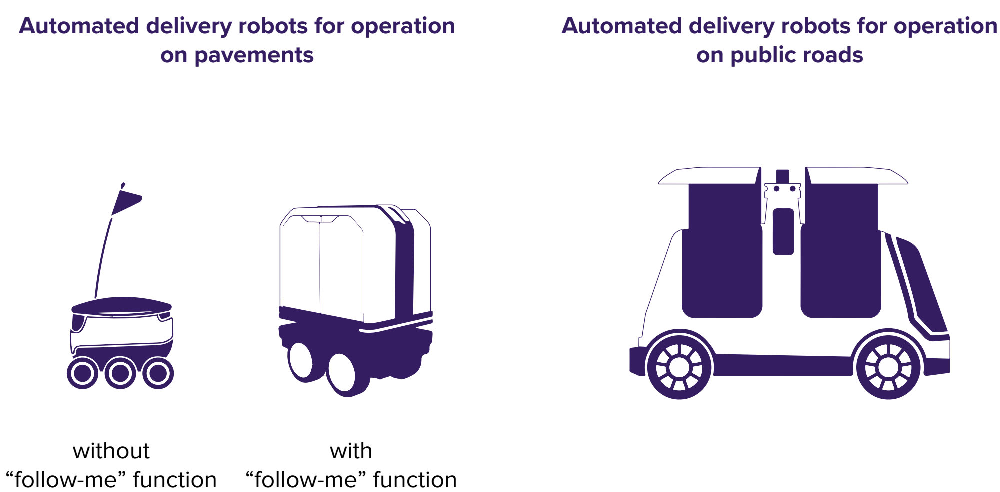
Source: the authors

5. DELIVERY ROBOTS

Delivery robots are driverless, often electric transport vehicles that assume the last mile of delivery from an inner-city warehouse or stationary retailer to customers within a defined permissible area (cf. Vogler et al. 2018: 152; Leerkamp 2017: 17). Their applications include special shipments that need to be delivered flexibly, rapidly and cheaply in a local environment, same-day or same-hour delivery, food consignments and home deliveries of medical products (cf. Hofer et al. 2018: 17). Some logistics concepts also involve lorries taking delivery robots to a large delivery area, where they carry out final delivery to customers (cf. Jennings/Figliozzi 2019: 321; DHL 2014: 32).

Various different types of delivery robot are now being developed by numerous companies (cf. Baum et al. 2019: 2457; Steer 2020: XVIII; and Fig. 4 below).

Figure 4: Overview of different delivery robots



Source: the authors

5.1 DELIVERY ROBOTS FOR OPERATION ON PAVEMENTS

This type of delivery robot is not suitable for operation on the carriageways of public roads, but is used on pavements and in pedestrian zones, where the speed is limited to 6 km/h. These robots are currently used in office parks (e.g. in Mountain View, USA) or other special areas: the requirements on the automated driving system are not as high in such places as for operation on public roads (cf. Hern 2018). In addition, these robots usually only have a small loading volume (cf. Leerkamp 2017: 17).

a) Delivery robots for autonomous delivery
These robots are suitable for the autonomous delivery of individual items within a short timeframe (20–30 minutes), particularly in dense city districts. The manufacturers of these delivery robots include Starship Technologies, Kiwi and Marble. The robots usually have a small container in which parcels can be placed (cf. Marks 2019: 13ff.). In its current version, the delivery robot from Starship Technologies for example can transport a maximum of two parcels, each measuring 35 x 34 x 15 cm (cf. Ninnemann et al. 2017: 86). Once the delivery robot arrives at its

destination, the customer can open the lid of the container at their front door using a one-time PIN that is sent to them via smartphone (cf. Vogler et al. 2018: 152).

b) Delivery robots with "follow-me" function

Delivery robots that drive on pavements can also support distribution logistics by means of a follow-me function; i.e. loaded with the parcel, they follow the recipient or orderer of the delivery, who is thus relieved of the burden. An example is the *PostBOT* delivery robot from the company Effidence S.A.S., developed together with Deutsche Post. Unlike delivery robots, which carry out their deliveries autonomously, the follow-me models are usually somewhat larger. The *PostBOT*, for example, has six package containers and can transport consignments weighing up to 150 kg (cf. Gerdes/Heinemann 2019: 411).

5.2 DELIVERY ROBOTS FOR OPERATION ON PUBLIC ROADS

Delivery robots that drive on public roads travel at speeds of up to 40 or 50 km/h and due to their size have a larger load volume than the models described above. They are typically used for autonomous delivery of individual items within a short timeframe (20–30 minutes), especially in areas with high customer density. Examples of this type of delivery robot are the *Nuro R1* and its successor *Nuro R2*, or *Robomart* and *Udelv* (Baum et al. 2019: 2458; Marks 2019: 22). The *Nuro R2* recently received the first nationwide temporary exemption from the U.S. Department of Transportation for testing on public roads without a driver (USDOT 2020: 5). These vehicles are not only suitable for last-mile delivery: Waymo, for example, recently announced that in the course of its ongoing test operations in Chandler, Arizona, its vehicles will also be used to deliver packages from local UPS shops to a UPS package sorting facility; however, delivery of packages directly to customers is not yet planned (UPS 2020). In the typical suburban areas of the USA where these vehicles are on the roads, with very wide streets, single-family homes and only few pedestrians and cyclists (e.g. *Nuro R2* in Scottsdale, Arizona, or Houston, Texas; cf. Nuro 2020), it is much easier for customers to pick up their goods from the vehicle at the kerb or in special areas where the robots are permitted to stop (so-called "self-driving pick-ups") than in corresponding neighbourhoods in Europe, which often have narrower streets and higher densities.

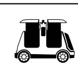
6. SELECTED EXAMPLES OF TESTS WITH DELIVERY ROBOTS

Numerous countries are testing delivery robots in pilot trials. While most of the robots being tested in Germany, Austria and Switzerland are not intended for use on public roads but only operate on pavements and in pedestrian zones (cf. Baum et al. 2019: 2459; Hofer et al. 2018: 17), tests and pilot trials with delivery robots have already been carried out on public roads in the USA. Table 1 on the next page gives an overview of selected examples.

With the exception of Switzerland, the test areas were mostly in the centre or business district of a large city. The follow-me delivery robot was tested in the small town of Bad Hersfeld, but here too in the central, commercial district. In the USA, the road-going model was tested on public roads in residential and commercial areas on the outskirts of cities and in suburbs.

The tests served to determine how safe, practicable and economical the operation of delivery robots can be from the perspective of the logistics companies. In addition to the postal service,

Table 1: Overview of selected tests and pilot trials carried out to date with delivery robots

					Priority issues					Evaluation method		
Location	**Period**	**Type of delivery robot**	**Company**	**Neighbourhood type**	**Commercial exploitability (business cases)**	**Safety and reliability**	**Technical feasibility**	**Customer acceptance**	**Interaction with other road users**	**Recording of vehicle data**	**Focus group discussions with stakeholders**	**Recording feedback from passers-by**
Hamburg (DE)[1]	12/2016–3/2017, 5/2017 and 1/2018	 Starship	Hermes, Domino's Pizza, Foodora	Mixed	✓	✓	✓	✓		✓	✓	
Bad Hersfeld (DE)[2]	10/2017–11/2018	 PostBOT	Deutsche Post	Centre, commercial	✓	✓				✓		
Graz (AT)[3]	autumn 2017	 Jetflyer	Austrian Post	Centre, commercial		✓	✓			✓		
Zurich, Bern, Köniz, Biberist, Dübendorf, Zuchwil (CH)[4]	8/2016–12/2016 and 9/2017–1/2018	 Starship	Schweizer Post, Jelmoli	Centre, commercial, residential	✓	✓	✓		✓	✓		✓
Scottsdale, AZ Houston, TX (USA)[5]	8/2018–3/2019 and 3/2019	 Nuro R1, R2	Kroger, Fry's Food, Walmart, Domino's Pizza	Residential, commercial	✓	✓	✓	✓		✓		

Source: 1 – Brandt et al. (2018: 8); Ninnemann et al. (2017: 85f.); Hermes (2017a, b); Leitschuh (2018) I 2 – Gerdes/Heinemann (2019: 411f.) I 3 – APA 2017, Eigner 2017 I 4 – Marazzo/Mischler (2018) I 5 – Nuro (2018); Shaheen/Cohen (2020: 249); Wiles (2019) the test users include CEP services and retail, restaurant and supermarket chains. However, no comprehensive evaluation or scientific monitoring took place aside from the companies' own interest in gaining knowledge. The tests did not address important issues such as conflicts of goals and use in the public streetscape, or especially interaction with other road users. By way of exception, however, the tests in Switzerland took more detailed account of these aspects, although they were not subjected to comprehensive scientific evaluation.

7. "PAVEMENT-COMPATIBLE" DELIVERY ROBOTS AS A SOLUTION FOR THE LAST MILE?

As the analysis shows, developments worldwide are mostly concerned with robots that travel on pavements and/or in pedestrian zones (cf. Baum et al. 2019: 2459); the following remarks therefore focus on this use case (see also Fig. 5).

As mentioned, much is expected of "pavement-compatible" delivery robots in high-density urban areas for delivery of individual items within short timeframes; however, significant economic potential can only be exploited once the robots no longer have to be accompanied by humans, but merely be remotely monitored by a human operator due to legal requirements (cf. Hermes 2017b). On the other hand, it remains to be clarified what requirements the legislators will place on this monitoring and what tensions will arise regarding the precision and type of monitoring and the resulting personnel costs – e.g. with or without simultaneous monitoring of several vehicles. Delivery robots with a follow-me function, on the other hand, could reduce the physical burden on delivery personnel, with the additional advantage that these persons could intervene in the event of malfunction or conflict. If the vehicles are electrically powered, this could bring about a reduction in CO_2 and noise emissions, although well-founded impact analyses are still lacking here. Only Jennings and Figliozzi have established in comparative simulations that the combination of delivery robots and conventional delivery vehicles makes for reduced delivery times, mileage and costs, especially in areas with high customer density, as compared with the use of delivery vehicles alone (cf. Jennings/Figliozzi 2019: 324). For delivery companies, the costs for acquisition and operation of a delivery robot are more than offset by the transport revenue that can be generated over the last mile (cf. Hofer et al. 2018: 48). Delivery robots are currently still too expensive, which is why only pilot trials have been implemented so far in German-speaking countries (cf. Hermes 2017b, Marazzo/Mischler 2018: 1; Wittenhorst 2019). Even in the long term, it remains to be seen to what extent aspects such as customer density, settlement density or purpose of use would yield a positive cost-benefit ratio, as the delivery robots only have a relatively small load volume (cf. Hofer et al. 2018: 48). In addition, security aspects (vehicle theft) and vandalism would have to be taken into account in the operation of these vehicles (cf. Paddeu et al. 2019: 32; Kunze 2016: 292; Hofer et al. 2018: 18).

The pilot tests also reveal specific technical problems such as limited battery power or user-friendliness of the user interface. The delivery robots also require a powerful LTE mobile network, which is not always available in all areas (Hermes 2017a; Marrazzo/Mischler 2018: 2). However, these problems are expected to be solved in the near future.

The situation is different when it comes to the challenges encountered in the interaction between humans and delivery robots in public spaces. These involve lack of acceptance, specific disruptive effects and hazards:

- Delivery robots restrict the freedom of movement of all pedestrians, but especially of people with limited mobility – above all those with walking aids (cf. Lenthang 2019; Hofer et al. 2018: 48), and of children and the elderly (cf. Marks 2019: 14).

- They can pose a hazard in public spaces if pedestrians cannot avoid them in time to prevent a collision due to impaired reactions, mobility, etc., or if they unexpectedly change direction.

- This effect is amplified on narrow pavements or pedestrian crossings with a high number of pedestrians walking at different speeds and in various directions (cf. Leerkamp 2017: 17; Marazzo/Mischler 2018: 4; Hsu 2019).

Conflicts are inevitable especially in the following driving situations that delivery robots constantly have to master (cf. Keesmaat 2020: 9; Groot 2019: 64):

- driving around obstacles,

- crossing lanes at a pedestrian crossing or traffic lights; Marazzo and Mischler (2018: 4) report for example that the green phase was too short for the delivery robot and accompanying person to cross,

- overtaking slow-moving pedestrians,

- contact with a playing child, a group of children or a large crowd of people, and

- driving onto/off a kerb or ramp (cf. Leerkamp 2017: 17).

Automated driving of the delivery robot in dense mixed traffic, which involves interaction with numerous and diverse road users, is a relatively complex driving task that only allows travel at low speeds (cf. Hofer et al. 2018: 49; cf. Fig. 6). It also remains largely unclear what technical requirements the pavements must fulfil in view of the above-mentioned conflicts in driving situations, especially with regard to kerbstones, pedestrian crossings at intersections or walking and cycling paths designated with different colours.

There are also numerous barriers to be overcome in the delivery process. For example, the logistics concept must determine how consignments are to reach customers who are not at home – or how deliveries are to be made in multistorey buildings, since the robot cannot climb stairs. Drop-off or parcel boxes that are accessible to delivery robots at ground level currently only exist in a few places.

At present, the legal framework for operation of delivery robots on public roads is relatively rigid and restrictive in Germany and Switzerland as compared to some states of the USA (cf. Jennings/Figliozzi 2019). No automated delivery robot may be operated in public spaces without an accompanying person. In Germany, an exemption is usually granted for this purpose in accordance with the Road Traffic Code (StVO) and the Road Traffic Licensing Regulations (StVZO), which include specific conditions and requirements for the operation of delivery robots (cf. Brandt et al. 2018: 7). Data protection also plays a role here, as delivery robots use image-based sensors to record their surroundings and also collect "critical" personal data of other road users in order to recognize objects. The issue here is compliance with national data protection laws and the European General Data Protection Regulation (GDPR), especially Article 25 (data protection through technology design). It must be ensured that in the course of recognition of other road users by the delivery robots, only personal data are processed that are necessary for this purpose (cf. Brandt et al. 2018: 8; Hoffmann/Prause 2018: 11). This also applies to possible remote video-based monitoring of the delivery robots by the operators. In particular, the requirement that the delivery robot be accompanied by an attendant at all times in public spaces makes the use of such robots unprofitable for the operating companies. Rather, the tests with automated delivery robots serve above all to gain practical experience with new technologies as a basis for exploring scope for action from the perspective of the companies (cf. Ninnemann et al. 2017: 138), so that they can advocate for their interests more specifically, for example to gain authorization for operation without an accompanying person. However, these interests stand in contrast to the major challenges experienced in the public space.

Figure 5: Overview of strengths, weaknesses, opportunities and risks of automated delivery robots driving on pavements for the last mile

Strengths	Weaknesses
• optimized delivery of individual consignments in short timeframes • increased efficiency by supporting the delivery agent (parallel execution of other tasks) • reduction of CO_2 and noise emissions through electric drive	• technical problems: battery power, user interface, flexibility of the system, complex mixed traffic • poor economic efficiency due to the need for an accompanying person, high purchase price, low payload • inability to climb stairs • special drop-off boxes needed for the recipient if no one is at home
Opportunities	**Risks**
• remote monitoring by a human operator, enabling exploitation of economic potential • reduced physical burden on delivery personnel due to delivery robots with follow-me function • in combination with delivery vehicles, lower delivery times and costs compared to delivery with conventional vans alone (especially with high customer density) and possibly also reduced mileage (but more journeys/mileage may be necessary due to low loading capacity)	• impaired freedom of movement for all pedestrians • danger to pedestrians, especially persons with limited mobility, children, the elderly, etc. • potential for conflict when crossing a carriageway at pedestrian crossings or traffic lights, when overtaking slow-moving pedestrians or when encountering a large crowd of people • security aspects (e.g. vehicle theft) and vandalism • collection of personal data

Source: the authors

8. IMPLICATIONS FOR PLANNING

Initial experience from tests with automated delivery robots gives rise to hopes of economic potential for distribution logistics over the last mile. In the future, however, further detailed and spatially differentiated analyses will be needed to determine what areas offer what potential for covering the last mile. The experience gained in the tests also demonstrates the problems and risks posed by delivery robots in operation on public spaces, especially on pavements. The aspects that need to be considered for planning and (transport) policy, along with the existing scope for action, are therefore briefly outlined in the following.

In addition to the distribution of goods, already today there are a number of further demands on the public streetscape in urban areas that imply conflicts of use and interest (cf. Buthe et al. 2018: 121). Delivery robots – together with scooters, loading areas, etc. – additionally increase the already high pressure of use on public space particularly in dense urban neighbourhoods, above all on pavements. Public space is not only traffic space, but also a place to stay and meet people (cf. Stadt Wien 2018: 11), especially on pavements in the area of transition between buildings and the streetscape, where people talk to each other, look into shop windows, etc. The competing space requirements on the part of delivery robots to use pavements for driving and parking gives rise to conflict, especially in densely populated urban neighbourhoods (cf. Peters 2019: 76). This is all the more problematical since (1) it is precisely here that delivery concepts with robots are better suited by their very nature, due to the high customer density and thus economic efficiency; and (2) delivery robots operating on pavements will always have a low loading capacity (the vehicle width can hardly be greater than the scope of movement of a human, and requirements on the automated transfer of items from the robot to the parcel box, e.g. involving sorting the parcels in reverse order of delivery, do not allow optimal use to be made of the robot's storage space). A greater number of vehicles are therefore expected to be required than with the use of conventional delivery vehicles, and also in comparison with cargo bikes.

This also contrasts with the desire to "reclaim public space" by reducing traffic areas and increasing recreational areas for better quality of life and an attractive living environment. Delivery robots from commercial providers also restrict the free use of public space by all and contribute to a "privatization of public spaces" (cf. Marks 2019: 14; Wong 2017): the pavement clearly belongs to pedestrians.

If delivery robots become established, an additional need for adaptation of the infrastructure can be expected, along with further costs. Delivery concepts using robots require parcel boxes for households, for example, since personal delivery on the doorstep is hardly feasible due to the robots' inability to climb stairs. The green traffic light phases for pedestrians would also have to be extended if the delivery robots move more slowly than pedestrians. This raises the question as to who would bear the costs and ultimately also the responsibility for implementation (cf. Hofer et al. 2018: 48).

Even though the technological development is not yet sufficiently advanced to allow delivery robots to operate in public spaces on pavements at all times and under all conditions, it is necessary to give thought now to delivery robots in terms of planning. Firstly, we are living in an age of transformation of public spaces – away from traffic space, towards open space for all – and secondly, the qualities of public spaces must be secured at a very early stage. If this does not happen now, a blend of rapid technological advances in delivery robots and a marked increase in deliveries as a result of e-commerce could raise the political pressure to act so quickly that the regulatory measures outlined below would take effect either too late or not at all.

At the strategic level, data protection law and road traffic law – as a part of national (or EU) legislation – influence whether and in what ways delivery robots can be deployed in public spaces. Cities and municipalities can influence national legislation through their associations or by means of the countervailing principle in terms of spatial planning, but they also have planning levers of their own. To this end, it is necessary to address the topic of delivery robots in strategic concepts related to public space (e.g. the specialized concepts "Public Space" and "Mobility in the Planning Context of Vienna"). Furthermore, the required responsibilities, competences and resources must be established within the administrative sphere. Real experiments initiated by municipalities, which take into account conflicts of use and the effects of delivery robots, appear to be a first important step towards assessing possible applications in the urban space. It is important that the cities and municipalities take the initiative here.

Specific traffic planning measures that cities and municipalities could implement as regulatory instruments include "geofencing" – the spatially and temporally differentiated regulation of restricted zones – wherever the compatibility of delivery robots in public space cannot be ensured. A further measure would be the licensing of delivery robots in urban areas, in order to limit their number and to impose conditions on their operation. The measure of real-time pricing is a market-based instrument that levies dynamic charges based on the spatial and temporal compatibility of the delivery robots in public spaces. How these measures can be specifically devised and adapted to spatial situations, and how they can optimally complement each other, is currently still open and requires further research.

9. CONCLUSION

E-commerce is gaining an ever-greater share of the market, with a rapid increase in the number of deliveries to households. Logistics companies benefit from automation and digitalization whenever they succeed in optimizing the processes of the "last mile" – especially in terms of costs, but also of delivery times. High expectations are placed here in delivery robots. Even though numerous technological matters are yet to be resolved, delivery robots are already on the roads today in some cities and will be in seen more cities in the future. Low speeds for the delivery robots, combined with a simple operational design domain (ODD), favour early deployment. To what extent pavements can provide simple ODDs is the subject of much speculation. While unambiguous traffic regulations apply on carriageways, with defined directions of motion for road users, pavements are characterized by dynamic rules of distancing and walking behaviour: pedestrians arbitrarily change their speed and direction of motion. As pedestrian density increases, so too do the demands on the delivery robots' ability to navigate, with the result that simple design domains on the pavement become highly complex (cf. Keesmaat 2020: 16).

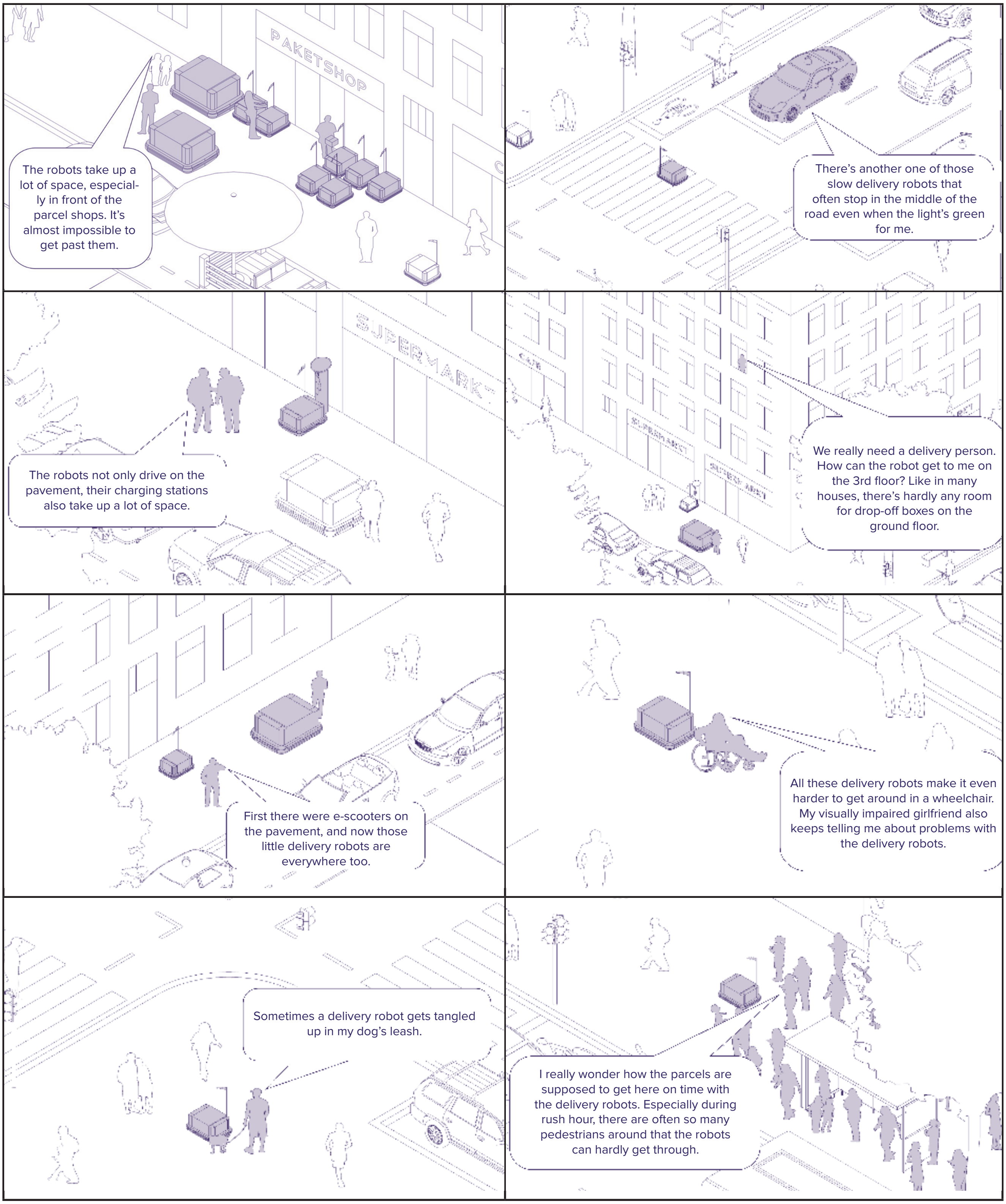
What deployment scenarios are conceivable for delivery robots? A possible, and in fact probable scenario is that they will not encounter much conflict in loosely built-up suburban areas or on very wide carriageways with little traffic (since issues such as passing stopped vehicles play a less significant role here), although the economic viability is doubtful. Real-time pricing based on pedestrian density and/or regulation by means of licensing would be possible as control measures in traffic planning.

The other scenario of using delivery robots in densely built-up urban areas entails much higher risks and negative impact. Strong regulation by means of exclusion zones, licensing, etc. seems necessary here. Pavements should really not be used; the delivery robots should only travel on the carriageway or in the vicinity of parking spaces (alternative use of parking lanes).

However, current pilot tests show that developments are focusing on delivery robots travelling on pavements. This trend is diametrically opposed to the use of public space for more stay and less transit. Pavements are highly important parts of the public arena that fulfil a variety of functions as linear open spaces: meeting people briefly, resting, waiting, playing, walking, observing, looking and sitting are part and parcel of everyday urban life. These qualities are often underestimated today, as frequent parking on pavements has shown.

Delivery robots – whether travelling on the pavement or parked at pick-up stations, charging stations or on the pavement – give rise to more pressure of usage, intensify competition for space and endanger passers-by. They are therefore especially critical in crowded spaces

Figure 6: Overview of the various usage demands and possible conflicts in the public space when using of delivery robots



Source: the authors

where many people are on the move, and inconvenience above all people with limited mobility, children and the elderly.

The pilot tests carried out to date have not adequately addressed these important aspects and focus solely on the “drivability” and economic efficiency of delivery robots. The real test of whether deployment is appropriate must be the quality of public space. Here, there is a great need for interdisciplinary experimentation and research in these “real-life laboratories” in order to take adequate account of the complexity of public space. The key questions focus on what and how the streetscape-related, spatial, situational, social, etc. conditions determine the acceptance of delivery robots and new logistics concepts on the part of passers-by and customers (cf. Groot 2019: 64). The effects of traffic planning measures are also of particular interest here, so that cities and municipalities can prepare themselves for this future task. There is currently a lack of comprehensive analyses of the impact of logistics concepts with delivery robots in terms of traffic and the environment, and of their consequences for the quality of public spaces and road safety; a differentiated approach to social spaces is needed here, with a strong focus on the user (Soteropoulos et al. 2019: 163). The vehemence with which commercial interests are asserted in this connection must be countered with an orientation towards the common good, which is to be integrated into processes of democratic discourse.

10. AN INTERVIEW BY MARTIN BERGER AND AGGELOS SOTEROPOULOS WITH BERT LEERKAMP

1. **What developments are you expecting for the next few years in the field of e-commerce? What is the impact of the current Covid-19 crisis?**

   Bert Leerkamp: According to various forecasts, B2C deliveries will continue to grow at a relatively high rate of 5% to 10% annually over the next ten years. The online food trade is characterized by high growth rates, although currently at a very low absolute level. In extreme cases, where the costs are not passed on to consumers, this could partly eliminate the “buffer stock” function of refrigerators in favour of widespread on-demand ordering – but this is yet to come about. Other areas of the non-food sector also still seem to have above-average demand potential. However, a distinction must be made here between online sales, which includes “click and collect” (collection by the customer from a stationary retailer), and parcel delivery in B2C.

2. **Freight transport in cities was long given rather scant attention in municipal transport and urban planning. Is this still the case? Where do the major challenges lie in terms of transport policy and planning?**

   BL: In Germany, the public debate surrounding climate protection and clean air – and with it the establishment of various funding programmes on the part of the federal and state governments – has led to a marked increase in attention and a great deal of activity in urban logistics. As I see it, the major challenge in transport policy consists in regaining the quality of public spaces in terms of urban planning and design, which has been lost in many cities as a result of increased orientation towards cars and is now only improving gradually and very laboriously. It will be challenging to reach a social consensus for this urban redevelopment that goes beyond the elimination of these problems and requirements for action that are the subject of current debate on air pollution, and which is described as a comprehensive transport transformation. The climate protection argument is perhaps neither forceful nor persistent enough to bring about this transformation. But other European metropolises may well lead the way here and thereby gain highly effective competitive advantages in attracting technology-oriented companies, which will compete for highly qualified workers. This could give a boost to urban redevelopment, which must go hand in hand with changes in mobility behaviour.

In my opinion, the logistics of urban supply and disposal do not face any really major challenges as a result of such a transport transformation. Logistics is accustomed to finding optimal solutions under the given conditions and constantly optimizing itself. Conversely, this means that cities must define these conditions unambiguously, clearly and reliably. For example, changes to the accessibility of inner-city areas for delivery traffic, as we outlined in the current guideline "Liefern ohne Lasten" (delivering without burden; publisher: Agora Verkehrswende 2020), must be announced in advance and implemented in a binding manner and with sufficient lead time. On the other hand, in the process of exchange between municipal planning, trade, services and the transport industry it must be ensured that no counterproductive measures are planned.

3. Why is the "last mile" of delivery so cost-intensive for logistics companies? Will this cost factor change over the years? What are the trends that influence cost dynamics? And how great is the motivation of logistics companies to save costs?

BL: To name just a few examples, the following factors have contributed to rises in costs or will do so in the future:

1. the constantly increasing distance between the last transfer points (forwarding and CEP depots) and the delivery destinations, which necessitate longer journeys and therefore also increased deployment of personnel and vehicles (outsourcing of logistics locations from the city centres) and

2. increasing requirements on service, especially deadline deliveries, which reduce the scope of bundling consignments.

3. The diversification of the range of goods in the consumer sector and, at the same time, emerging competition from online retail have forced retailers to keep increasing their responsiveness; this involves more frequent deliveries from a greater number of senders with smaller consignment sizes, so here too there are negative effects on bundling capability.

4. In online retail, deadline deliveries also have a cost-driving effect: existing, well-founded delivery timeframes in the cities mean that the CEP service providers have to drive into city centres with several delivery vehicles at once during the short morning delivery timeframe – which is further shortened due to the trend towards later shop opening times – in order to successfully deliver all their consignments. The remaining consignments are then distributed in the wider city area; this reduces area-based bundling capability.

5. Further CEP volume growth in B2C overburdens the capacities of the logistics companies, leading to negative economies of scale: additional volume generates disproportionately increasing handling costs, with no increase in revenue per consignment.

6. The cost reduction potential has been exhausted – also as a result of wage dumping and outsourcing to subcontractors – and can no longer absorb the cost increases. Wages

will rise in future due to a shortage of personnel. The procurement of e-vehicles following the introduction of zero-emission zones will likewise lead to higher costs.

4. How do you assess the technological development of delivery robots? What is the current focus of research? Is much progress being made? What are the biggest technological hurdles facing economical operation in practice? Which development path is likely to be pursued – towards operation on roads or on pavements?

BL: The projects I know of often seem to me to be demonstration projects with a generous share of marketing intent – companies like to come across as being innovative and show that they are part of the solution to existing problems. I still fail to see any independent, comprehensive (holistic) assessment of the technological impact. In my opinion, the regulatory frameworks are kept more or less in the background; it is all about technical feasibility, and the impression to be conveyed is that autonomous vehicles could assume a large part of the delivery operations. Positive environmental effects are sometimes wrongly attributed, or it is assumed that they are a specific feature of autonomous vehicles. In fact, however, these effects are due to the electric drive, and a comparison with other solutions such as the cargo bike is lacking.

The autonomous or automated technical systems must function reliably under "chaotic" conditions, since highly diverse combinations of individual disturbances are encountered in practical operation. Humans quickly find acceptable solutions in such situations; technical systems, on the other hand, must be programmed to come up with solutions to all sorts of malfunctions occurring individually or in combination. In addition, functionable systems must include redundancies in their safety-relevant features. This all reduces the economic efficiency of the systems and makes them more susceptible to technical failure (e.g. of sensors, mechanics or energy supply). The monitoring and maintenance, and interventions in case of malfunction, give rise to additional costs.

Conditions of the system environment – in this case public space – that can be created in the laboratory are often not able to be transferred to reality. For example, I think it would be difficult to navigate a delivery robot only on a pavement, and not on an adjacent cycle path if this is not very clearly marked – what sensor system could do that? Demands for designing public spaces to suit the technology are to be viewed with scepticism – who should bear the costs, and who would benefit? This would not be practicable on a widespread basis.

In "mass transport", i.e. parcel delivery in densely populated areas, deliveries will still largely be carried out by humans because this is more economical. In very sparsely populated areas, I could envisage (ground-based or airborne) automated or autonomous systems in special situations, for example delivery of urgent goods to islands by drone, or delivery to individual farmsteads in mountainous regions; as I've mentioned, niche operations will be carried out on the carriageways rather than on pavements, because there are simply no pavements in these areas.

5. Conflicts between delivery robots and pedestrians in the streetscape are inevitable. What are the most critical issues here? What problems of acceptance are encountered? In your view, should the pavement be taboo for delivery robots? Do you see any areas that are more suitable for delivery robots, and any that are particularly problematical? What criteria should apply here?

BL: People will not accept obstruction by technical systems, as this would be seen as an unfair distribution of individual benefits in favour of the recipients and the logistics companies, and as a collective burden. Already today, the pavements of typical main roads are too narrow and force people to come into close contact with each other. If technical systems are to interact, presumably the only solution can be that they must evade humans, but this would impair the operation of the autonomous systems.

In practice, pavements are taboo for the above reasons, besides being unsuitable from a technical point of view. Criteria for use are: unconditional compatibility with the current environment (no requirement on the part of the environment to adapt to the system), and no obstruction to pedestrians, bicycles, or to persons with impaired mobility, vision or hearing, economic advantages under the overall conditions mentioned above, no negative effects on road safety.

6. **As e-commerce gains increasing market share and brick-and-mortar retail is on the decline, pedestrian shopping is also decreasing in volume. How do you assess this shift from physical to virtual mobility? Are there now fewer pedestrians on the pavements who can “hinder” delivery robots, resulting in their further proliferation?**

BL: From mobility surveys, it is possible to estimate what proportion of pedestrian traffic serves the purpose of shopping. Although this is concentrated in commercial areas, only a small part of pedestrian traffic can be transferred to online retail. In any case, people are likely to spend the time they save by not having to go shopping with a visit to a café – and will thus still travel on foot. So all in all, the effect is marginal and rather theoretical. And do we want streets devoid of people?

7. **For many years, efforts have been undertaken to give more room to pedestrians and cyclists in public space – but as yet with only moderate success. However, in the course of the Covid-19 crisis carriageways and parking spaces have been temporarily reallocated to pedestrians and cyclists in numerous cities such as Berlin, Vienna or Brussels. Can this crisis be seen as a tipping point – as an opportunity to actually bring about a redistribution of public space?**

BL: In my experience, municipalities have been very hesitant to take up this opportunity, although Berlin is an exception here. People often point out existing concepts and bemoan a lack of work assignments from city councils, thus implying that there is no basis for action. At the same time, I have noticed that the matter of redistribution is being raised more and more frequently and emphatically by a larger number of population groups. This should hopefully become sustainable even without Corona and influence political decision-making.

8. **Municipalities and cities are important stakeholders when it comes to locally implementing new mobility solutions such as delivery robots. What framework conditions are required at the other political levels? Is the problem being perceived and discussed at the level of local politics and administration? What protagonists are pushing this issue? What are their interests and motives? How do you perceive the vehemence with which commercial actors are asserting their interests?**

BL: The Road Traffic Act, which is administered by the federal government in consultation with the states, is decisive in Germany. The Federal Ordinance on Very Small Electric Vehicles (eKDV), which was only recently introduced, would have to be modified. In local and national politics, I have noticed that the concepts discussed here (delivery robots) are often seen in an undifferentiated way as innovative solutions with a fundamentally positive connotation. At times I gain the impression that the focus on and the undifferentiated welcoming of autonomous delivery systems serve to distract from a need for action that does not align with people's own objectives and would be more inconvenient to implement (primacy of technology versus an integral approach to the transport transformation). Commercial protagonists in logistics are approaching this topic very gingerly and, in my estimation, see little potential in this regard. Recently, in a working group on urban logistics in Düsseldorf, none of the CEP companies in attendance mentioned delivery robots as a possible solution.

9. **Does it make sense for municipalities and cities to act now and regulate the use of public spaces by delivery robots, or are the conditions still far too uncertain? Is the development of regulatory provisions keeping pace with technological progress? What regulatory innovations are being discussed, how do you rate the chances of these being implemented, and what risks are involved? In San Francisco, for example, licences are issued to individual providers for the operation of delivery robots. Would this model also be conceivable for municipalities and cities in German-speaking countries?**

BL: An early signal from the municipalities regarding their preferences for the use of pavements may be helpful for those who take a purely technical view of the whole issue and ignore the problematical framework conditions. I don't have an overview of where which regulatory innovations are being discussed. Municipalities in Germany are currently having ambivalent experience with licensed sharing systems (e-scooters). There is a great need for regulation and subsequent adjustment (e.g. prohibited areas), and the contributions to sustainable transport that are of benefit to municipalities are in conflict with observable negative effects (e.g. widespread abandonment of e-scooters on pavements, use for fun at night with disturbance of the peace, etc.). The municipalities would have to venture into new legal territory here. The relationship between the basic right to general and unrestricted use of public space on the one hand and licensing (i.e. restriction of use) on the other would have to be fundamentally clarified.

10. **What alternatives are there for covering the last mile apart from the use of delivery robots? Are there any other technological developments with potential, such as drones? Or would this necessitate social and organizational innovations? Do customers need to change their behaviour, or are technical or infrastructural measures sufficient to ensure the quality of public spaces? Could "nudging" – influencing people's behaviour (e.g. by displaying CO_2 consumption for the various different delivery options) – prove useful here?**

BL: I would give priority to two options: (1) CEP service providers could work with micro-hubs, from where they deliver consignments by cargo bike, and (2) forwarding agents working for the receivers could bundle consignments by area: a sender would write the address of such an agent on the package, which then serves as the delivery address for the CEP service provider. The receiving agent then bundles consignments for delivery on the basis of the recipients' addresses. This system is being successfully used by the company ABC-Logistik in Düsseldorf with around 150 retailers; it bundles B2B package consignments for trade operators and large office locations. A cargo bike is also used for this purpose.

11. **Where do you see the need for research at the interface of public space and last-mile logistics, with or without delivery robots? Should the public sector actively regulate innovations such as delivery robots, or rely on the market?**

BL: At present, I see a need for transformative research that would support or enable change and would test, evaluate and then disseminate good solutions. I don't see any need for the public sector to initiate research in order to promote the use of delivery robots, since I don't think the economic potential for their use in cities, or their positive effects for society, are sufficient.

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