International
Transport Forum

The Final Frontier of Urban Logistics

Tackling the Last Metres

Mobility
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The International Transport Forum

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Executive summary

Key messages

Automated delivery drones and robots may not be effective for last-metre operations in urban areas.

Operational limitations – including large dimensions, elevated costs, limited capacities, public acceptance, and access restrictions in urban areas – make their use better suited to non-urban contexts.

Emerging automated last-metre alternatives could exacerbate street-space management tensions.

Unless properly managed, intensifying the use of robots or drones in already highly-contested urban street spaces could significantly negatively impact liveability and well-being in cities.

Transferring last-metre parcel delivery operations to recipients can be effective in urban areas.

Relying on pick-up and drop-off points (including parcel lockers and retail locations) may be the most effective and user-friendly solution to improve operational efficiencies of parcel deliveries in urban areas.

Main findings

This report investigates innovative delivery methods – including porters, bicycles, and automated pods and drones – that may enhance the efficiency and security of the final delivery step. The potential use of four automated delivery alternatives is analysed using the ITF urban-agent-based modelling framework. The use of these delivery robots and drones is simulated in a complex urban environment that includes passenger and freight movements, as well as vehicles ranging from large trucks and lorries to small micromobility alternatives for passengers and cargo bicycles for freight.

Operational research has long optimised vehicle delivery routing to increase cost efficiencies and reduce times and distances travelled. However, there is evidence to suggest that much of the time used during parcel delivery is spent in the last metres of the delivery, i.e. going to doors to deliver parcels, re-delivering missed deliveries, moving through floors of a building or waiting for recipients to collect the parcels. This highlights the complexity of the last step of the chain: reaching the final consumer.

This complexity is further exacerbated by increasing demand. Increased freight demand in cities has resulted in significant environmental and economic costs related to added vehicle kilometres travelled, congestion, increasing parking pressure and space consumption conflicts. More demand for urban freight also results in more missed deliveries and second attempts, which worsen these impacts and create significant additional costs. As such, companies and cities have expressed interest in developing more efficient ways to deliver packages and goods at lower environmental and monetary costs.

The results of the modelling exercise conducted for this study show that automated drones and robots are unlikely to significantly displace existing last-mile and last-metre alternatives. Among the automated alternatives, small sidewalk robots are found to be the most promising, but their use cases remain limited. Any attempts at mass implementation will face the increased difficulty of frequent interactions with pedestrians and other users of pavement space. How safe these interactions are and how priority is established when human-robot encounters inevitably occur will be critical to the social sustainability of these services.

Delivery drones will likely have even more marginal case uses in dense urban areas. Their large dimensions, elevated costs and limited carrying capacities, coupled with limited landing spaces, make their use as last-metre solutions better suited to high-value goods in non-urban contexts.

Critically, without access to final delivery locations where they can safely drop off packages, autonomous and combined last-metre solutions will face the same temporal challenges that logistics employees face: waiting for customers to collect packages from public pathways or streets and having to make multiple delivery attempts when customers are not available. Similarly, using robots to deliver to pre-defined locations would require transferring the final metres of the delivery to the recipients. This is particularly relevant for business-to-consumer services.

Although the mass adoption of these new automated alternatives does not seem imminent, operators' and researchers' continued interest in automation means that cities and policy makers must be prepared to manage the eventual uptake of these or other alternatives in the future.

Finally, a greater uptake of light(er) freight vehicles and porters to replace established trucks, lorries and light-duty commercial vehicles in the final stage of delivery all share a significant limitation: smaller capacities. Therefore, implementing these suggested alternatives would require additional urban depots to counteract capacity constraints. These micro depots add complexity and costs to the logistics operation that could counteract cost savings and efficiency gains if not correctly managed.

Top recommendations

Prioritise feasible last-metre solutions that fit the context.

Lower-tech solutions for the last metres of urban deliveries, like using pick-up points wherein recipients take responsibility for the last metres, could be more efficient, easier to implement and more effective at mitigating negative externalities than automated solutions.

Establish effective policy frameworks to manage urban freight operations and safeguard public interests while allowing innovation.

Last-mile solutions are expected to continue diversifying in the coming years. This will further increase competition and existing tensions in street space allocation, prioritisation and use. Urban logistics policy must balance the interests of private stakeholders while ensuring that innovation remains aligned with public interests and the needs of society as a whole.

Anticipate the associated risks of potential logistics interventions.

Policy makers should carefully analyse the potential impacts of proposed new last-metre services, including emerging automated delivery solutions, before deciding how to manage their use and deployment.

Recognise the added legal complexities and responsibilities of pursuing urban automated deliveries.

Before deploying innovative, automated last-metre solutions for urban freight deliveries, policy makers should align local, regional and national policies and ensure they are prepared to manage the added legal complexities of automation. For instance, policy makers establishing rules for mobility-space use bear a fundamental responsibility to ensure that the uptake of sidewalk delivery robots, drones or any other delivery innovation does not compromise pedestrians' and other users' safety in public spaces.

Last-mile logistics and the importance of the last metres

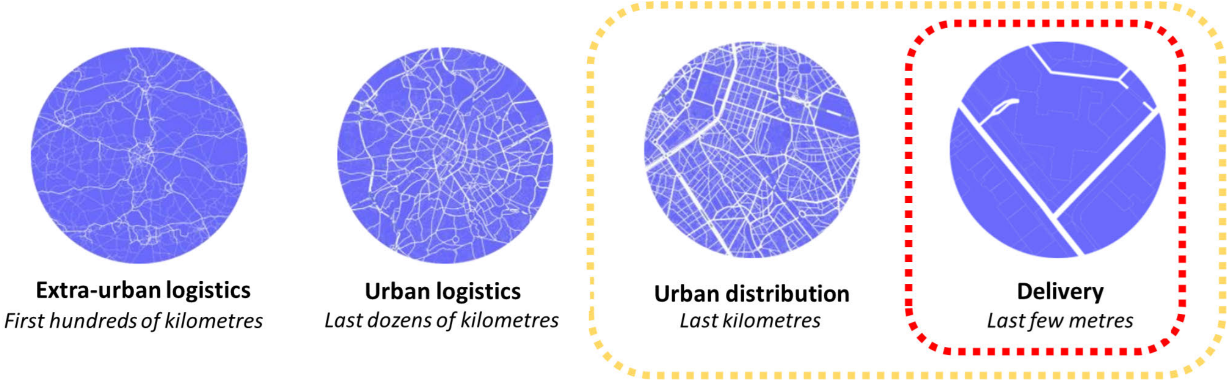
This project examines various options for tackling the final step in the logistics chain. Last-mile (or last-kilometre) deliveries are of course critical, but how can parcels efficiently and securely travel the last few metres from the delivery vehicle, package locker or local drop-off location to the recipient's front door?

These very last metres are the final frontier for urban deliveries. The rise of e-commerce has increased the number of deliveries in already crowded cities and is expanding the needs and requirements of urban logistics, necessitating the distribution of goods to more locations.

The different scales of urban freight operations

Serving the logistic needs of urban areas is a complex endeavour that requires access to global supply chains. From the global gateways, freight operations are broadly organised at four scales: extra-urban logistics, urban logistics, urban distribution (i.e. last-mile delivery) and finally at the smallest scale, the last hundred-or-so metres of the delivery between the delivery vehicles and the final destination (Figure 1).

Figure 1. The scale of freight operations



Source: Adapted from ITF (2022a)

What is last-mile logistics?

Last-mile logistics has long been an established operational and research field, and in the previous ten years there has been a growing interest in the field (see Liu and Hassini, 2023). Last-mile delivery can be understood as the logistical freight operations at the levels of strategic decision making and long-term planning, ranging from the distribution centre to the final destination, regardless of how it is organised (Liu and Hassini, 2023).

Last-mile logistics centres – which tend to be medium, small and micro-size depots – serve inbound trucks and outbound urban vehicles. Trucks, vans, light commercial vehicles (LCVs) and light-duty vehicles (LDVs), and bicycle alternatives are currently used for last-mile deliveries in different contexts.

However, the systemic characteristics of last-mile logistics vary significantly between emerging and mature markets. These include differences in the distribution network design, the network architecture (e.g. the number of tiers), the characteristics of the logistic facilities, and the transportation services used (Janjevic and Winkenbach, 2020).

The challenges of last-mile delivery

There has been a significant increase in the last-mile delivery market's scale, which includes business-to-consumer deliveries, business-to-business pickups and deliveries related to stocking. This has been buoyed by enormous growth in retail e-commerce sales, further accelerated by the COVID-19 pandemic (UNCTAD, 2022). Post-pandemic e-commerce has not continued to grow at the same rate, but is expected to continue expanding.

More e-commerce activity leads to a rise in freight transport demand, which in turn is linked to increased emissions and congestion in the absence of measures to decarbonise freight activity (ITF, 2023a). Today, e-commerce revenue exceeds USD 1 trillion in both the US and China and continues to grow worldwide. Recent industry calculations expect this growth to continue, with an expected global compound annual growth of more than 11% between 2024 and 2029 (Statista, 2024). Despite this, many cities are still not considering last-mile logistics as part of their sustainability plans and even fewer are dedicating resources to this field (Maxner, Dalla Chiara and Goodchild, 2024).

The market for last-mile-delivery parcel distribution is highly competitive and has low-profit margins (Allen et al., 2018). This situation has resulted in an increasingly complex system with growing externalities. These include the added strain and competition for the use of footpath, curb and road space (ITF, 2022a) and the environmental impacts of these services, which can be mitigated by fleet electrification and the use of smaller vehicles (ITF, 2023b). However, fleet renewal and electrification measures would require high short-term investment by operators.

In addition to questions related to environmental sustainability, last-mile delivery faces numerous operational concerns ranging from costs and time pressure to increasing volumes and an ageing workforce (Allen et al., 2018; Boysen, Fedtke and Schwerdfeger, 2021).

Cost considerations are particularly relevant to operators who must balance cost-effectiveness with sustainability aims in a highly competitive market. These costs include commercial vehicle insurance, which can account for 60% of the total cost of ownership of delivery vehicles in some contexts (Lal et al., 2023), as well as significant financial payments for road infractions – usually parking and waiting infringements in congested urban centres (Allen et al., 2018).

Furthermore, demand patterns and workloads vary throughout the day, week, season and time of the year. To account for this, modern approaches must be flexible and scalable so that services can be ramped down or up to meet changing needs (Mohammad et al. , 2023).

How much time is spent idling or parked on the curb?

Vehicle routing problems for logistics distribution are among the most studied problems in operational research (see Braekers, Ramaekers and Van Nieuwenhuyse (2016); Konstantakopoulos, Gayialis and Kechagias, (2022) and Zhang, Ge, Yang and Tong, (2022) for recent reviews on the topic). However, despite this focus on optimising vehicle delivery routing, there is evidence that much of the time used during parcel delivery is associated with the last metres of the delivery – that is, going to doors to deliver the parcels, returning to the vehicle, or climbing stairs.

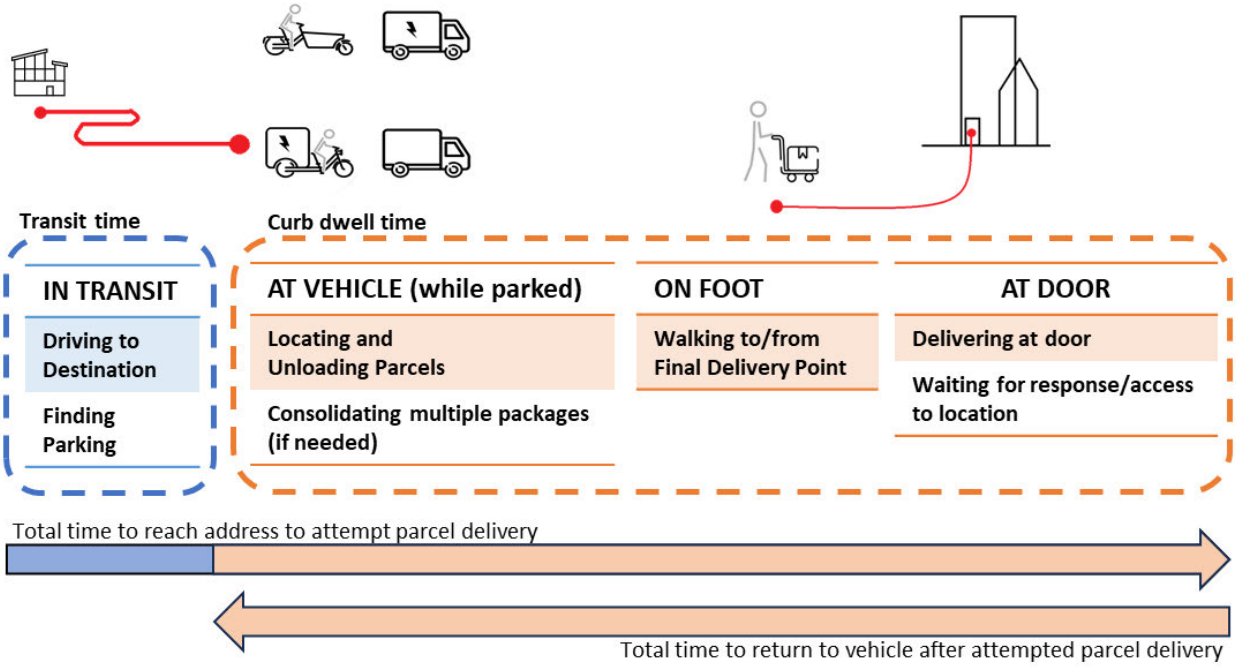
Broadly speaking, the time-use for parcel delivery attempts can be divided between the time spent in transit and the time spent on the curb making the delivery (see Figure 2). Of these, the curb time component is the most complex.

Travel Time

Travel time can be divided into two main tasks: driving to the destination and finding appropriate parking once the destination has been reached.

Finding the most efficient route for the vehicles is a critical operational component of logistics activities. However, existing optimisation strategies are well suited to deal with this challenge. Technological development today enables adaptive routing that can consider alternatives in real time to account for changes to traffic circulation and congestion.

Figure 2. Time use in parcel delivery attempts



Source: ITF (2024)

Finding parking for freight deliveries in congested urban areas can be more challenging (Dalla Chiara, Krutein, Ranjbari and Goodchild, 2022; Iacobucci, McDonald, Edwards and Steiner, 2022). However, despite the extraordinary amount of interest in optimising vehicle routing (e.g. Konstantakopoulos et al., 2022), much of this literature fails to consider the need to find parking (Reed, Campbell and Thomas, 2024).

In congested urban areas there are often limited parking bays for freight vehicles. As a result, it is common for these to be occupied, or for the nearest designated loading/unloading zone to be inconvenient or far removed from the destination. More stops tend to occur in unregulated zones than in regulated loading/unloading areas – often outside the time slots specified in city regulations (Galende-Hernández, Sainz-Palmero and Fuente, 2024).

Under these conditions, drivers must balance the parking search time, the access time (on foot) needed to make the delivery and the cost of parking (Amaya, Encarnación and Delgado-Lindeman, 2023).

This often results in unsafe practices and illegal parking or in a costly search for parking. In fact, more stops tend to occur in unregulated zones than in regulated loading/unloading areas – often outside the time slots of city regulations (Galende-Hernández et al., 2024). Additionally, cruising for parking has long been a concern for urban areas due to potentially adding to the vehicle kilometres travelled in cities and contributing to congestion (Shoup, 2006). Although much of the focus of the research has been on passenger cars, cruising for parking is also a significant concern for last-mile deliveries. A case study in Seattle, for instance, found that parcel delivery drivers spent more than 1 hour per day cruising for parking (Dalla Chiara and Goodchild, 2020), while in Brussels a recent study found that vans spent as much as 25 minutes per stop searching for parking (kale ai, 2023).

Curb Time or Dwell Time

Once the vehicle has been parked, the last several metres of the delivery on the curb begin. It is at this stage where much of the delivery time is spent. While surprising when considering the small distances travelled in comparison to the total route, this is a direct result of the complexity of this step. Curb time includes time spent locating, unloading, and potentially consolidating parcels (see e.g. Figure 3), walking to and from the customer's premises, waiting for access at entrances, and time spent inside these premises (e.g. walking up or down stairs or gaining proof of delivery if necessary).

While the specifics vary by context, it is common for curb time to be longer than the time spent driving. For instance, a study in Sweden found that parcel vans were parked for 41% of their route duration as drivers made final deliveries on foot (Sanchez-Diaz et al. , 2020), while another study by Allen et al. (2018) found that delivery vehicles in central London were parked or idle for more than 60% of a carrier's 7-hour-plus round. In the United States, a case study relying on driver ride-alongs in Washington DC and Seattle found that 80% of the operating time occurred while idle or parked (Dalla Chiara, Krutein, Ranjbari and Goodchild, 2021).

Allen et al. (2018) found that drivers, on average, spent more than 4 minutes to deliver or collect a package once parked and walked as much as 12 km throughout the day (nearly 8 km on average). This corresponds to more than 100 meters at each delivery or pick-up.

These conditions have resulted in a drive to understand how this stage of the delivery process can be optimised, as well as in significant investments to try to develop innovative solutions for last-mile delivery. The use of smaller vehicles and the reliance on active-travel alternatives (such as cargo bikes and porters) can help relieve some of the tensions that are present in urban curbs, but do not entirely resolve them.

Figure 3. Curb-side freight consolidation in New York City

Source: Philippe Crist (ITF)

What are the costs of missed deliveries?

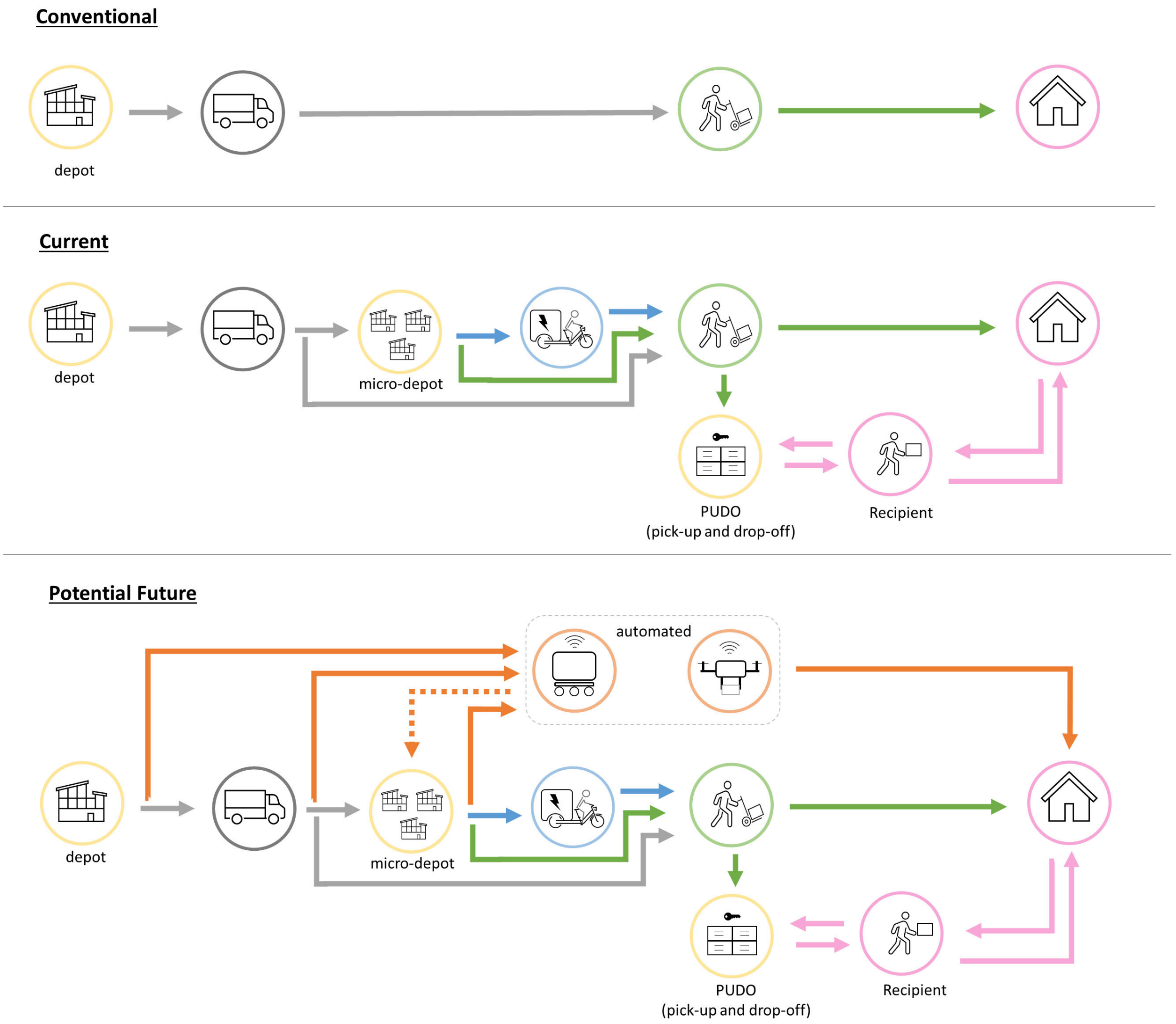
Significantly, when the delivery cannot be made, it adds to the system's inefficiency. In addition to the time spent while being unable to deliver the package, a similar amount of time would need to be spent on a different day to re-attempt the delivery. This contributes further costs to the delivery process. Many packages end up requiring more than two attempts to complete the delivery. For example, another case study in central London found that, on average, 2.4 delivery attempts were made if the first attempt failed (Bates et al., 2018). However, this is highly dependent on service providers. Currently, providers may only perform one delivery attempt before redirecting the parcels to a pick-up location or parcel locker, or returning it to the sender.

Bates et al. (2018) also found that Saturday was particularly inefficient for deliveries to businesses, with an almost 50% rate of failed deliveries, which resulted in additional trips on Monday. During the week, missed delivery rates ranged from 7% to 14%, depending on the weekday. In general, proportionally more failed deliveries were recorded after 17:00h, likely due to customers having left their offices to go home.

The evolution of delivery services

Last-mile delivery concepts have proliferated in recent years, and how goods move between different logistical nodes and finally reach consumers has continued to diversify (see Figure 4), changing how parcels reach their final destinations. However, despite the surge in the amount of last-mile parcel logistics and the proliferation of alternatives, it has been argued that their on-street characteristics and impacts are still poorly understood, partly because of the vast array of actors and the siloed way in which each supply chain functions (Allen et al., 2018).

Figure 4. The growth of last-mile distribution alternatives



Source: ITF (2024)

The most common last-mile delivery concept still relies on a driver in a van or truck delivering directly to the customer after departing a large depot. However, in order to minimise the number of necessary stops along a route, and to increase efficiencies, these vans are increasingly being used to serve pick-up and drop-off (PUDO) location alternatives, including retail parcel shops and self-serve parcel lockers. Recipients collect their packages at these locations at a later stage, without needing to co-ordinate with the logistics operator.

There has also been a trend to transfer part of the activity conventionally performed by trucks to less-polluting alternative modes. The surge in electrified cargo bikes means that delivery by e-bicycle – and by other small micro-delivery vehicles – is becoming common in many urban contexts (Figure 5). However, capacity and range constraints require additional satellite micro-depots within urban areas to effectively deploy these services, which can also be accompanied by additional labour requirements.

Figure 5. Examples of light, last-mile freight-delivery alternatives in Paris, France

Source: John P. Pritchard (ITF)

In many contexts there has also been a growing number of so-called "crowd shippers", i.e. delivery personnel not directly employed by logistics operators (Allen et al., 2018; Boysen et al., 2021).

Finally, there has been much interest in autonomous delivery robots, with both aerial drones and terrestrial surface-delivery robot solutions being proposed. However, as of today, despite significant effort and investment, there are still no large-scale deployments of these automated drone or pod services in urban contexts.

The growing need for micro depots or urban logistics hubs

The diversification of last-mile delivery alternatives – including to lower-capacity vehicles or modes with shorter effective ranges (see e.g. Figure 5 and Figure 6) – coupled with growing customer expectations of quick deliveries, has led to an increase in the need for urban logistics hubs. These strategically located facilities within urban areas can significantly optimise last-mile delivery by serving as crucial points for the consolidation, distribution and management of freight including reverse logistics (e.g. the return of goods and waste collection) (ITF, 2024).

Figure 6. Shift to lower-capacity vehicles for last-mile parcel deliveries in Paris, France

Source: Philippe Crist (ITF)

In addition to large urban consolidation stations used for cross-docking (usually located at the edges of the urban areas), there has a been a growing set of new real-state formats catering to urban logistics (Dablanc, 2023). These include:

- **Logistics hotels/distribution centres:** medium-to-large hubs used for storage and cross-docking that can serve the urban area more broadly
- **Logistics micro depots:** small hubs (usually less than 2 000 m^2) where cross-docking is possible and which serve particular local areas of the urban conglomeration
- **Fast delivery hubs:** extra-small hubs that are used for storage and fulfilment only and which also serve local areas

As highlighted in ITF (2024), the size, function and amount of these hubs influence the operational potential. There is a clear trade-off between the size of each of the depots in a logistics operation and the number of depots needed to serve an area. Additionally, implementing these hubs can be costly in some contexts (Robichet, Nierat and Combes, 2022) and difficult to implement in others due to land use restrictions (Silva, Amaral and Fontes, 2023).

Despite these difficulties, however, urban logistics hubs can help minimise the environmental costs of freight by reducing externalities (Dablanc, 2023) and can be effective at contributing to freight-efficient land use. Freight-efficient land use (FELU) patterns should minimise the social costs (private plus external costs) associated with both the supply chains and the economic activities that consume and produce goods (Holguin-Veras et al., 2021). These FELU principles aim to: minimise the social costs of supply chains at all their stages; foster compactness of supply chains, thereby reducing the distances travelled; mitigate supply chain externalities; identify appropriate solutions that account for local contexts, and effectively engage stakeholders.

A systemic approach to analysing the social costs of the complete logistics chain, rather than focusing on local impacts alone (e.g. the impact of a particular micro-hub on its direct vicinity) can help foster the establishment of a system that serves the entire urban conglomeration in a more efficient and effective manner.

Establishing FELU plans (Holguin-Veras et al., 2021; Holguín-Veras et al., 2022) can help guide policy makers and operators in developing effective strategies for addressing the growing need for more urban logistic hubs – and, more broadly, the potential re-imagining and re-organisation of the logistic chain.

In addition to the broader patterns discussed above, from an operational perspective, the last few metres of the delivery remain extraordinarily challenging. Last-metre delivery can be broadly understood as the segment of the logistics chain that entails the process of transferring the parcels from the curb to the hands of the intended recipient. This segment of the delivery has costly components tied to access to curb space and competition with other street-space uses. It also faces inefficiencies related to the interaction between public and private spaces necessary to make the final delivery. In particular, the need to access private premises can lead to costly delays and can exacerbate the issue of missed deliveries.

How can new innovations impact the last metres of the logistic chain?

Human-centred operational innovations and the maturation of services relying on established technologies, including e-bike deliveries and automated parcel lockers, have already begun reshaping urban logistics. Breakthrough technological innovations in the form of automated delivery alternatives promise to alter this landscape even further.

As the available alternatives increase, it is essential to understand how these different services can help deliver better outcomes. Policy makers must understand the inherent strengths and limitations of different proposals – and must critically assess whether these innovations could transform the last-metre component of urban logistics without compromising liveability and well-being in cities.

Human-centred operational innovations can improve the efficiency of the last metres

Human-centred operational innovations have shown some promise in terms of improving the effectiveness of urban logistics' last few metres of the delivery chain. The penetration of bicycle delivery, particularly e-cargo bikes, in different global contexts has already altered the urban logistics landscape. This trend is particularly noticeable in more-developed markets, while in developing markets, the use of electric three-wheelers, motorcycles and personal vehicles in some urban areas is more common (Janjevic and Winkenbach, 2020).

Porters, who are often gig economy "crowd shippers" (see Chapter 1), have also become more prominent for last-metre deliveries in some contexts. These delivery workers transport packages from local fulfilment centres or micro depots using various modes, including walking, cycling, and a combination of public transport and active modes (Janjevic and Winkenbach, 2020).

Additionally, during particularly high-demand seasons, some logistics operators opt to use seasonal “driver helpers” to increase the effectiveness of deliveries. In some cases, this approach may roughly halve the time drivers spend at each delivery stop (Lu, Suzuki and Clottey, 2020). The approach has two common variations: *dependent* and *independent* driver helpers. Dependent workers accompany the driver during the complete route, acting as a team to speed up deliveries. In contrast, independent helpers are used for nodes with multiple customers or deliveries, like office buildings, large retail centres or large apartment complexes. They do not travel with the driver and instead travel by other means to the predetermined multi-delivery nodes, where the driver will only drop off the packages before proceeding with their route (Lu, Suzuki and Clottey, 2022).

In both cases, the use of a driver and a helper improves the capacity of vehicles, permitting an increase in the number of packages that can be delivered without needing to expand fleet sizes (Lu et al., 2022). From the operator's perspective, the added efficiency in the last few metres of each stop along a route must be balanced against the added costs of labour.

Small(er) vehicles reduce curb time and delivery times, and minimise environmental costs

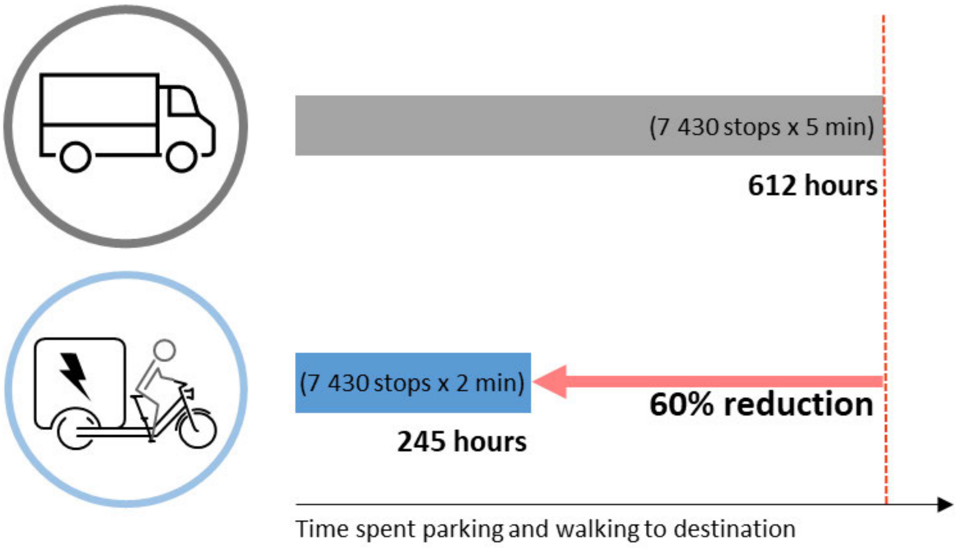
In addition to the use of driver helpers, the shift of last-mile alternatives towards lighter vehicles (e.g. cargo bikes, micro vans) can also improve the efficiency of the last metres of the delivery and help minimise the amount of time spent dwelling or parked at the curb. Smaller vehicles can potentially provide benefits in terms of reduced space consumption and associated emissions, while also reducing costs and improving the operational efficiency by allowing deliveries to park closer to the intended destination (thus minimising walking time) and avoid congestion delays in some contexts.

A recent study in Brussels analysed the extent of the potential operational benefits of cargo bikes compared to conventional vans, finding that the smaller vehicles could park closer to the final delivery point (less than 30 meters), travel faster in congested conditions (16 kph vs 11 kph) and reduce associated costs (kale ai, 2023). As a result, they estimated that the use of cargo bikes could result in a 60% reduction in how much time is spent searching for parking and walking to the delivery destination (see Figure 7). The combination of cargo bikes and hubs can achieve progressive reductions in distances and hours travelled, up to a density of about 150 deliveries/km^2 (Dalla Chiara et al., 2020).

Additionally, the environmental gains can be significant, contributing to large reductions in environmental and societal externalities when compared to the use of large vans, even when the latter are electric. The social and environmental costs (per km travelled) of diesel vans can be nine times higher than those of cargo e-bikes, while those of electric vans are seven times higher (Just Economics, 2022).

However, scaling up this sector remains a challenge. To deliver these potential gains in a societally just manner, it is critical to ensure that labour rights are not eroded and that riders have access to good and fair employment (Couve, Lam and Verlinghieri, 2023).

Figure 7. Estimated total time spent parking and walking to destination: cargo bikes vs vans



Source: kale ai (2023)

Parcel lockers and pick-up locations transfer the last-metre responsibility to recipients

Consolidating freight activity can provide environmental and operational gains at all stages of the logistic chain by contributing to greater economies of scale and potentially increasing vehicle load factors, reducing both the number of empty runs and vehicle kilometres travelled. Consolidation could significantly reduce the fleet size required for last-mile services while substantially reducing the time needed and the associated emissions (McLeod et al., 2020).

Despite this potential, however, the large number of operators, the siloed nature of vertically integrated logistic chains, and the sector's competitive nature complicate consolidating trips between operators.

Common-carrier parcel lockers offer a means of delivery consolidation in congested urban areas and can be placed in buildings, retail locations, stations and other public hubs (Ranjbari, Diehl, Dalla Chiara and Goodchild, 2023). These lockers and lower-tech pick-up points at local businesses offer the opportunity to consolidate the last metres of the delivery chain in instances where consolidating vehicle loads may not be feasible (ITF, 2024). Pick-up solutions have been well-established in many locations for several years (Morganti, Dablanc and Fortin, 2014) and have been increasing in popularity as an alternative to home deliveries.

The lockers consolidate multiple deliveries into fewer delivery hubs, which creates delivery density and, as noted earlier, potentially reduces vehicle kilometres travelled. It can also reduce failed delivery attempts, improving the system's overall efficiency (Ranjbari et al., 2023; Seghezzi, Siragusa and Mangiaracina, 2022). This alternative can be more cost-effective and environmentally friendly than home deliveries (Dong, Hovi and Pinchasik, 2023).

With pick-up locations, the last-metre component of the delivery is effectively transferred to the recipient. Logistics providers transport goods into cities, while consumers either receive goods at their doorstep or travel to pick them up from designated locations. Less transport by one party may result in more transport by the other party. As a result, although they can generate cost savings and reduce CO_2 emissions in urban areas, they could potentially increase emissions in more remote and rural areas due to the longer distances associated with the collection (Niemeijer and Buijs, 2023; Peppel and Spinler, 2022), as well as in urban areas in some conditions, where the environmental footprint is influenced by how the parcels are collected (Hovi and Bø, 2024).

Depending on the sustainability of the modes chosen by providers and consumers, the net effect can be positive or negative. For a complete analysis, researchers and policy makers must consider the travel by both (ITF, 2024).

Breakthrough technological proposals for last-metre delivery emphasise automation

Given the economic challenges of last-mile delivery and the costly nature of the last metres, most proposed solutions emphasise automation (see Figure 8), potentially increasing operational efficiencies while reducing human labour costs.

As highlighted by Srinivas, Ramachandiran and Rajendran (2022), the terminology varies in the literature, but most proposals can be broadly categorised into three types of vehicles:

1. **Large-capacity autonomous surface-delivery vehicles** which can operate on roads
2. **Smaller autonomous ground-delivery vehicles** (i.e. sidewalk delivery robots, or SDRs) which can operate on pathways or sidewalks
3. **Autonomous aerial drones**, sometimes called unmanned aerial vehicles (UAVs)

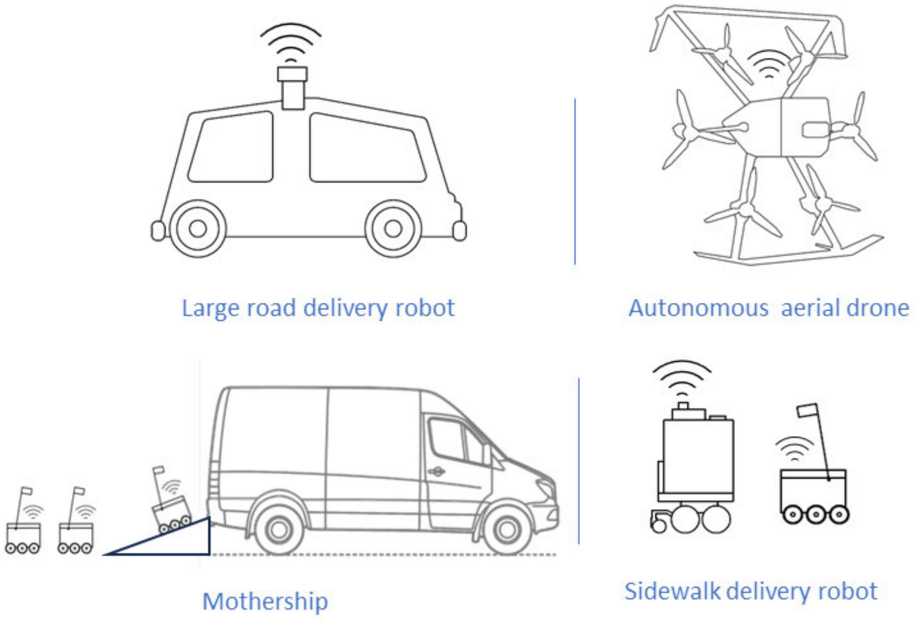
These alternatives can be further disaggregated based on their operational characteristics. Proposals include stand-alone options, departing from depots and micro-depots, and combining these modes with other modes to improve operational efficiency.

A notable example of combined approaches is "motherships" or truck-launched delivery drones and robots, where small delivery robots are launched from larger vehicles closer to their final destinations. These "mothership" alternatives can be understood as an automated version of driver helpers. Drivers (or automated vans) can unload delivery robots at predetermined locations and then continue to deliver other packages along their route before collecting the deployed drones later.

Mobile parcel lockers, which combine lockers with autonomous vehicle capabilities, have also been proposed with a view to improving accessibility and convenience while minimising some externalities (Liu et al., 2023).

The uptake of any combination of these automated solutions would change the cost structure of the associated services. Critically, automation will have direct effects (e.g. the replacement of labour), second-order effects (e.g. changes in use and activity to reflect changing costs and capabilities) and finally, broader tertiary effects on several crucial areas, including infrastructure use, urban space use, and equity (ITF, 2023c).

Figure 8. Breakthrough technological proposals for last-metre delivery emphasise automation



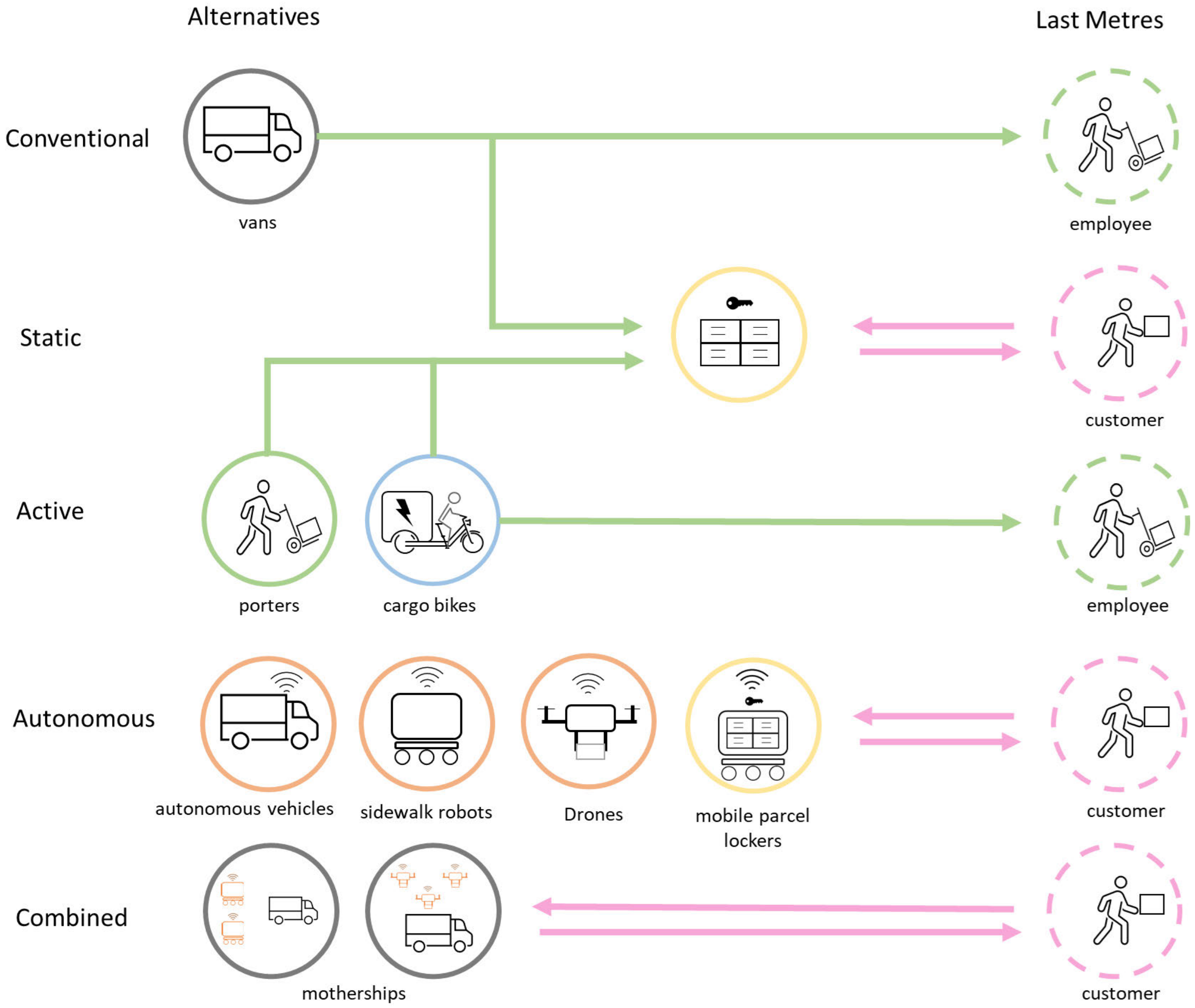
Source: ITF (2024)

Drones and delivery robots might not replace humans in last-metre operations

Given the capacity and range limitations of new last-mile and last-metre alternatives, the need for additional depots and micro depots requires additional operational costs. In addition, as highlighted in Figure 9, it is critical to understand that much of the operational gain in urban areas is associated with transferring the last few metres of the delivery to the customer or recipient.

Parcel lockers and pick-up and drop-off locations increase efficiency by limiting the number of stops in a route, while simultaneously decreasing the probability that a second trip will need to be made to any location because of a missed delivery. They explicitly transfer the time and effort required to make the final delivery to the parcel recipients, who must travel to collect each package and carry it home.

Figure 9. The last metres of last-mile delivery alternatives



Source: ITF (2024)

Unfortunately, without having access to safe locations to drop off packages, autonomous and combined last-metre solutions would face the same temporal challenges that logistics employees face: waiting for customers to collect the package from public sidewalks or streets and having to make multiple attempts of delivery when customers are not at home. Similarly, using the robots to deliver to pre-defined locations would require transferring the last metres of the delivery to the recipients. This is particularly relevant for business-to-consumer services.

As such, while there may be labour cost savings associated with automating sections of the delivery in dense urban areas, these innovations will be unlikely to significantly replace humans in the last metres. Instead, autonomous delivery robots and drones may be better suited to intermediate sections of last-mile delivery operations, such as re-stocking depots and micro-depots, where dedicated loading bays and facilities could allow for a seamless transition to cross-docks and other segments of the logistic chain.

Given the less-complex transport space in non-urban and suburban areas, less-complex air space limitations, and the greater likelihood of available private secured landing spaces (e.g. yards and fields), aerial drones may be able to serve the last metres in these areas to a greater degree. Under these conditions they can improve delivery speeds and accessibility in more remote locations.

However, the feasibility and safety implications of these delivery services would vary depending on the context. A combination of cultural and personal preferences, weather conditions (including heavy rain or wind), and improved efficiencies of other delivery alternatives could affect the use of drones to varying degrees in different contexts (ITF, 2021). Additionally, public acceptance must overcome citizen concerns, including legal issues to do with privacy and trespassing (Bafouni-Kotta et al., 2023).

Finally, dedicated small and medium-size delivery robots in large, multi-customer complexes could be useful for distributing packages within these complexes (e.g. apartment/office buildings or malls) after being dropped off by logistic operators, thus minimising the time spent at these locations.

What is the demand for innovative automated deliveries in cities?

This chapter assesses the potential penetration of innovative last-mile technological developments, including unmanned surface and air drones, using the ITF in-house agent-based model.

Modelling the penetration of autonomous delivery alternatives in cities

Models are essential for effective, evidence-based policy making because they provide a common ground to objectively discuss the policy implications of different transport alternatives (Ortúzar and Willumsen, 2011). The modelling for this study further develops ITF's urban-agent-based modelling framework by integrating four types of automated delivery vehicles: a drone and three surface vehicles (or delivery robots) of different sizes.

Agent-based modelling simulations are commonly used to understand the interactions between independent, autonomous agents. They are stochastic models built-up from individual units or agents that are each assigned certain attributes. This framework permits the analysis of the interactions between different agents whose attributes and preferences vary

Here, it is applied to represent a typical day of a complex urban system where passenger and freight activity must interact on the roads with space and safety restrictions. Residents may travel using a broad range of modes including walking, cycling, micromobility, private vehicles and public transport, while freight activity includes trucks, lorries, light commercial vehicles, light-duty vehicles (LDVs), cargo bicycles – and, now, four different automated alternatives.

The ITF agent-based modelling simulation

A shared simulation model based on the Greater Dublin Area (ITF, 2018) was used to test the updated logistics fleet types discussed in this report. However, the results depend on a synthetically generated, plausible characterisation of the logistics transport supply and parking availability. As such, the results of this report should not be used to assess the results or impacts specifically in the case of Dublin. This model was first developed to simulate shared mobility (ITF, 2018), and has been subsequently updated to include safety parameters and space-consumption assessments (ITF, 2022b) as well as urban freight and passenger interactions (ITF, 2022a) and the uptake of electric light mobility alternatives (ITF, 2023b).

The ITF agent-based model characterises the daily freight travel activity of different vehicle types sorted by ten commodity types and six travel-distance bands. It accounts for all freight needs of the synthetic mid-size European city used in the analysis, including parcels, deliveries, climate-controlled goods, waste-removal and construction.

The model framework has three components: a lexicographic demand module, an infrastructure optimisation module, and an operations and management module (Figure 10):

1. **Lexicographic demand model:** The comparative preferences of an agent are ordered given the bundle of available modal alternatives. Given these preferences, an agent will always choose their preferred alternative if available, regardless of the availability of other options. If the preferred mode is not available, it will select the 2nd preferred alternative, and so on, creating a cascading decision tree. This is done separately for passenger demand and freight demand since the vehicles used, and the preferences, are entirely separate. More details on the passenger demand lexicographic model can be found in ITF (2022b, 2023b). Freight preferences are mainly based on the characteristics of each of the ten commodity types considered in the model. Each commodity has different weight profiles, activity distances, and propensities to be transported by certain modes.
2. **Transport infrastructure optimisation:** Each street segment in the simulation is optimised through what is referred to as a “greedy” optimisation approach, wherein each specific segment is optimised individually and co-ordinated with the neighbouring segments. There are 19 different road typologies with different flow capacities and free-flow speeds for the different vehicle types. The optimisation here seeks to balance network capacities, parking availability (and efficiency), and the safety of the system as a whole. Safety is reflected primarily in how different vehicles and pedestrians can coexist while travelling at different speeds. It considers the intensity and severity of conflicts between pedestrians, freight vehicles, and motorised and non-motorised passenger vehicles.
3. **Transport operations and management:** Finally, the model considers how the different fleet alternatives can be used to match the demand. The freight operations and management component includes truck-based alternatives, light commercial vehicle alternatives, micro freight alternatives, and robot and drone automated alternatives. The model also includes an EV charging component (ITF, 2023b) with at-home and on-street charging for passenger vehicles; charging of e-freight vehicles occurs at depots, and logistics hubs.

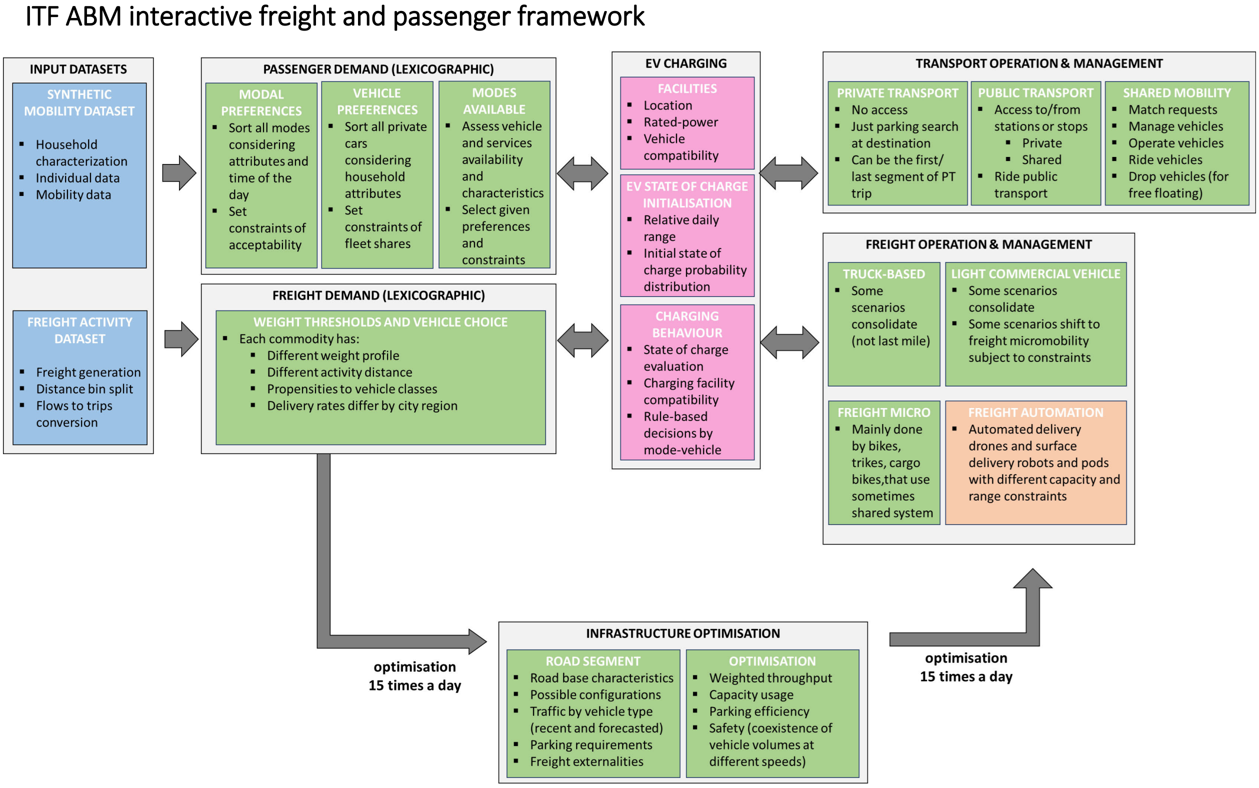
Integrating automated delivery alternatives into the model

The modelled automated mobile freight alternatives are representative of different robots that have been tested or are currently on the market. The aim is to provide a broad overview of these technologies and the potential impacts their operation could have in their different variations.

The surface drones include (a) two footpath robots with small and medium capacities that can share the infrastructure with pedestrians and light vehicle users like cyclists and (b) a larger-capacity alternative that must share the space with large, motorised vehicles (see Figure 11 for details). These alternatives complement the existing conventional and e-freight bikes, LDVs (1.5 T), LCVs (4T) and medium-capacity (8T) trucks already included in the modelling framework.

Among the automated alternatives, the drone has the maximum potential speed, reaching speeds of up to 80 kph, but the lowest carrying capacity, carrying loads of up to approximately 2.25 kg (Chen, 2023). This capacity is lower than the sidewalk robots included in this exercise, which can carry a maximum of 10 kg and 45 kg, despite the drone being significantly larger than the smallest robot. At the other extreme, the automated road version has a carrying capacity of 225 kg and can travel at speeds similar to those of conventional motorised vehicles in cities.

Figure 10. Adjusted model framework including last-metre automated freight alternatives



Source: ITF (2024)

Designing a complex urban scenario to simulate usage

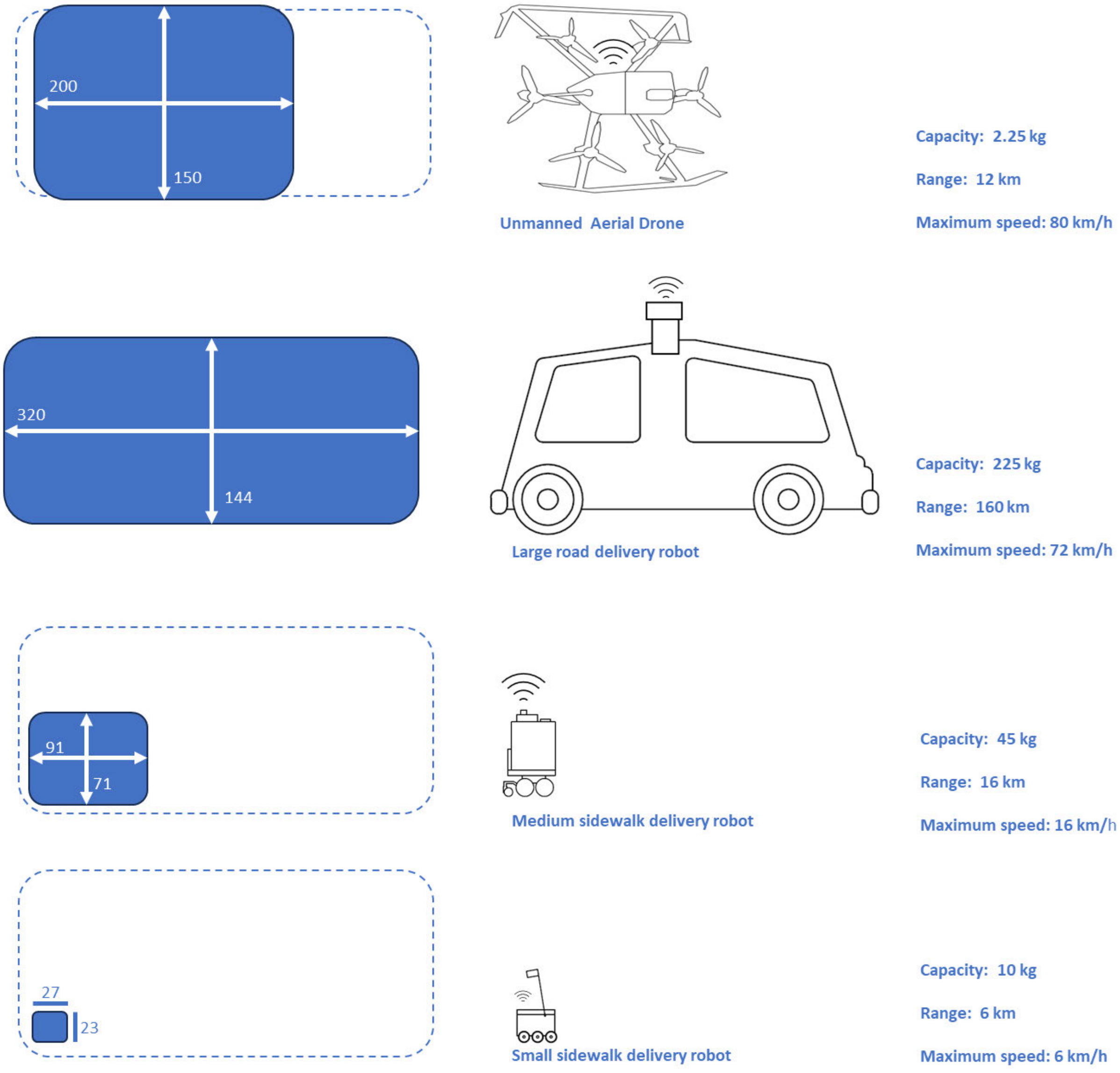
These technological last-mile alternatives are integrated into a scenario with broader uptake of light mobility vehicles for both passenger and freight, with a transition to electric vehicles (ITF, 2023b). This scenario assumes that effective decarbonising policies focused on more-sustainable transport can lead to mode shifts.

By doing so, it is possible to analyse the potential uptake and use cases for these delivery innovations (in contrast to classical logistics operations), embedded into a more up-to-date urban context that also includes recent additions to the urban landscape, e.g. cargo bikes for logistics operations. It also captures the potential areas of conflict between their operations and the uptake of a more diversified passenger mobility fleet that includes not only pedestrians and large motorised vehicles but also small microcars and micromobility alternatives for passengers. In the case of freight transport, the improvement of vehicle capacity use is due to changes in operations that favour load consolidation. These include the increased use of urban logistic hubs for eLCV deliveries and break-bulk (i.e., non-containerised cargo) operations between these vehicles and e-cargo bikes.

A utility-based sorting algorithm is used to select the freight mode and estimate the propensity to shift vehicles given a commodity type and distance band, with a hierarchical decision tree triggering potential mode shifts under the right conditions.

The trade-off between the different freight modes considers only whether the associated freight demand is compatible with the various robots and drones in terms of urban space use, travel time, vehicle capacities and total weight limits. It does not account for operational preferences and the monetary costs associated with the use of different modes. As such, the "what-if" analysis assumes that the available fleets are cost competitive – and estimates only the potential uptake considering the technical and operational limits of the alternatives.

Figure 11. Characterisation of modelled automated delivery drones and robots



Source: ITF (2024)

Note: Dimensions (in cm) and speeds shown are intended to be representative of recent in-use or tested delivery robots.

Aerial drones are likely to have a marginal effect on logistics operations

The results (see Table 1) of the agent-based simulation suggest that current last-metre proposals would have a marginal effect on total urban logistics operations. However, they can play a small role in delivery and parcel services.

In particular, aerial drones have minimal use cases within urban conglomerations. A negligible amount of activity would transfer to this mode in the tested scenario. This is primarily due to the capacity limitations of these modes coupled with the inefficiency in space use. Whereas many readers might imagine small domestic drones, actual delivery drones are much larger, often occupying close to 4 m^2 of space (see Figure 11 and Figure 15), while often having carrying capacities below 5 kg. Most business-to-consumer parcels are within this limit, but it severely constrains the ability to combine multiple parcels, limiting its broader uptake.

Often touted as a last-mile solution in dense urban centres, these drones' large size would often require dropping off the packages in delivery parking spots because there is limited private space inside homes – for instance, in a yard or on a lawn that could serve as a landing spot. In many urban areas, this would result in the last metres of delivery needing to be done by the customer, who would need to meet the drone to collect their delivery. As such, drones seem better suited to high-value deliveries in remote, rural, or even suburban areas with less competition for road and curb space.

It should be noted that the current simulation models drone activities in public urban space. This means that, given their large size and potential risk to pedestrians, the drones cannot land on or hover above footpaths. Also, the model required the drones to use designated freight parking and loading/unloading zones for those tasks. The use of "vertiports" was considered only in urban depots and micro depots. For all other trips, drones required the use of public space and infrastructure to make the deliveries, similarly to all other freight alternatives considered in the model.

Rooftop "vertiports" – where drones can deliver directly to a consumer's home, potentially even without the need to land – have been suggested as a way to encourage the use of drones (ITF, 2021). However, the large-scale implementation of "vertiports" in private buildings was considered unfeasible.

Table 1. Vehicle kilometres and tonne-kilometres of freight, by mode

Vehicle type	Distance (vehicle km)	Vkm (%)	Activity (tonne-km)	tkm (%)	% of parcels (tonne-km)	% deliveries (tonne-km)
Bicycle/e-bicycle delivery	491 052	29.1%	191	0.0%	-	39.1%
Cargo/e-cargo bicycle	209 445	16.3%	8 278	0.4%	12.7%	-
Motorbike/e-motorbike	67 112	4.0%	274	0.0%	-	56.4%
Car/e-car	258 914	15.4%	9 383	0.0%	12.6%	2.3%
LCV/e-LCV	50 445	3.0%	22 817	1.0%	70.5%	-
Medium truck	209 445	12.4%	622 166	27.6%	0.3%	-
Large truck	220 306	13.1%	1 589 359	70.5%	0.0%	-
Surface delivery robots	**89 344**	**5.3%**	**2 634**	**0.1%**	**3.9%**	**1.1%**
Unmanned aerial drones	**22 875**	**1.4%**	**41**	**0.0%**	**0.0%**	**1.1%**

Note: Modelled values from ITF Urban agent-based model simulation. LCV = light commercial vehicle; vkm = vehicle kilometres; tkm = tonne-kilometres.

In addition, the large-scale implementation of a dense "vertiport" network is significantly hindered by several factors that are difficult to overcome:

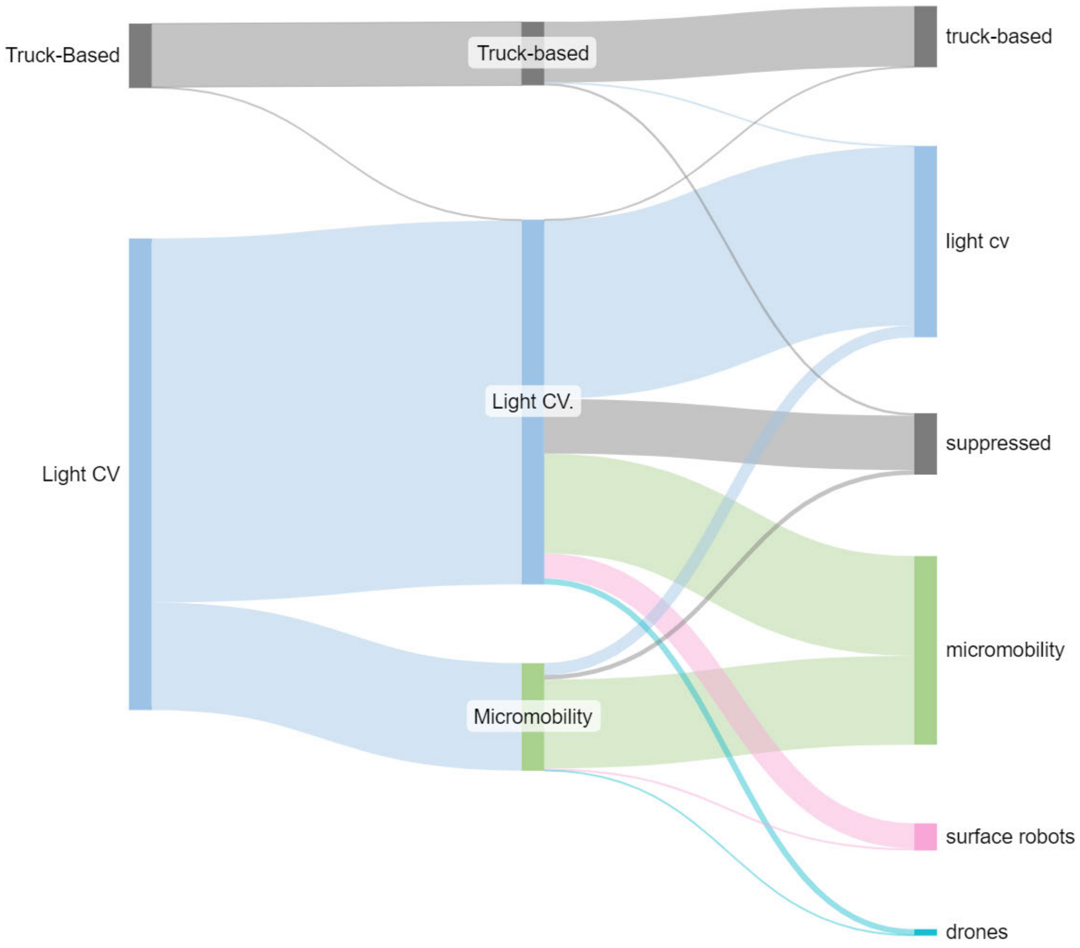
- **Rooftop design:** While flat roofs may meet the requirements for conversion to be used as "vertiports", their implementation in many other types of common angled rooftops (including gabled, mansard and curved roofs) would be more difficult.
- **Rooftop use:** Mechanical, electrical and plumbing service installations that provide function and comfort to buildings are often placed on rooftops. These include ventilation units and telecommunications infrastructure.
- **Security:** Rooftops are often restricted due to safety and security concerns. Providing safe access to many rooftops would require significant adjustments to their use, and potential retrofits.
- **Scale:** The immense density of the "vertiports" required to provide comprehensive coverage to a city is likely to limit their large-scale implementation.
- **Legal considerations:** The legal responsibility for these "vertiports" – which would be on private properties (e.g. buildings and homes) but used by external private stakeholders (i.e. freight operators) – needs to be examined. At this stage, in most contexts there is no clear legal framework to define responsibilities within an urban air mobility ecosystem.
- **Policy complexity of urban-airspace management:** Airspace above cities is designed and operated in line with various requirements. Although cities may not be responsible for managing airspace, they are likely to be responsible for managing the rooftops and other city locations that may be used to land.
- **Costs:** Finally, the cost of installing, safely operating and maintaining these "vertiports" is unclear, but could become very high when combined with the need of retrofitting existing structures to fit their needs.

Sidewalk delivery robots show the most potential among the automated alternatives

The penetration of the different types of surface delivery robots shows greater promise than aerial drones (see Table 1). These robots could perform as much as 5% of the freight vehicle km travelled within the urban area. Unfortunately, the small dimensions and low carrying capacity mean that this would only represent 0.1% of the total tonne-km of activity in the urban simulation.

To better understand what trips these surface drones would be likely to replace, two different scenarios were compared within the agent-based simulation. The first modelled a transition from a fully motorised freight fleet to a scenario with a significant uptake of micromobility freight alternatives (e.g. cargo bikes). Under these conditions, some of the trips that would have been performed by light-duty commercial vehicles of 1.5 T or 4T are found to be compatible with micromobility freight modes (see Figure 12).

Figure 12. Modelled modal shift with increased last-metre alternatives (trips)



Note: Modelled results. Total trips (including supressed trips) remain balanced in all columns of the graph. Flow colours are based on target modes. Vehicle abbreviations: "Light CV" includes 1.5 T and 4T light commercial vehicles.

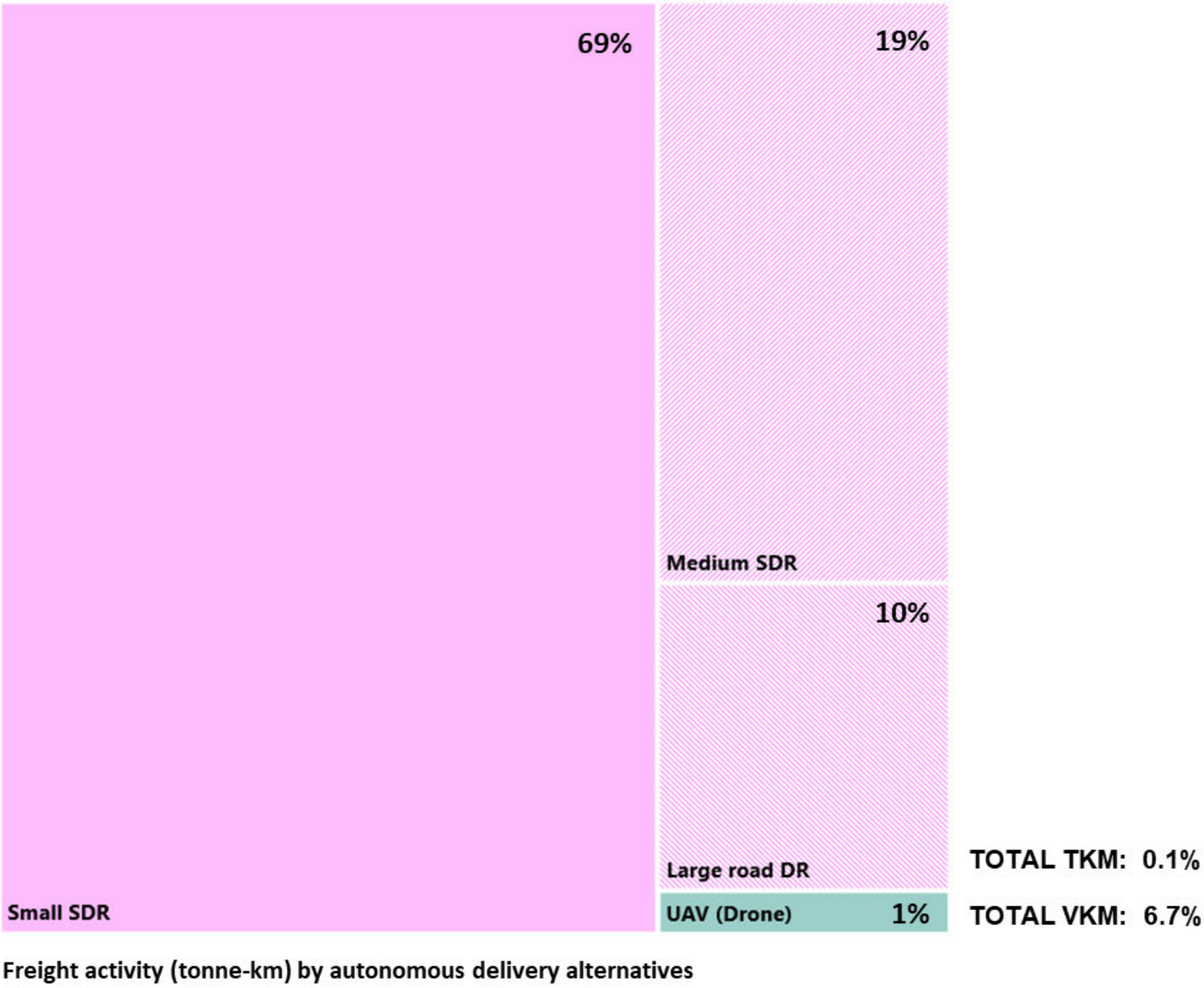
Source: ITF (2024)

Further expanding the availability of freight alternatives shows that the use of drones and surface robots, along with higher uptake of micromobility alternatives and increased use of urban logistic hubs for eLCV deliveries and break-bulk operations between these vehicles and e-cargo bikes, can reduce some of the trips that would otherwise be performed by LCVs. Some micromobility trips are also likely to shift to drones and surface robots (see Figure 12).

The footpath or sidewalk variation of these robots was found to be more likely to have a higher uptake than the larger autonomous road-delivery vehicles. The smallest variety was found to have more than twice the number of trips, and more than twice the number of tonnes of cargo, than the other two larger surface alternatives (see Figure 13). Other studies have highlighted their potential use (Garus, Christidis, Mourtzouchou, Duboz and Ciuffo, 2024), although there are potentially significant equity and safety concerns (Garus et al., 2022).

That said, the penetration of these automated alternatives remains below the potential of e-cargo bikes and other bike delivery alternatives. This is in line with previous studies on cargo bikes, which have found that they could replace conventional vans under some conditions (ITF, 2023b; Melo and Baptista, 2017).

Figure 13. Freight activity by delivery robots and drones within the modelled urban area (tkm)



Note: Modelled results. Vehicle abbreviations: “SDR” - sidewalk delivery robot, “DR” – delivery robot, “UAV” – unmanned aerial vehicle.

Source: ITF (2024)

What are the challenges of integrating last-metre delivery innovations into cities?

The last metres of the last mile, particularly in urban areas, are likely to remain some of the most complex and costly stages of the complete logistic chain. While current uses remain limited, there is still a possibility that automated freight delivery use cases will become feasible as technologies mature or new breakthrough innovations arise.

As with all freight activities, authorities and policy makers can influence where, when, how, and how much logistic movements occur. Effective policy frameworks should support and encourage the adoption of last-metre logistics that are best suited for particular contexts and minimise unintended externalities. In doing so they must balance the interests of private stakeholders and the needs of society as a whole. The frameworks should ensure that operational innovations remain aligned with public interests.

Accommodating this growing demand in sustainable and socially acceptable ways is a critical challenge for cities. Proposed solutions include porters, bicycle deliveries and automated delivery pods. But which mix of options is the best solution for which context? And how should different solutions be blended to accommodate distinct needs within the same cities? Finally, how should last-metre deliveries be managed and regulated, and by whom?

The feasibility of drones and delivery robot services remains a challenge

The promise of drones and delivery robots relies on breakthrough technologies that disrupt conventional and long-standing delivery operations (Robichet et al., 2022). Advocates for these automated last-metre alternatives promise that these solutions can reduce the energy consumption and CO_2 emissions associated with freight in urban areas while simultaneously reducing delivery time and costs (Figliozzi and Jennings, 2020).

Operational research exercises have shown that mothership alternatives, stand-alone surface drones and even parcel lockers may reduce the operational costs of logistics providers and provide associate environmental gains (Heimfarth, Ostermeier and Hübner, 2022; Moradi, Sadati and Çatay, 2023). In the case of truck-launched robots, the degree of these travel-time savings would be significantly impacted by the speed ratio between the truck and the robot, the robot's load capacity, and the distribution and configuration of the delivery locations (Simoni, Kutanoglu and Claudel, 2020). Motherships are likely more effective in suburban contexts, while surface delivery robots show more economic potential in urban centres (Lemardelé, Estrada, Pagès and Bachofner, 2021).

Selecting the appropriate configuration of services that fit local needs is therefore critical. To do this, it is important to consider the effects that could create inefficiencies in other dimensions. For instance, environmental gains can be offset by economic costs. The use of drones and robots may improve some operational outcomes, but their benefits would need to be large enough to counteract the costs of the additional micro-urban depots, hubs or mobile assets (e.g. parked containers or mobile parcel hubs) that may be needed due to more limited capacities and ranges. These can be significantly more expensive compared to logistical depots outside the urban core of cities. With a high density of pickups and deliveries, it is possible for these costs to be more than enough to cancel out the savings on transport costs, particularly in areas with very high land pressures (Robichet et al., 2022). Silva et al. (2023) highlights that these issues could be exacerbated in historical centres, where in addition to limited existing space for loading and unloading goods, the implementation of depots, micro depots or even parcel lockers could be complicated by preservation regulations.

The last 20 years have seen widely publicised drone and robot delivery pilots and programs by large logistical operators, as well as significant efforts in research and development. For instance, Amazon first unveiled its drone prototypes and program more than ten years ago (CBS News, 2013), promising 30-minute deliveries by drone. These announcements have resulted in the widespread public expectation of the imminent penetration of new logistical alternatives. As far back as 2017, for instance, a survey in the United States found that close to 30% of respondents expected delivery robots to be in use within a year, and an additional 50% believed that they would be in use by 2022 (OIG, 2018).

Despite these efforts by researchers and logistic operators, however, the dream of autonomous delivery vehicles, robots and drones remains largely unfulfilled as of today. Most of these alternatives remain theoretical in nature. They have yet to be implemented at a large scale, with many unsuccessful pilot trials having been discontinued or strongly delayed.

While there are many examples of autonomous vehicle developers of delivery robots in Europe (Buldeo Rai, Touami and Dablanc, 2022) and elsewhere, large-scale SDR applications by logistics operators have stalled. Unmanned SDRs and drones have been challenging to implement, with large logistics companies, including Amazon and FedEx, abandoning their programs in recent years (Garland, 2023), citing a failure of these programs to meet client needs and expectations (Reuters, 2022) and a lack of near-term value (Gitlin, 2022; Sidhart, 2022).

Similarly, while the Amazon air drone program continues to operate, it remains in the testing phase despite billions invested (Link and Dave, 2023). The program has faced difficulties navigating the legal and policy requirements to safely operate drones in urban areas (Amazon, 2023). Beyond this, the mode's inherent limitations complicate the use cases for urban logistics. The latest version of their drone, the MK30, can only carry 2.5 kg of weight (Chen, 2023) and could cost as much as USD 62 per delivery (Kim and Long, 2022). To make this a viable alternative, costs must be reduced significantly. Autonomous delivery alternatives are unlikely to attract significant use unless prices are lower than conventional home delivery.

Given the operational limitations, the most promising uses for these drones remain the delivery of high-value goods like medicines to remote or difficult-to-reach regions. There have already been many proof-of-concept tests worldwide, with Africa leading the way with several advanced-stage pilots that have already undergone technology demonstration, safety and feasibility testing and have proceeded to measure effectiveness and impact (UPDWG, n.d.). This is in line with expert studies highlighting that although there is some possibility that technology development and operational innovations could make drones’ use in urban areas possible, their most likely use will be in remote locations (Peppel, Ringbeck and Spinler, 2022).

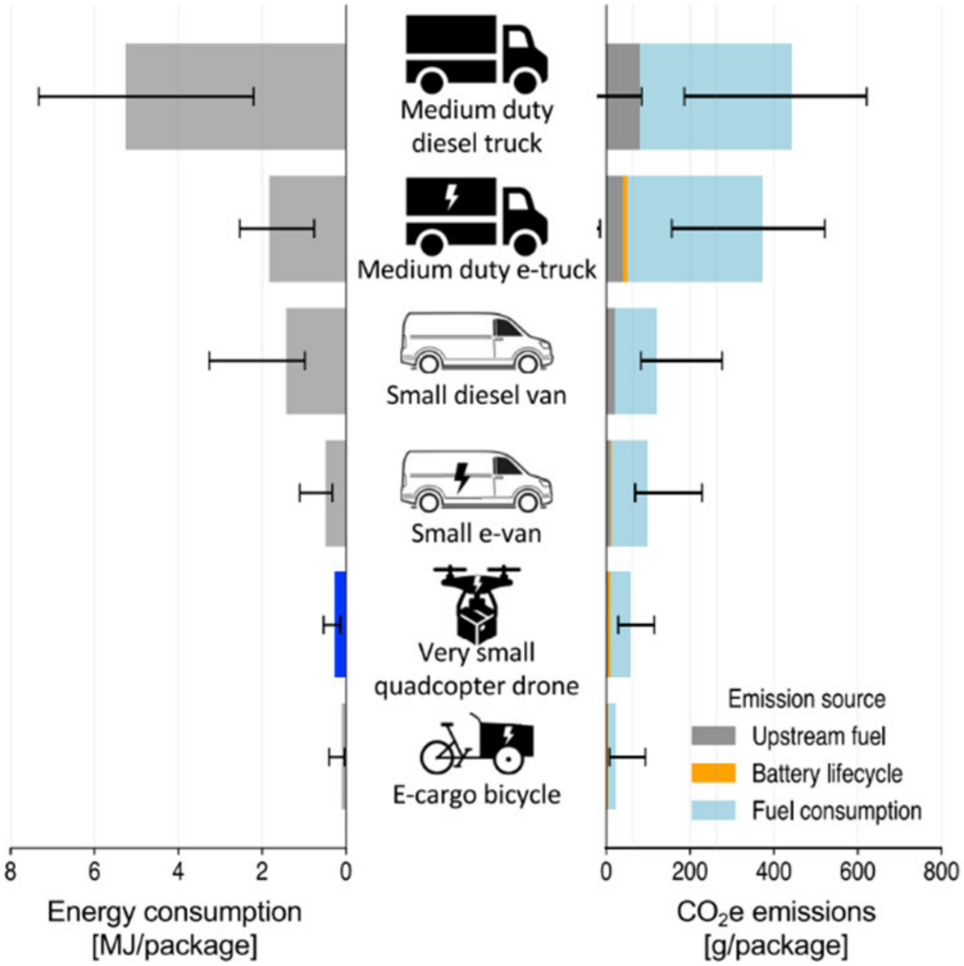
Drone deliveries may not deliver on environmental promises

In addition to operational concerns limiting the applicability of aerial drone deliveries as a last-metre solution within urban areas, the environmental case for these delivery options also remains unresolved. Measuring the environmental impacts of different delivery alternatives remains complex. Examining the complete system, including modelling the relevant operational and service changes that could accompany savings from replacing other modes, is critical. As such, isolating the impact or benefits of drones alone can be challenging (Campbell, 2022).

Rodrigues et al. (2022) have produced one of the few empirical field studies on drone emissions. Relying on data from 188 drone flights, they estimated that drones could potentially emit less CO_2 per package than all tested alternatives except for electric cargo bikes (See Figure 14). However, uncertainties due to variations in carbon intensity, battery lifecycle emissions and the density of deliveries could potentially make associated emissions as high as those of small electric (or diesel) vans.

However, as highlighted by (Campbell, 2022) those tests relied on significantly smaller drones than current iterations being tested by logistical operators. They used drones that weighed only 2.4 kg and could carry payloads of less than 0.5 kg over 2 km. As such, they are unlikely to reflect the energy consumption of the much larger multi-copter drones designed to travel long distances. For instance, Amazon's latest version of their delivery drone currently being tested is more than 1.5 m wide and 1.5 m tall (See Figure 15).

Figure 14. Energy consumption and associated CO_2 emissions of delivery alternatives



Source: Taken from Rodrigues et al. (2022)

A scenario analysis of larger drones, for instance, found that in many scenarios, there were no environmental gains over conventional delivery vans, and they had significantly higher greenhouse-gas emissions than electric vehicle alternatives, even when serving low-density rural areas (Kirschstein, 2020). Other studies have been slightly more optimistic, with some modelled results showing that drones can have an environmental advantage in CO_2 reductions over trucks when serving few recipients at relatively close distances – while failing to deliver better emissions outcomes in large service zones with many deliveries (Goodchild and Toy, 2018). Similarly, Raghunatha et al. (2023) found that drones could environmentally outperform diesel trucks in rural areas, but that due to the high energy demand at take-off and landing, that they would be unable to compete with electric vehicles.

Finally, in addition to emissions-related considerations, noise and visual pollution are important barriers for drones. As of right now, there is no clear understanding of acceptable thresholds.

Figure 15. Amazon MK30 delivery drone

Source: Taken from Chen (2023)

Emerging last-mile services will further exacerbate street-space management tensions

Companies continue to try to create more efficient ways to deliver packages. This continuous diversification of delivery methods and vehicles has exacerbated existing tensions in the management and use of street space. Critically, emerging automated services such as delivery robots and drones that are still in testing or not yet implemented at large scales could significantly increase the four main tensions of street management: liveability, capacity, network, and design (ITF, 2022a) (see Figure 16).

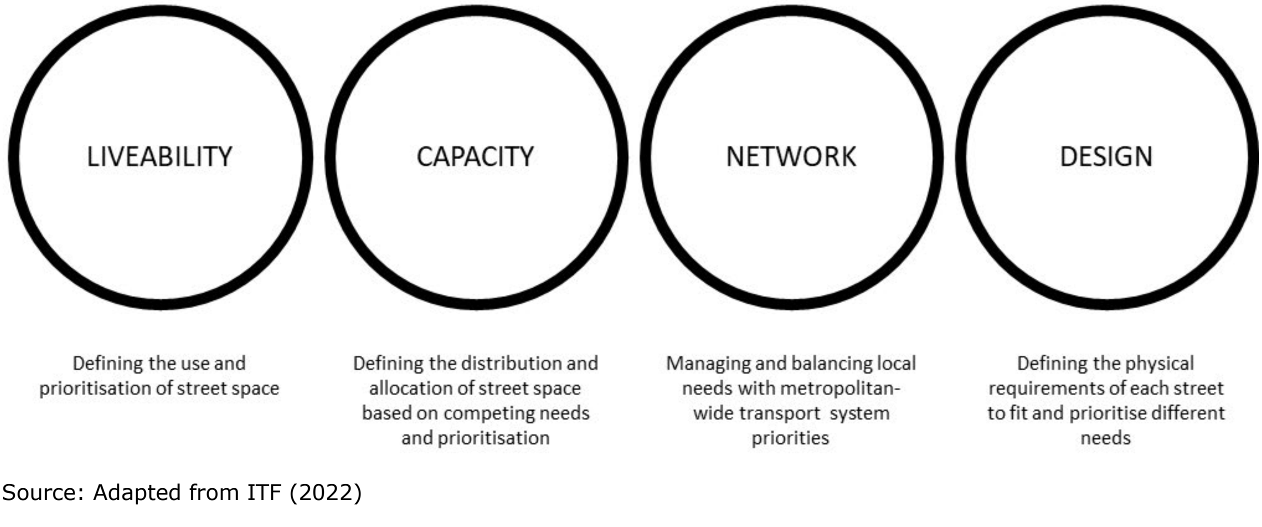
Unless these tensions are properly managed, intensifying the use of robots or drones in already highly contested urban street spaces could have a significant negative impact on liveability. In particular, the smaller robots that use pavements and footpaths to distribute goods will face the increased difficulty of frequent interactions with pedestrians and other users of pavement space for non-mobility uses. How safe these interactions are and how priority is established when human-robot encounters inevitably occur will be critical to the social sustainability of these services.

Authorities will need to decide carefully:

1. **Where** and **when** these automated services should be allowed to operate
2. **If**, **where** and **when** their movement should be prioritised
3. **What** physical requirements are needed for their operation
4. **Who** bears the responsibility for accidents
5. **Who** would intervene to resolve emergency cases.

Managing these tensions will be crucial to public acceptance of any new last-metre innovation that may become feasible in the coming years.

Figure 16. Central tensions of street space management



Source: Adapted from ITF (2022)

Effective policies and regulations are needed to limit negative impacts and ensure safety

While the specific case uses for automated deliveries are yet to develop, it remains possible that they may play some role in the future of cities. As such, policy makers must design a policy framework that enables the proliferation of innovative solutions currently on the horizon and those that are yet to be developed. This will require aligning policy directions and goals at the local, regional and national levels (ITF, 2023d) or, when appropriate, at the supra-national level – as is the case for regulation at the European Union, for instance.

Effective freight policies would require ensuring that no elements of the system end up in "no man's land," either outside the competencies of any agency or ignored in the decision-making process. In the case of last-mile and last-metre logistics operations, competent authorities may include metropolitan regions, cities, and stakeholders and decision-makers responsible for the management or operation of roads, footpaths and airspace.

Policies must ensure that citizens' safety, security and well-being are maintained. This will necessarily require managing the prioritisation and street space allocation and use. Urban logistics innovations are developing in parallel with the light mobility transition in the passenger transport sector – and face many of the same challenges. Minimising the seriousness of potential new conflicts that could arise from an ever-growing diversification of the vehicle fleets sharing the same space is critical (ITF, 2023d).

Policy makers must also be prepared to manage the added legal complexities of automation before deploying innovative automated last-metre solutions for urban freight deliveries. For instance, policy makers establishing rules for mobility-space use bear a fundamental responsibility to ensure that the uptake of sidewalk delivery robots, drones or any other delivery innovation does not compromise pedestrians’ and other users’ safety in public spaces.

Finally, privacy remains a critical hurdle for the acceptance of automated vehicles of any kind (Leon, Chen and Ratcliffe, 2023). Policy makers must ensure that data is treated as foundational infrastructure with a proper regulatory framework that includes checks and balances (ITF, 2023e). Operating automated services requires data collection and analysis – sometimes in real time. As such, before the deployment of any of these services, policy makers should guarantee that data protection regulations are in place that clearly define what data can be collected, what it can be used for, and how it can be shared.

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The Final Frontier of Urban Logistics

Tackling the Last Metres

This project examines various options for tackling the final step in the logistics chain. Last-mile deliveries are critical, but how can parcels efficiently and securely travel from the delivery vehicle, package locker or local drop-off location to the recipient's front door?

These very last metres are the final frontier for urban deliveries. The rise of e-commerce has increased the number of deliveries in already crowded cities. Accommodating this growing demand in ways that are both sustainable and socially acceptable is a critical challenge for cities. Proposed solutions include porters, bicycle deliveries and automated delivery pods.

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