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20 Automated deliveries

The future of urban logistics?

Jakob Puchinger

Introduction

Connecting producers with their end users, urban logistics and last-mile distribution are critical components of the supply chain. With the world's population on the rise, the volume of urban deliveries is hitting record levels, and global supply chains rely heavily on maritime transport for long-distance transportation of non-urgent goods. This chapter aims to discuss the future of urban distribution with a focus on robot-based last-mile deliveries. The connection to maritime ports is achieved through multi-tiered delivery systems linking ports via inland corridors, transshipment points, warehouses, urban consolidation centres (optional), and, finally, last-mile deliveries to customers.

In recent years, technological advancements have led to increased experimentation with unmanned aerial vehicles (UAVs or drones) and robots for last-mile deliveries. Some experiments have involved using drones for deliveries in suburban or rural areas from designated drone ports, for instance (Amazon Prime Air, 2022). Other companies have experimented with van-based drones to increase distribution efficiency in locations where delivery points are further apart than those found in highly urbanized settings (Stewart, 2017). Other experiments have been carried out using robots to deliver goods, with pizza delivery robots being one of the earliest examples (Davies, 2022). In urban settings, and in the wake of significant backing from investors, the topic of automated deliveries is increasingly coming to the fore. However, a number of major regulatory subjects remain unresolved (Biermann et al., 2021).

On examining the range of possible uses of robot and drone deliveries, it becomes clear that an extensive use of drones is not a viable option in densely populated areas, at least not for the foreseeable future. Slow-driving robots, however, have emerged as an interesting alternative in areas with limited access for vans and cars, as they are smaller, quieter, and more environmentally friendly than car- or scooter-based delivery solutions. Several experiments have already been conducted on university campuses and pedestrianized areas (Britt, 2019), and it is anticipated that many more similar experiments will be carried out in the future, as companies are drawn in by the prospect of boosting efficiency and bringing down costs by eliminating the need for delivery personnel. Recently, a new type of fast-food truck

offering advanced levels of consumer interaction was tested out in Shanghai, which allows customers to order and pay for their food directly at the robotic vehicle (Wong, 2020). A recent review on automated deliveries in e-commerce sector (Rai et al., 2022) provides a detailed overview of this topic, including a focus on past and ongoing experiments, recent literature, interviews with major French actors and their insights, and a discussion of the impact of the COVID-19 pandemic.

This chapter will begin by providing an overview of urban logistics, last-mile delivery, as well as how they interact with maritime and inland ports. It will then shed light on the latest advancements in hardware and experimentation in automated deliveries. After that, it will delve into the environmental, legal, economic, and social factors associated with the introduction of automated delivery vehicles in urban settings. In addition, it will present recent research focused on planning robot delivery operations in cities. Finally, this chapter will conclude by proposing a forward-thinking vision for the future development of urban automated deliveries.

Urban logistics and maritime ports

More than half of the world's population currently resides in cities, and this number is set to rise in the coming years, with figures expected to reach almost 70% by 2050 (United Nations, 2018). In Europe, urban areas are home to more than 74% of the population (*ibid.*), and against a backdrop of increased traffic congestion, cities are faced with an ever-increasing demand for mobility. The steady growth of e-commerce and urban deliveries has brought about a fundamental shift in the urban logistics landscape (Dablanc, 2019). Persistent consumer demands for higher service quality and virtually instant deliveries, combined with a surge in delivery volumes, have severely disrupted urban freight operations.

In the wake of the COVID-19 pandemic, the demand for urban deliveries has risen even further (Dablanc, 2023), and the number of delivery vehicles in cities is expected to increase by 36% in city centres by 2030 (Pandemic, Parcels and Public Vaccination, 2021). In light of these changes, cities will need to regulate access to their central areas, with a particular emphasis on reducing local pollutants, traffic, and noise. This will, in turn, call for greater coordination in terms of resource allocation, including the development of delivery zones and the use of connected delivery vehicles, such as electric delivery vans, cargo-bikes, and automated electric delivery vehicles.

Larsen and Van Woensel (2019) provide an overview of urban logistics and deliveries in their 2019 work, which examines macro trends such as digitalization, automation, and e-commerce, as well as possible avenues for achieving more sustainable delivery practices. In their literature review on last-mile logistics published in 2019, Olsson et al. (2019) present last-mile delivery as a crucial operational component, ensuring the successful transportation of goods to the end customer or parcel pickup point. However, when implementing a last-mile logistics system, operators must also consider certain strategic and technical aspects, such as network design, warehouse locations, inner city consolidation centres, and

fleet composition. As will be explored later in this chapter, the interplay between these various decision-making levels, technological advances, political decisions, and legislation, as well as customer behaviour and public opinion will all play a significant role in shaping the future of urban deliveries.

The connection between seaports and their hinterlands is a highly important topic, and it has already been widely discussed in literature. In a recent review by Witte et al. (2019), for instance, the authors discuss the research carried out over the past 30 years, demonstrating how the concept of so-called inland ports has seen a shift within global supply chains and that these ports have gone from having a passive “follower” status to taking on a more active “leader” role. Inland ports also play a key role in large cities, serving as important distribution centres and logistics platforms for the local area. In this vein, megacities have a vested interest in controlling certain logistics activities, and, depending on the policy and governance structure, inland ports can be a means for them to do so, as they can be controlled by the public sector. The situation in the Paris region is a clear example of how inland ports can be leveraged for this purpose (Raimbault, 2019). Furthermore, the merger of the maritime port of Le Havre with the river ports of Rouen and Paris (Haropa port¹) in 2021 is equally a testament to the importance of the link between maritime logistics and cities.

When linking urban last-mile deliveries with maritime logistics, a series of strategic decision-making challenges arise. One such example is the recent case study presented by Bouchery et al. (2021), which examines the optimal location for dividing and unloading maritime containers into smaller shipments. The authors raise the question of whether it is more effective to perform such operations in close proximity to the seaport, or instead at an inland port. In response, the authors put forward a decision model and present a case study in Sweden, before concluding that using a hinterland port is typically the better option in this case.

Automated delivery vehicles

Automated delivery technology is a fairly recent addition to the logistics scene, and so design proposals and prototypical developments for new vehicles abound. Given the importance of sustainability and combatting global and local levels of pollution, the vast majority of such vehicles are battery-powered, eschewing traditional combustion engines. In addition, the use of electric drivetrain systems is also highly advantageous, offering smaller size, simpler design, and better motion control than their traditional counterparts. Currently, all of the vehicles hitting the market require remote control by a human operator, mainly due to unresolved questions surrounding liability. However, a recent study suggests that in the future, a single supervisor could oversee a fleet of 50–100 robots or about 10 automated mobile parcel lockers (Joerss et al., 2016). Robots usually rely on high-speed data connections, as they depend on ongoing map updates to operate safely. Current experiments show that mapping data are updated and uploaded just once daily (Brandt et al., 2019, p. 4).

The development of automated delivery vehicles will be shaped by their scope of use, with their areas of navigation – such as streets, cycle paths, pavements, or other pedestrian areas – acting as a major differentiating factor. Automated delivery vehicles operating on streets will be subject to the same legal and security requirements as those for passenger transport and will need to be able to merge into traffic flows and interact safely with other road users, including cars, pedestrians, and cyclists. Slower vehicles, in contrast, such as smaller robots operating on pavements and pedestrian areas only, may face fewer legal challenges as they pose less of a security risk. Currently, most companies developing automated delivery vehicles are focusing on pavement operations. Jennings and Figliozzi (2019) propose the term “sidewalk automated delivery robots” (SADR) for these vehicles, which can carry out delivery tasks from a sender to a recipient without human intervention. SADRs hold much promise for the future of distribution, as they are expected to yield faster delivery times and at a lower cost.

In their recent work, Baum et al. (2019) provide a systematic overview of the use of “automated-micro vehicles” in the context of urban deliveries. The authors categorize various vehicle concepts based on the necessary infrastructure (non-road and road), the vehicle type (automated bikes or delivery robots), and the human reference (autonomous or requiring human intervention). In addition to this classification, the authors analyse the major companies and projects offering such vehicles, providing a comprehensive overview of the current market landscape.

Delivery robots present several distinguishing characteristics based on their technical specifications, including their speed, size, weight, capacity, and range. Starship robots, for example, have a range of 6 km, a speed of 6 km/h, and a payload capacity of around 10 kg (Jennings & Figliozzi, 2019). However, in more recent press statements, Starship robots have been claimed to boast a range of up to 40 km (Lunden, 2022). The technical characteristics of these vehicles are evolving rapidly, especially in terms of battery capacity and automated driving capabilities. In their study, Jennings and Figliozzi (2019) provide technical details for various delivery robots, citing speeds ranging from 6 to approximately 55 km/h, payload capacities of 10–50 kilograms, and have ranges spanning 6–78 km.

A recent prototype developed by Mercedes-Benz offers an attractive new prospect for automatic delivery vehicles: a van capable of picking up new parcels, as well as recharging or replacing robot batteries where necessary (Burgess, 2016). An in-depth analysis of the operational planning of such a “mothership” concept has already formed the focus of various studies (Yu et al., 2020, 2022a, 2022b) and will be discussed in more detail later in this chapter.

Environmental aspects

Robot manufacturers, as well as the companies testing and using such novel delivery technologies, share a common goal: to reduce emissions while increasing overall system efficiency and bringing down costs. The energy consumption and emissions of road-automated delivery robots have been investigated in a study by

Figliozzi and Jennings (2020). The authors found that roadside delivery robots are set to offer greater efficiency in terms of energy consumption and emissions compared to SADR. As is the case with delivery drones, it could be argued that due to their limited capacity, the use of additional warehouses required for these robots may offset these benefits and negatively contribute to life-cycle greenhouse gas emissions. However, it is expected that overall street travel distances and delivery times will be reduced, which should in turn mitigate associated externalities such as traffic congestion, CO₂ emissions, and noise pollution. Nevertheless, increased travel on pavements may give rise to new negative externalities and safety concerns, especially for pedestrians (Jennings & Figliozzi, 2019; Figliozzi & Jennings, 2020).

Social acceptance

Getting the general public onboard will be critical for the successful large-scale roll-out of delivery robots. This is especially the case for SADR, and careful consideration of how and where these robots can coexist with pedestrians will be crucial. A recent master's thesis written by De Groot (2019) offers an in-depth examination of the acceptance of delivery robots by pedestrians and presents a technology acceptance model for delivery robots. This model primarily considers the perceived ease of use and usefulness of delivery robots, which have a direct impact on attitudes and levels of acceptance. Ease of use is based on the ability of SADR to interact with pedestrians on the pavement. To this end, the author proposes the concept of “predictable manoeuvring” whereby pedestrians can anticipate the robot's movements. To determine this, researchers have used computational experiments to simulate the behaviour of robots and pedestrians, utilizing the social-force model, which is widely used in the field (Helbing & Molnar, 1995). The results of these studies indicated that robots should be perceived as “less dynamic” than pedestrians by moving and changing directions at a slower pace. This finding aligns with later conclusions in this chapter, which indicate slow robot speeds do not negatively impact operational efficiency (Yu et al., 2020). Other factors, such as perceived job losses, or the prevalence of sensory devices such as cameras and microphones on pavements, may also significantly impact levels of social acceptance.

One of the major challenges that needs to be addressed in robot-based deliveries is the final part of the delivery. Several options present themselves: customers may have to collect their order from outside their building; the robot may be able to drop off the order in an automated locker for the customer to retrieve at their convenience; or the robot might possess advanced technology that will enable it to enter buildings, climb stairs, and more. These questions surrounding the final stage of delivery remain largely unresolved. The National League of Cities (NLC)'s Center for City Solutions, a research and advocacy organization in the United States, has offered an interesting solution: that of combining robotic delivery vehicles with human porters for the final leg of the journey.²

Legal concerns

The deployment of automated vehicles, particularly robot delivery vehicles, presents a number of legal challenges. In their 2018 work, Hoffman and Prause analysed the regulatory framework for robot delivery vehicles. The authors found that, traffic law and regulations need to be adapted to account for these vehicles, especially with regard to liability issues. In many national legislations, a distinction is made between product liability and tort liability. In the case of robotic delivery vehicles, tort liability would arise from the failure to use or operate the product in accordance with the law (e.g. traffic law), while product liability would result from the robot not functioning correctly. Furthermore, most robot delivery vehicles require supervision and must be controlled remotely, at least in part, necessitating a continuous exchange of data between the robot and the control centre. This data will be collected by the robot through various sensors such as cameras, microphones, and light detection and ranging (LiDAR). This massive data collection is necessary for the operation of the robots, as well as for documenting accidents or other problematic situations. This raises privacy concerns that will need to be addressed if manufacturers are to comply with the various regulations in force such as the European Union's General Data Protection Regulation (GDPR). On one hand, the data related to the delivery itself is not problematic, as it serves a clear purpose – that of successfully delivering a product to the end user. On the other hand, delivery robots will also collect other forms of data, such as visual data and sound recordings, to provide evidence in case of accidents, for example. The data gathered may include the personal information of passers-by in the street, which will be collected and processed without their explicit consent. These issues will need to be addressed moving forward to ensure GDPR compliance. Hoffmann and Prause (2018) suggest using measures such as pseudonymization of personal data and data encryption as a possible solution.

The legal aspects under discussion also raise the question of policy, as laws and regulations are typically used to implement specific policies. Over the last few decades, the notion of smart cities, powered by technology, has emerged as a promising solution to many urban challenges. A prevailing technocentrism has led to a focus on reducing congestion and accidents, largely overlooking the quality of life of local residents (the emphasis on connected and automated cars is a prime example of this). However, in his recent book, Green (2019) puts forward the concept of a “Smart enough city,” arguing that technology should be implemented “to address social needs and advance policy, rather than adapting goals and values to align with technology” (p. 159). As such, cities must carefully consider the role and place they wish to assign to automated vehicles as a whole, and automated delivery robots specifically, to ensure that they enhance, and not erode, the quality of city life.

Economic aspects and cost

In terms of costs and economic viability, the availability of relevant literature is relatively limited. Starship, for example, offers food delivery services on several

college campuses in the United States, charging US \$1.99 (Feldman, 2019) per delivery. However, the actual cost per delivery is estimated to be less than €1.00, considerably lower than the cost of equivalent human deliveries, which is highly dependent on local circumstances (Hoffmann & Prause, 2018). The cost of a robot-based delivery system can vary considerably, depending on the demand structure and logistics network design. Studies have demonstrated that by combining robots with vans, they can outperform conventional vans, though this will depend on the network structure and customer distribution (Jennings & Figliozzi, 2019).

Planning robot deliveries

In recent years, researchers have turned their attention towards exploring the potential operational benefits of using automated vehicles for urban deliveries. Bakach et al. (2021, 2022), for instance, have examined robot delivery operations centred around robot hubs. Yu et al. (2020, 2022a, 2022b), on the other hand, have focused on the various questions surrounding “mothership” models, that is where vans transport one or several delivery robots.

In their 2021 work, Bakach et al. examine a two-tier delivery network, whereby robots operate on the second tier and are based at robot hubs. These hubs are supplied by traditional vehicles such as vans or trucks. The authors propose a model and methodology to determine the optimal number of robots and hubs to efficiently serve a customer base, as well as comparing the operational costs of the robot-based system to those of a conventional truck-based system. Across various case studies, the results show that the new robot-based system offers significant savings on operational costs, ranging from 70% to 90%, depending on parameters such as robot speeds, driver wages, and customer time windows.

Yu et al. (2020) investigated the use of robots for second-level route deliveries in a two-echelon urban delivery system. The concept involves a mothership van carrying robots on the first-level route, dropping them off, and picking them up at parking areas, while the robots handle deliveries on the second-level routes. Only robots are authorized to deliver goods to customers, and pedestrian zones in city centres or campuses constitute the target areas for their deployment. The authors proposed mathematical models and specialized algorithms to model and resolve operational planning challenges. A sensitivity analysis was conducted using a large testbed of artificial test instances, with a focus on robot speeds. On analysing their findings, the authors recommended keeping robot speeds low to ensure a pedestrian-friendly insertion into the urban environment, as system performance gains were negligible with increasing robot speeds.

In addition, in their 2022 study, Bakach et al. examined the potential issue of sharing pavements with pedestrians. The authors suggested that it could be beneficial for the robots to avoid routes with high pedestrian densities, as this would improve the overall public acceptability of the system. In their study, the authors focused on a robot-based last-mile delivery problem that involves flexible path planning in zones with varying pedestrian flow densities. A model and specific algorithm are proposed in the paper, taking into account the stochastic travel times

of the robots. Based on extensive computational experiments, the study demonstrated that considering varying pedestrian flow leads to alternative path choices in 30% of cases.

Yu et al. (2022a) have also studied a generic problem variant for van-based robots where robots and vans perform pickup and delivery operations in a city environment. In this study, the authors factor in restricted access zones in certain areas of the city, such as university campuses or pedestrian zones, which can only be accessed by robots. Vans can directly deliver to some customers, however, and can also drop off and pick up their robots at predefined parking areas, which also serve as locations for reloading the robots and swapping out their batteries where necessary. Using a case study of the city of Xi'an (China), the authors performed a comparative analysis of this approach with more traditional delivery approaches involving fixed robot hubs. The results showed that the mothership-based approach can be highly advantageous, resulting in a cost reduction of more than 10% in some cases, depending on the fixed cost setting of the hubs.

In another investigation by Yu et al., a comprehensive examination of robot battery usage and different recharging strategies was conducted (2022b), focusing on a two-echelon electric-van-based robot delivery system with en-route charging. The distinctive feature of this study was the prospect of recharging the robots while they are being transported in the vans, potentially saving time in comparison to systems where recharging is limited to specific parking areas. The authors present a model and a specific algorithm to perform a computational analysis. Through an analysis of various factors such as vehicle charging modes, charging rates, and maximum battery capacities, the findings revealed that en-route charging can lead to cost reductions in certain cases.

All this research points to the cost-effectiveness of implementing robot-based deliveries in the distribution process. The findings outlined in this chapter demonstrate that, from an operational standpoint, automated solutions can help bring costs down considerably in comparison with more conventional delivery approaches. This economic viability explains the growing interest for these new technologies within the distribution industry.

Conclusion and future prospects

The outlook for future technology advancements in automatic deliveries is a cautiously positive one, with promises of attractive cost reductions and reduced environmental impacts for urban deliveries. Still, as these robots begin to take to the streets, certain societal questions will inevitably arise, particularly with regards to the impact on urban landscapes, where space has already become a prized commodity. In addition, delivery robots may decrease face-to-face interactions – a laudable objective during the COVID-19 pandemic, but perhaps not so desirable for the future of our society. There is no shortage of proposals and discussions on the topic, including combining robots, vans, and other transport modes with human porters in densely populated areas. Though these robots offer clear advantages, it

is worth remembering that wheel-based delivery robots may not always be able to ensure final delivery to the end consumer.

The rise in urban deliveries, both currently and in the years to come, risks to diminish the appeal of urban centres with local shopping options, which could change the face of our cities. Technological and operational advancements in robotic deliveries are expected to be significant, and, as with every technological leap, these developments will trigger economic and societal consequences that will affect the way cities function. Moreover, the interaction with longer-distance deliveries is predicted to play a crucial role in attaining efficient and sustainable urban logistics systems. New multimodal interactions are also anticipated. Cities with rivers passing through their central areas offer unique opportunities for such intermodal connections, enabling high-volume shipments to be delivered to the heart of the city while reducing inbound road traffic. In order to enhance the quality of life in urban areas by minimizing traffic and other externalities, increased collaboration among economic stakeholders, researchers, and local governments will be necessary to effectively leverage these new technologies. This can be achieved by coordinated efforts between stakeholders to improve the quality and efficiency of deliveries, while also ensuring that cities remain attractive and liveable spaces.

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Notes

1 www.haropaport.com/en

2 <http://avfutures.nlc.org/jobs-and-the-economy>

References

- Amazon Prime Air Prepares for Drone Deliveries. (2022, June 13). www.aboutamazon.com/news/transportation/amazon-prime-air-prepares-for-drone-deliveries.
- Bakach, I., Campbell, A. M., & Ehmke, J. F. (2021). A two-tier urban delivery network with robot-based deliveries. *Networks*, 78(4), 461–483.
- Bakach, I., Campbell, A. M., & Ehmke, J. F. (2022). Robot-based last-mile deliveries with pedestrian zones. *Frontiers in Future Transportation*, 2, 32.
- Baum, L., Assmann, T., & Strubelt, H. (2019). State of the art – automated micro-vehicles for urban logistics. *IFAC-PapersOnLine*, 52(13), 2455–2462.

- Biermann, F., Coates, R., Ponto, L. R., Straubinger, A., & Walulik, J. (2021). Ready for take off? Integrating drones into the transport system. In *ITF Research Reports*. Paris: OECD Publishing. <http://dx.doi.org/10.2139/ssrn.3795545>
- Bouchery, Y., Woxenius, J., & Bergqvist, R. (2021). Where to open maritime containers? A decision model at the interface of maritime and urban logistics. *World Review of Intermodal Transportation Research*, 10(1), 6–29.
- Brandt, C., Böker, B., Bullinger, A., Conrads, M., Duisberg, A., & Stahl-Rolf, S. (2019). *Fallstudie: Delivery robot Hamburg für KEP-Zustellung* [PDF file]. www.bmwk.de/Redaktion/DE/Downloads/C-D/delivery-robot-hamburg.pdf?__blob=publicationFile&v=4
- Britt, P. (2019, November 6). *Field report: Starship delivery robots a hit at Purdue University*. www.roboticsbusinessreview.com/news/field-report-starship-delivery-robots-a-hit-at-purdue-university/
- Burgess, M. (2016, September 7) *Mercedes vans filled with swarming delivery bots could be heading to your hometown*. www.wired.co.uk/article/mercedes-starship-drones-delivery-van
- Dablanc, L. (2019). E-commerce trends and implications for urban logistics. In M. Browne, S. Behrends, J. Woxenius, G. Giuliano, & J. Holguin-Veras (Eds.), *Urban logistics: Management, policy, and innovation in a rapidly changing environment* (pp. 167–195). London & New York: Kogan Page.
- Dablanc, L. (2023). Urban logistics and COVID-19. In J. Zhang & Y. Hayashi (Eds.), *Transportation amid pandemics* (pp. 131–141). Cambridge, MA: Elsevier.
- Davies, C (2022, March 7). *Domino's autonomous pizza delivery robot doesn't need tipping*. www.slashgear.com/790145/dominos-autonomous-pizza-delivery-robot-doesnt-need-tipping/
- De Groot, S. (2019). *Pedestrian acceptance of delivery robots: Appearance, interaction and intelligence design* (Master's thesis, Faculty of Industrial Design Engineering at Delft University of Technology).
- Feldman, A. (2019, August 20). *Starship technologies raises \$40 million to expand its food-delivery robots on college campuses*. www.forbes.com/sites/amyfeldman/2019/08/20/starship-technologies-raises-40m-to-expand-its-food-delivery-robots-on-college-campuses/
- Figliozi, M., & Jennings, D. (2020). Autonomous delivery robots and their potential impacts on urban freight energy consumption and emissions. *Transportation Research Procedia*, 46, 21–28.
- Green, B. (2019). *The smart enough city: Putting technology in its place to reclaim our urban future*. Cambridge, MA: MIT Press.
- Helbing, D., & Molnar, P. (1995). Social force model for pedestrian dynamics. *Physical Review E*, 51(5), 4282.
- Hoffmann, T., & Prause, G. (2018). On the regulatory framework for last-mile delivery robots. *Machines*, 6(3), 33.
- Jennings, D., & Figliozi, M. (2019). Study of sidewalk autonomous delivery robots and their potential impacts on freight efficiency and travel. *Transport Research Record*, 2673(6), 317–326.
- Joerss, M., Neuhaus, F., & Schröder, J. (2016, October 19). *How customer demands are reshaping last-mile delivery*. www.mckinsey.com/industries/travel-transport-and-logistics/our-insights/how-customer-demands-are-reshaping-last-mile-delivery
- Larsen, A., & Van Woensel, T. (2019). Freight, logistics and the delivery of goods in cities. *Transforming Urban Mobility: DTU International Energy Report*, 62–71.
- Lunden, I. (2022, January 25). *Starship technologies picks up €50M from the EU's investment arm to expand its fleet of autonomous delivery robots*. <https://techcrunch.com/2022/01/25/>

- starship-technologies-picks-up-e50m-from-the-eus-investment-arm-to-expand-its-fleet-of-autonomous-delivery-robots/
- Olsson, J., Hellström, D., & Pålsson, H. (2019). Framework of last mile logistics research: A systematic review of the literature. *Sustainability*, *11*(24), 7131.
- Pandemic, parcels and public vaccination envisioning the next normal for the last-mile ecosystem, insight report.* (2021, April). https://www3.weforum.org/docs/WEF_Pandemic_Parcel_and_Public_Vaccination_report_2021.pdf
- Rai, H. B., Touami, S., & Dablanc, L. (2022). Autonomous e-commerce delivery in ordinary and exceptional circumstances: The French case. *Research in Transportation Business & Management*, *45*, 100774.
- Raimbault, N. (2019). From regional planning to port regionalization and urban logistics: The inland port and the governance of logistics development in the Paris region. *Journal of Transport Geography*, *78*, 205–213.
- Stewart, J. (2017, February 21). *A drone-slinging ups van delivers the future.* www.wired.com/2017/02/drone-slinging-ups-van-delivers-future/
- United Nations: Department of Economic and Social Affairs Population Dynamics: World Urbanization Prospects 2018. (2018). <https://population.un.org/wup/>
- Witte, P., Wiegmans, B., & Ng, A. K. (2019). A critical review on the evolution and development of inland port research. *Journal of Transport Geography*, *74*, 53–61.
- Wong, A. (2020, November 18). *KFC deploys autonomous 5G “food trucks” in China.* <https://soyacincau.com/2020/11/18/kfc-autonomous-5g-restaurant-on-wheels-china/>
- Yu, S., Puchinger, J., & Sun, S. (2020). Two-echelon urban deliveries using autonomous vehicles. *Transportation Research Part E: Logistics and Transportation Review*, *141*, 102018.
- Yu, S., Puchinger, J., & Sun, S. (2022a). Van-based robot hybrid pickup and delivery routing problem. *European Journal of Operational Research*, *298*(3), 894–914.
- Yu, S., Puchinger, J., & Sun, S. (2022b). Electric van-based robot deliveries with en-route charging. *European Journal of Operational Research*. <https://doi.org/10.1016/j.ejor.2022.06.056>