The LogiSmile Project – Piloting Autonomous Vehicles for Last-Mile Logistics in European cities

Clément Lemardelé[a]*, Albert Baldó[a], Adina Aniculaesei[b], Andreas Rausch[b], Mariona Conill[c], Lars Everding[d], Thomas Vietor[d], Torben Hegerhorst[e], Roman Henze[e], László Mátyus[f], Laia Pagès[a], Vidal Roca[g], Alberto Sanfeliu[h], Angel Santamaria-Navarro[h], István Tóháti[f]

[a]CARNET Barcelona – The Future Mobility Research Hub, C. Jordi Girona, 29, Nexus II Building - Office 0A, 08034 Barcelona, Spain
[b]Technische Universität Clausthal, Institute of Software and Systems Engineering, Arnold-Sommerfeld Str. 1, 38678 Clausthal-Zellerfeld, Germany
[c]Àrea Metropolitana de Barcelona, carrer 62, 16-18 - Zona Franca, 08040 Barcelona, Spain
[d]Technische Universität Braunschweig, Institute for Engineering Design, Hermann-Blenk-Str. 42, 38108 Braunschweig, Germany
[e]Technische Universität Braunschweig, Institute of Automotive Engineering, Hans-Sommer-Str. 4, 38106 Braunschweig, Germany
[f]Directorate of innovation and service development, DKV Debrecen Exclusive Public Transport Company Ltd., Salétrom utca 3. 4025 Debrecen, Hungary
[g]PTV Planung Transport Verkehr GmbH, Haid-und-Neu-Straße 15, 76131 Karlsruhe, Germany
[h]Institut de Robòtica i Informàtica Industrial, CSIC-UPC, C. Llorens i Artigas, 4-6, 08028, Barcelona, Spain

Abstract

The use of autonomous technologies for last-mile logistics has the potential to reduce operation costs, cut emissions from the delivery sector, improve safety levels in communities, and provide efficient delivery solutions in areas which experience access regulations. Unfortunately, the implementation of real-life, economically-sustainable, and safe use cases in open urban environments remains scarce, especially in Europe. As a consequence, there is a real need for pilot tests of innovative delivery schemes based on autonomous technologies, not only in numerical simulations, but also in representative urban settings throughout Europe. In this paper, we will present the LogiSmile project, in which a consortium of European partners is piloting a transport management system for autonomous last-mile logistics. Beyond describing the delivery characteristics and use cases of this system, we also highlight the lessons learnt during the course of the project about managing innovation in the urban mobility field, gathering insight form the innovation triple helix (academia, industry and public sector).

Peer-review under responsibility of the scientific committee of the 15th Conference on Transport Engineering
Keywords: CEP market; autonomous delivery robot; autonomous hub vehicle; pilot test; innovation triple helix

1. Introduction

Considering that the transport sector, excluding international aviation and shipping, represents around 20% of the total greenhouse gas (GHG) emissions in Europe (European Environment Agency, 2019), improving the efficiency of mobility is a great leverage to enhance sustainability. Even if electric or hydrogen vehicles have the potential to reduce emissions in cities (Davis & Figliozzi, 2013), they will hardly solve the problem of urban congestion. Efforts to solely equip the same vehicles with low-emission powertrain technology will not be enough to make cities more sustainable.

* Corresponding author.
E-mail address: clement.lemardele@carnetbarcelona.com

Peer-review under responsibility of the scientific committee of the 15th Conference on Transport Engineering

Instead, new mobility concepts must be developed to handle traffic more efficiently and with more appropriate vehicle sizes (ILS, KE-Consult, Prognos, 2019).

This principle especially applies to urban freight distribution and, in particular, to the courier, express, parcel (CEP) market which includes the transportation and logistics services associated with the movement of individual shipments whose weight ranges below the general cargo market.

Considering the CEP market particular characteristics (ILS, KE-Consult, Prognos, 2019), and that personnel costs represent around 70% of the last-mile total operation costs (Observatory of road freight transport in Catalonia, 2019), autonomous robotics has the potential to reduce the CEP delivery costs (Jennings & Figliozzi, 2019; Jennings & Figliozzi, 2020; Lemardelé et al., 2021), environmental impact (Figliozzi, 2020) and make last-mile operations in dense areas with access regulation more efficient. Unfortunately, even if many studies are being done on an analytical basis (Ulmer & Streng, 2019), more on-field data is needed to validate, feed the research and make logistics models more representative.

2. The LogiSmile project

LogiSmile is a two-year project, co-funded by the European Institute of Innovation and Technology (EIT) Urban Mobility, which pursues two principal objectives:

- Propose an innovative delivery scheme which relies on the collaboration of two autonomous vehicles with different sizes and characteristics.
- Implement autonomous delivery vehicle pilots in several European cities.

2.1. AHV/ADR cooperation

The transportation management system (TMS) proposed and piloted within the LogiSmile project is based on four elements:

- An autonomous hub vehicle (AHV) named Pluto (see Fig. 1). This high-capacity vehicle is essentially used to carry parcels from a warehouse (which may be located in the city outskirts) to the considered service region, generating large economies of scale. The long range and high traveling speed of the AHV makes operations on metropolitan highways possible.
- An autonomous delivery robot (ADR) named Ona (see Fig. 1), in charge of final deliveries to recipients. Thanks to its smaller capacity (around 1 m^3), this vehicle is more flexible and adapted to dense city centers, where access regulations could exist for the AHV. Unlike other already existing concepts (Bambridge, 2017), Ona is a multi-drop-off vehicle which includes different types of sensors for autonomous navigation (Vaquero, 2021), enabling a reduction of total traveled distances and operation costs.
- A Mission Manager (LMAD, 2023) in charge of optimizing and monitoring the robots' operations. The Mission Manager creates optimized logistics routes based on delivery locations and time windows and ensures that all delivery processes are working as expected (see Fig. 1).
- A Central Command Center (CCC), which is a remote center that takes control of the mission in case of failure or unexpected events.

The Mission Manager handles the communication and interaction needs with the various stakeholders interacting with the digital platform, namely the recipients, the logistics operators handling the parcels and potentially safety operators near or remote from the delivery robots. Delivery updates include timely notifications for the recipients about their delivery with critical data (location, PIN code for fetching parcel), to reduce chances of missed deliveries. Also, there is an interface to manage the compartments of a given robot's cargo system by recipients, couriers, or administrators. Finally, one of the Mission Manager's main roles is to create optimized logistics missions where, the AHV and ADR routes as well as the meeting points' location are optimized to decrease delivery distance, delivery time and costs. At a meeting point, parcels are transhipped from the AHV to the ADR. Once the ADR is fully loaded, it starts visiting final recipients. In the meantime, depending on the demand, the AHV moves to the following meeting point or wait for the ADR to return at the first meeting point if several ADR delivery routes are needed in the same neighbourhood.

The CCC is usually located in a remote location, where the operational team controls the mission of the AHV and ADR. The objective is to monitor the path of the vehicles and take control of them in case of failure or unexpected events. In case of failure, the CCC remotely tries to correct the situation, but in case that this is not possible, an urban team approaches the robot and takes control of it. In the LogiSmile project, for the ADR, the technical team was operating, monitoring and taking control of the robots if necessary.

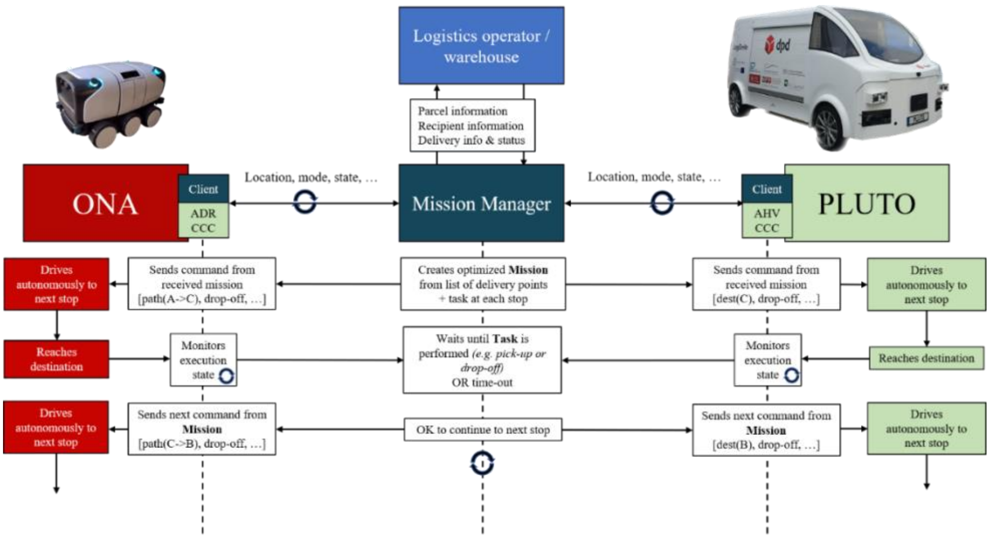


Fig. 1. Joint delivery user story. CCC = Central Command Center.

2.2. Commercial use cases

The TMS proposed in the LogiSmile project presents manifold use cases, which were explored in a top-down approach with the collaboration of international interdisciplinary mobility experts from the innovation triple helix (academia, industrial partners, and public authorities). These use cases were classified into three categories, depending on their level of maturity and feasibility, with the objective of implementing proofs of concept already in 2022 but also providing research lines for future investigation: 1. Technically-feasible use cases for 2022 which did not require the cooperation between the AHV and the ADR (individual separate validation of the two robots), 2. Potential collaborative opportunities for the second year of the project (2023), and 3. Use cases which may be realized by demonstrators in the future (year 2024 and beyond)

These possible applications and use cases are depicted in Fig. 2. Each one was placed in an attractiveness-feasibility matrix. The Y-axis of this matrix represents the social but also business attractiveness, while the X-axis stands for the technical and budgetary feasibility (see Fig. 2). This classification was performed and agreed between all mobility experts present during the workshops.

Finally, as a result of this process, the two use cases “AHV logistics on industrial site” and “ADR e-commerce delivery and pick-up” were selected for the LogiSmile activities in 2022. These two types of implementation showed an interesting trade-off between technical feasibility and business attractiveness and they were adequate to settle realistic and representative demonstrators already in the first year of the project.

It should be noted that a combination of automated and human delivery personnel may be necessary for specific areas and circumstances – for example, for bulky and/or heavy goods. The second year of the project anticipates the execution of the first steps towards the AHV/ADR collaboration considering joint interaction at a defined meeting point.

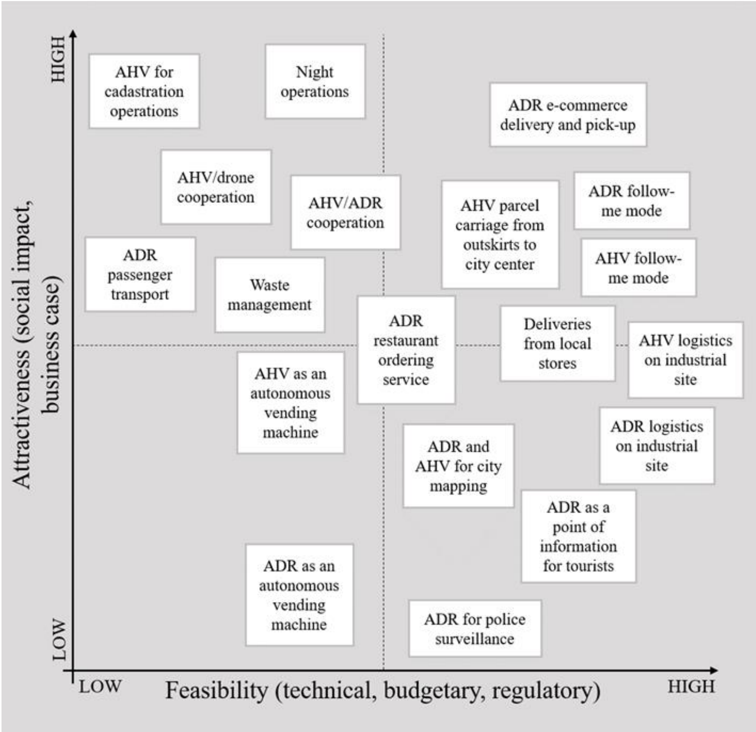


Fig. 2. Attractiveness-feasibility matrix of commercial use cases

2.3. City pilots

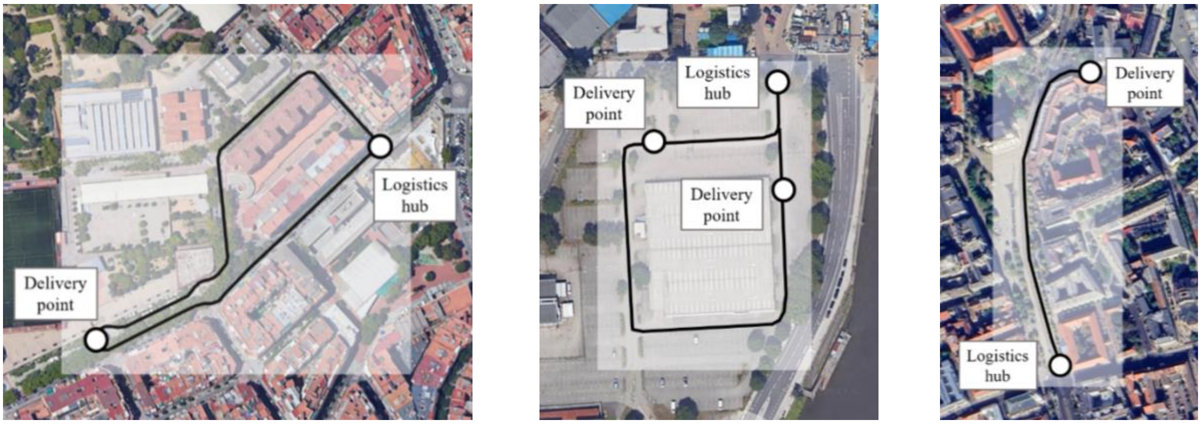
As explained previously, the first year of the project was focused on the integration of Pluto (AHV), Ona (ADR) and the Mission Manager as well as the validation in real environments of Pluto and Ona, separately. Ona was piloted in the cities of Esplugues de Llobregat (Spain) and Debrecen (Hungary) whereas Pluto was validated in the HomePort area (Hamburg, Germany). The objective of piloting Pluto and Ona in three different cities was to analyse different use cases and how autonomous vehicles with distinct characteristics could integrate in different urban settings. Table 1 presents a comparison of the city pilots that took place during the first year of the project.

2.3.1. Esplugues city pilot, Spain

Esplugues de Llobregat is a city of around 46,000 inhabitants and 4.6 km^2, located in the first crown of the Barcelona Metropolitan Area. It is crossed by two high-capacity roads, dividing the municipal territory into two parts: a northern part with single-family housing and high slope streets, and a southern relatively plain part with much denser urban characteristics. This territorial segregation is an advantage for the LogiSmile project because the autonomous robots could be tested in distinct urban settings.

It is important to mention that the city is partly located within the Barcelona Low Emission Zone (LEZ), creating access regulation for some types of logistics vehicles in the future (Mateu, 2022).

The city is planning an important demographic expansion in future years (La Vanguardia, 2022), which may worsen current mobility issues. Because of its geographical location, Esplugues de Llobregat acts as a gateway to Barcelona, so improving the quality of both private and goods transport is a key goal not only for the city but for the whole metropolitan area. In terms of city logistics, the improvement goals focus on the reduction of operation costs, parking issues, emissions and congestion, as well as more flexible and quicker deliveries.



a) b) c)

Fig. 3. Pilot tracks in a) Esplugues de Llobregat, b) Hamburg, and c) Debrecen.

Table 1. First-year city pilot characteristics.

	Can Vidalet – Esplugues de Llobregat (Spain)	HomePort – Hamburg (Germany)	City center – Debrecen (Hungary)
Tested vehicle	Ona	Pluto	Ona
Urbanistic setting	Very dense neighborhood	Industrial area	Dense neighborhood
Test track	One-way low-speed street Large pedestrian zone	Large mixed-traffic area	Large pedestrian area
Weather conditions	Hot, dry	Cold, rainy	Cold, rainy
Interaction with pedestrians and other road users	Low	Low	High
Overcome difficulties	High building – low Global Navigation Satellite System (GNSS) coverage	Adverse weather conditions	Frequent tram traffic going through the pedestrian area

The Esplugues pilot took place in the Can Vidalet neighborhood. Ona was validated on a 750-meter track, mixing pedestrian areas and roadways (see Fig. 3), during two weeks in June 2022. The test area is dense and characteristic of Mediterranean cities, with a high density of trees, zebra crossings, and urban furniture. The pilot streets were mainly one-way lanes with a maximum speed limit of 30 km/h, which is representative of future use cases since many European cities are considering reducing the current maximum speed limit in their streets (Barcelona City Council, 2023). An important aspect was the integration of the pilot within the overall city logistics strategy. The pilot track was meant to represent the route between a supermarket – whose construction was finalizing at the time of the pilot – operating as a distribution hub (Ajuntament d'Esplugues, 2022) and a commercial area, close to the "Rambla". For the project partners, it was import to integrate the LogiSmile pilots into a broader vision of the city logistics system to increase the representativeness and acceptability of our activities.

Indeed, the Barcelona Metropolitan Area (AMB) has approved its Urban Mobility Metropolitan Plan (PMMU). In the section dedicated to "Intelligent mobility management", it includes measures in the field of autonomous vehicles, logistics optimization, and promotion of R&D projects involving low-emission vehicles, among other topics (Barcelona Metropolitan Area, 2020). In this sense, the Logismile project is contributing to these measures, which clearly aligns with the PMMU.

2.3.2. Hamburg homePORT pilot, Germany

Pluto's pilot took place in the Free and Hanseatic City of Hamburg, the second largest city in Germany and the seventh largest in Europe with around 1.85 million citizens (Statistisches Bundesamt, 2021). Hamburg is a fast-growing city, and it is creating a new integrated digital mobility system that will handle urban traffic more effectively and with more suitable vehicle sizes (ILS, KE-Consult, Prognos, 2019). Hamburg's goal is to accelerate the transition to a model city with a strong focus on making mobility safer, more efficient, more comfortable and climate-neutral for everyone in both the city center and in outlying areas. Thanks to its characteristics, the AHV Pluto would be perfectly suited for less dense and rural areas.

The Hamburg Port Authority initiated the homePORT facility in 2020 (homePORT, 2023), a testing and development space for unmanned systems. The motivation was to establish a centrally located space with access to highly frequented infrastructure. The pilot test enabled us to validate Pluto in an industrial environment, which could be an additional use case in future years.

For the demonstration of Pluto at the homePort area, a plane driving circuit with good availability for GNSS-satellites was built (see Fig. 3b). During the project phase, Pluto was equipped with an automated rolling gate, which enables automated access to the vehicle cargo space for other automated systems like Ona, that could interact with Pluto for goods exchanges in future scope. The defined route for the demonstration included an automated journey between two delivery points and the interaction with a person responsible for the delivery. With future sight, the person could be replaced with a system like Ona for autonomous delivery scenarios. In addition, an emerging problem in the form of a bottleneck on the road was also to be solved within the demonstration scenario. This unexpected situation could not be solved by the driving system itself. The onboard runtime safety monitoring system of the AHV observed the specifics of the concrete road bottleneck through the vehicle's sensors and passed this information to the CCC. A human remote operator inside the CCC assessed the presented situation and reconfigured the AHV parameters accordingly. As a consequence, the delivery tour was successfully completed, thus highlighting Pluto's capabilities. In terms of the interaction of the various subsystems, the greatest challenge was achieving the necessary maneuverability of the vehicle in the narrow driving environment. However, this was solved in a targeted manner using appropriate planning algorithms, so that a total of more than 17 km could be covered in fully automated driving, further highlighting Pluto's capabilities for usage in more complex scenarios in the next steps.

2.3.3. Debrecen city pilot, Hungary

Debrecen is the second largest town in Hungary after the capital city. Its population is currently around 200,000 inhabitants (Hungarian Central Statistical Office, 2023). The residential function prevails in the eastern part of the city and the business function in the western one, which generates significant traffic every weekday through the city center, where most mobility issues are located. As a consequence, the Municipality of Debrecen aims to reduce the city's car traffic and allow space for sustainable and alternative modes of transport through sustainable and innovative methods (Debrecen Smart City, 2020).

The city center is heavily loaded with car traffic due to the mixing of diverse functions. A significant part of this traffic is accounted for by parcel service providers' vehicles, essentially vans and trucks. In addition to not being suitable for pedestrian-only areas, these vehicles also have significant pollution effects. The use of Pluto and Ona could greatly help improve this situation. In the long term, a successful implementation of autonomous technologies would make it easier to ban traditional parcel trucks from the city center, and the other residential areas of the city.

The most frequented area of the city center with restaurants and entertainment venues is the main street pedestrian zone, including Halköz Square. Here can be found numerous affluent, high-quality restaurants that deliver a significant number of orders every day, especially since the coronavirus pandemics. In addition, there are currently three different food delivery service providers in Debrecen. All these stakeholders may be interested in the LogiSmile project to cover their long-term food delivery demands. A significant amount of these orders come from the office workers of the city center, which area was largely in line with the action area of the pilot experiments in the LogiSmile project.

Finally, the Municipality of Debrecen and the institutions owned by the Municipality are located in many different buildings in different parts of the city center. There is a significant daily parcel delivery happening between these entities every day, as electronic transmission is not possible in many cases, such as official documents that must be signed by one of the representatives. This courier activity consumes significant labor forces and resources, which could be efficiently replaced by Pluto and/or Ona.

Ona's Debrecen pilot took place in the city center, between the Old and New Town Hall in November 2022. In this case, the 500-meter testing track was essentially pedestrian, enabling us to validate Ona in different conditions compared to the Esplugues city pilot. It is worth noticing that tram traffic or pedestrians were not altered to conduct the test.

3. Discussion and conclusion

As expected, the role of city representatives was fundamental in the project to define adequate and sustainable use cases, especially from the perspective of citizen acceptance. In addition, in the case of the Esplugues de Llobregat pilot, it is relevant that being this municipality part of the Barcelona Metropolitan Area (AMB) it is more viable to export this knowledge to other cities of the Barcelona metropolis. AMB is a supramunicipal public administration and can act as regulator entity with homogeneous criterion of the urban logistics in its territory.

At this stage of the project, it has become clear that the biggest challenge is the shortcomings in the regulation of self-driving vehicles. In the case of Hungary, for example, many elements of the pilot experiment depended on the transport category in which Ona could be classified. If Ona was given the "vehicle" category, then the various processes (regulation, authorization, insurance, etc.) were already known. However, Ona is more likely to fall into a category that does not yet exist and is unknown to the Hungarian law. In this case, factors such as the unique identification of the vehicle, the operative domain, the maximum permitted speed and the relevant authorizations shall be specified. Experience has shown that the decision-making process is slow and cumbersome. This may be due to uncertainty about the new technology. In our experience, the current EU rules can provide a good starting point for decision-makers in the different countries, however it can take a long time to adapt them for each and every country, based on their own demands.

In terms of integration with the Mission Manager, Ona represented a new type of delivery vehicle. First, it is navigating both on road and on sidewalks, whereas most other vehicles are restricted to be operating only on one of them. A key difference from other robots in the industry, is that Ona does not follow pre-recorded trajectories but computes her path dynamically based on the destination goal. This required rethinking the role and responsibilities of the Mission Manager. On the other hand, Ona is equipped with a robotic compartment system, with a single door, but multiple parcel shelves inside. This solution required adapting how the parcels were allocated to the robot. Throughout the different pilot tests, there was an increase of the complexity in terms of integration with the Mission Manager and interaction with other road users, which is a good sign for future tests and implementation. Given the results shown in the pilots, the connection between Pluto, Ona, the Mission Manager and the Central Command Center was very successful. The integration of this mission control set the baseline for the business-related layer for both robots, which defines the details of the last-mile delivery operation (e.g., connects with clients, manages the database of deliveries and parcels, or sets delivery and pickup points).

As general comments, there is a clear acceptance on the usage of these robots from pedestrians, other road users and citizens although there is also a clear worry about unemployment generated by its integration in our daily lives during the initial phases. This supports the idea that starting with small and localized implementations (in terms of geographical extent and performed delivery activities) and extending this deployment is the most sustainable way to introduce autonomous technologies in cities. Very focused use cases should be defined at the beginning of operations, and then extended while getting feedback from all stakeholders involved in city logistics operations.

Finally, the future research lines within the LogiSmile project will be focused on a joint pilot gathering Pluto and Ona in the city of Braunschweig (Germany). To this purpose, initial conceptual designs have already been developed to enable Ona and Pluto to realize the joint autonomous delivery scenarios. A new pilot will be implemented to achieve the objectives set at the beginning of the project.

Acknowledgements

The authors would like to acknowledge the participation of all LogiSmile partners in the project and the EIT Urban Mobility for its support. The LogiSmile project was co-funded by the EIT UM under the KAVA 22140. This work was also partially supported by the Spanish Ministry of Science and Innovation under the project AUDEL (TED2021-131759A-I00, funded by MCIN/AEI/10.13039/501100011033 and by the "European Union NextGenerationEU/

PRTR"), the project ROCOTRANSP (PID2019-106702RB-C2 funded by MCIN/ AEI /10.13039/501100011033) and by the Consolidated Research Group RAIG (2021 SGR 00510) of the Departament de Recerca i Universitats de la Generalitat de Catalunya.

References

Ajuntament d'Esplugues, 2022. Projecte executiu per la implantació d'un centre de ciclologística (hub) al mercat de Can Vidalet d'Esplugues de Llobregat. Accessed 2023-02-17. Retrieved from https://www.esplugues.cat/ambits/temes/urbanisme/projectes-en-exposicio-publica/projecte-executiu-per-a-la-ampliacio-d2019un-centre-de-ciclologistica-hub-al-mercat-de-can-vidalet-d2019esplugues-de-llobregat

Bambridge, J., 2017. Mercedes-Benz invests in 'Robovan' delivery system. Plant Machinery Vehicles. Accessed 2023-02-21. Retrieved from https://www.plantmachineryvehicles.com/pmv/article-42617-mercedes-benz-invests-in-robovan-delivery-system

Barcelona City Council, 2023. Barcelona Ciudad 30. Accessed 2023-02-16. Retrieved from https://www.barcelona.cat/mobilitat/es/barcelona-ciudad-30

Barcelona Metropolitan Area, 2020. Metropolitan Urban Mobility Plan 2019-2024. Synthesis of the Plan. Accessed 2023-03-10. Retrieved from https://docs.amb.cat/alfresco/api/-default-/public/alfresco/versions/1/nodes/1c80a9d8-3c0d-4ebe-9513-c0387757c5d5/content/AMB_PMMU%206%20print_EN_AF.pdf?attachment=false&mimeType=application/pdf&sizeInBytes=10282103

Davis, B., & Figliozzi, M., 2013. Life-cycle Evaluation of Urban Commercial Electric Vehicles and Their Potential Emission Reduction Impacts (No. 13-4482).

Debrecen Smart City, 2020. The Smart City Strategy of Debrecen. Accessed 2023-02-24. Retrieved from http://smartcity.debrecen.hu/docs/Debrecen%20Smart%20City%20Strategy.pdf

European Environment Agency, 2019. Greenhouse gas emissions by aggregated sector. Accessed 2023-03-07. Retrieved from https://www.eea.europa.eu/data-and-maps/daviz/ghg-emissions-by-aggregated-sector-5#tab-dashboard-02

Figliozzi, M. A., 2020. Carbon emissions reductions in last mile and grocery deliveries utilizing air and ground autonomous vehicles. Transportation Research Part D: Transport and Environment, 85, 102443.

Hegerhorst, T., Aniculaesei, A., Everding, L., Rodriguez Tesouro, A., Sanz-Pardo, L., Caballero Flores, D., Santamaria, A., & Riba, G., 2022. LogiSmile - DEL 06 – AHV/ADD cooperation concept note

homePORT, 2023. Innovate Maritime Logistics. Accessed 2023-02-24. Retrieved from https://www.homeport.hamburg/en/

Hungarian Central Statistical Office, 2023. Magyarország 50 legnépesebb települése, 2022. január 1. Accessed 2023-02-27. Retrieved from https://www.ksh.hu/stadat_files/fol/hu/fol0014.html

ILS, KE-Consult, & Prognos, 2019. Gesamtstädtisches Konzept Letzte Meile. Erstellung einer Roadmap für die Freie und Hansestadt Hamburg. Von Hamburg.de: https://www.hamburg.de/contentblob/13659130/0b92461c7279e99086b905b8d59e3bf1/data/endbericht-letzte-meile.pdf abgerufen

Jennings, D., & Figliozzi, M., 2019. Study of sidewalk autonomous delivery robots and their potential impacts on freight efficiency and travel. Transportation Research Record, 2673(6), 317-326.

Jennings, D., & Figliozzi, M., 2020. Study of road autonomous delivery robots and their potential effects on freight efficiency and travel. Transportation Research Record, 2674(9), 1019-1029.

La Vanguardia, 2022. La nueva área residencial de Esplugues tendrá más de 2.100 pisos. Accessed 2023-02-17. Retrieved from https://www.lavanguardia.com/local/baix-llobregat/20220419/8206565/nueva-area-residencial-esplugues-tendra-mas-2-100-pisos.html

Lemardelé, C., Estrada, M., Pagès, L., & Bachofner, M., 2021. Potentialities of drones and ground autonomous delivery devices for last-mile logistics. Transportation Research Part E: Logistics and Transportation Review, 149, 102325.

LMAD, 2023. LMAD's web page. Accessed 2023-02-16. Retrieved from https://www.lmad.eu/

Mateu, O., 2022. Barcelona estudia extender a enero las excepciones al transporte en su ZBE. El Mercantil. Accessed 2023-02-17. Retrieved from https://elmercantil.com/2022/12/15/barcelona-estudia-extender-a-enero-las-excepciones-al-transporte-en-su-zbe/

Observatory of road freight transport in Catalonia, 2019. Transport Newsletter 83.

Statistisches Bundesamt, 2021. Population: Administrative districts, reference date. Accessed 2023-03-07. Retrieved from https://www-genesis.destatis.de/genesis//online?operation=table&code=12411-0015&bypass=true&levelindex=0&levelid=1678213038149#abreadcrumb

Ulmer, M. W., & Streng, S., 2019. Same-day delivery with pickup stations and autonomous vehicles. Computers & Operations Research, 108, 1-19.

Vaquero, V., del Pino, I., Moreno-Noguer, F., Solà, J., Sanfeliu, A., & Andrade-Cetto, J., 2021. Dual-branch CNNs for vehicle detection and tracking on lidar data. IEEE Transactions on Intelligent Transportation Systems, Vol. 22, Issue. 11, pp. 6942-6953.