International Transport Forum | CPB Corporate Partnership Board

The Freight Space Race
Curbing the Impact of Freight Deliveries in Cities

Corporate Partnership Board Report

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The International Transport Forum

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Executive summary

What we did

This report explores ways of making deliveries in cities less disruptive and more sustainable by focusing on the street space use of freight activities. How goods are distributed in urban environments profoundly affects metropolitan life. Urban freight flows impact cities' economic vitality and environmental footprint, as well as the safety and efficiency of traffic. The street space use of freight activities reflects or is involved in these impacts. Fast emerging mobility innovations for passengers and freight add to the increased space use of e-commerce, increasing competition over the use of already scarce street space in cities. This is the origin of the urban freight space race: a race to understand, channel and harness urban space to improve deliveries, urban function and citizens' well-being. It is a race that concerns freight carriers, freight receivers, authorities and citizens.

The study examines 21 measures to explore how private and public actors can address urban freight's need for space. These measures relate to managing the times and spaces where freight activities occur, the types of vehicles used or characteristics of the associated freight flows – for instance, where they come from and how consolidated they are. The analysis builds on computer simulations of how the measures would impact space-use, road safety and the environment in a medium-sized European city. The intensity of implementation of measures and their impacts vary in our simulations according to the stakeholders who contribute to their implementation: private carriers, the public sector, civic society and end-receivers.

What we found

Managing urban freight movements is especially challenging for public authorities. Historically, they have paid more attention to people's mobility than freight distribution. Some authorities do not have jurisdiction to influence freight movements at a metropolitan scale. Moreover, understanding freight flows can be challenging when relevant data is difficult to collect. Identifying and then managing actors and flows across multiple goods distribution networks presents further difficulties. These challenges underscore the need for public authorities to become empowered and effective urban space managers able to ensure that people and goods move in ways that make cities more liveable.

Public action is essential for managing freight demand, delivery timing, and street space used for them – such as curb space. Actions by private carriers to make urban freight transport more space-efficient have limits. Simulations show that voluntary measures by these private actors reduce the number of freight trips only by half as much as private actions supported by public measures. Enhancing publicly-supported private action with measures by freight receivers – both people and businesses – could increase the consolidation of freight flows. In these situations, the number of urban freight trips would be three times less than with only private-sector voluntary action. Where public authorities incentivise space-efficient urban goods distribution, the space used for freight transport activity decreases by more than 30%, compared to less than 20% with only private voluntary measures.

Active public authorities are also essential for managing the timing of deliveries and dynamically allocating street space to fit passenger mobility and goods transport needs. Such a dynamic approach could decrease space use by almost 10%. Encouraging shared solutions for passenger mobility and integrating some freight and passenger flows could further improve it by up to 16%.

Space-use policies targeting urban freight activities have substantial co-benefits. Higher load factors and lighter, smaller and often electric vehicles reduce well-to-wheel carbon dioxide (CO_2) freight emissions by more than 60%. Freight emissions of nitrogen oxides (NO_x) would decrease by 78%, those of fine particulate matter by 90% and sulfur oxide (SO_x) emissions would disappear completely. Active management of urban road space also makes roads safer, with a collision risk between delivery vehicles and pedestrians or cyclists only about half as high.

What we recommend

Manage curb space with a focus on the needs of both passengers and goods transport

Authorities must look at how passengers and freight handlers use street space to achieve an overall positive outcome, including reduced tensions. Passengers use curb space as they travel with forms of active mobility or micromobility, as well as for parking. The same space is required for urban (un)loading operations, leading to possible crashes, lower road safety and hampered business activities. Policy decisions for promoting sustainable urban goods distribution require a good understanding of freight carriers' use cases for street space and their business models and passenger behaviour. To this end, authorities should engage with all relevant actors and survey transforming curb space use. Examples of measures that support better use of urban space for freight activities include providing dedicated cargo loading and unloading spaces in areas with high freight demand and clearly defined parking spaces for cargo bikes and electric vehicles.

Apply access restrictions for delivery vehicles in urban areas while considering business practices

Declaring parts of a city off limits for certain types of vehicles can accelerate the shift towards less space-intensive, cleaner vehicles. It can also reduce the volume of freight movements by increasing load factors. However, to be successful, access restrictions in cities should consider how freight carriers and receivers behave, and their business needs as key to promoting sustainable change. Not doing so could lead to restriction avoidance, longer trips and urban congestion.

Use more logistics data to better monitor and manage freight flows

Authorities will need more data to monitor freight flows and implement policies such as dynamic street-space allocation. This includes data on which vehicles move and when, what type of goods they carry, when and how they (un)load and how they interact with passengers while using street space. Data from freight receivers such as retail stores will improve cities' ability to manage last-mile deliveries. Data partnerships with private shippers, carriers and receivers will be essential. Authorities will also need to find ways to monitor and quickly respond to complex and rapidly evolving changes in urban logistics. Urban freight and logistics observatories can be a way to do this.

The urban freight space race

The way people and companies use public space, including streets, pavements and other mobility-related spaces, to move themselves and goods has a significant impact on the economy, the liveability of cities and the sustainability of transport systems. Cities have always had to balance the complex movement of passengers and freight while adapting to successive new technologies and shifts in urban activities. Today is no different as city streets must accommodate new transport modes, new mobility and distribution services and changes in travel, leisure and consumption behaviours – and absorb shocks like the Covid-19 pandemic. These changes impact the existing use of street space just as they create new demands for that space and its allocation. They underscore the need to look at how mobility policies and practices affect the use of street space and the shared responsibility of those who use that space to do so in a way that improves urban sustainability.

This report sheds light on the urban freight space race. It is considered a race because it requires fast and often conflicting responses from public authorities, freight carriers, freight receivers and the public. It takes place in a fast-paced environment, shaped by both e-commerce and new e-mobility solutions, where the rate of freight generation in cities around the world has quickened. Successfully addressing this challenge while aligning responses from all stakeholders can improve the liveability of cities. Failing to do so will erode the benefits of urbanisation. This report is the second of two studies on the spatial consumption of urban transport and its consequences. The first – *Streets that Fit: Re-allocating Space for Better Cities* (ITF, 2022) – investigated issues relating to the use of public space by passenger transport. It focused on measuring the use of space by transport activities and explored the potential for dynamically allocating urban space under certain conditions. The present report builds on desk research and quantitative analysis of urban logistics and the use of space by urban freight activities.

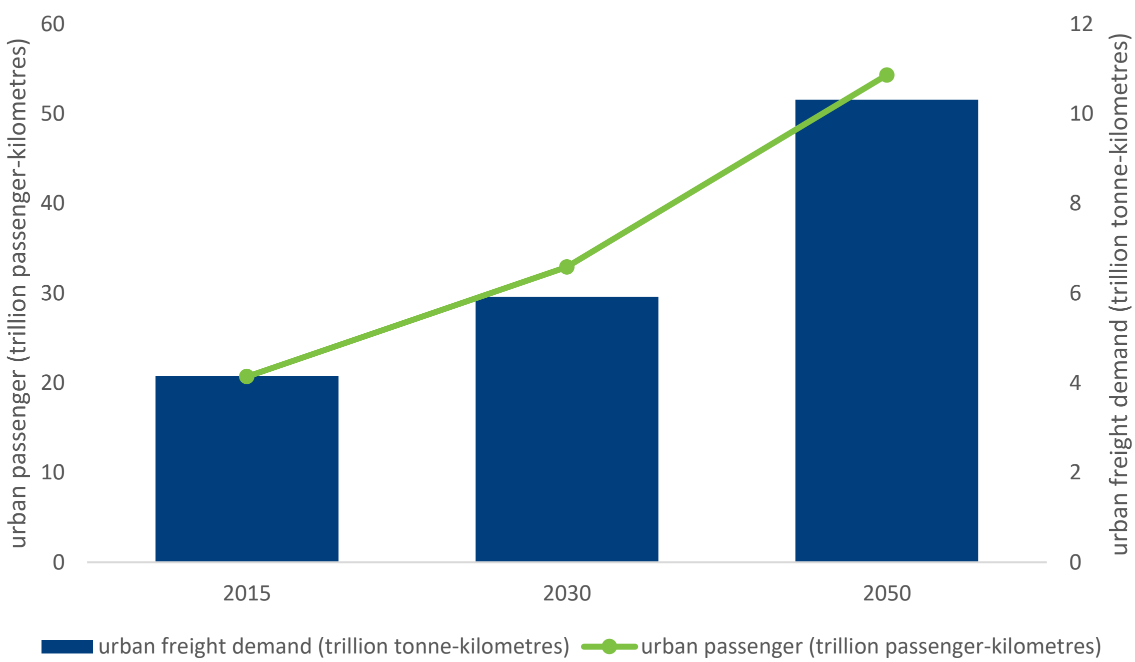
Why street space is important for mobility

People move through public spaces daily. They move directly – for example, when going places and parking their vehicles – and indirectly through the goods they consume. Urban mobility policies have typically focused on the movement of people rather than urban freight movements and related logistics. Nonetheless, the lorries, vans, mopeds or cargo bikes used to distribute goods and materials take up space as they move, load and unload. When goods are consumed, the reverse flow of waste, packaging and recycling must also be collected and brought to treatment centres – this, too, consumes space. Even the buildings that people and companies occupy generate transport flows – either for their construction, modification or demolition and for their servicing. Finally, movement is just one valued use of public space. Commercial activities also compete for street space use (for example, open-air markets or on-street dining in the post-Covid-19 context). But perhaps most fundamentally, street space is also a social and cultural space where people meet, interact and generate the kind of connections that have driven the benefits of living in cities for as long as they have existed.

Street space is a contested and scarce resource where simultaneous and sometimes incompatible demands compete for its use (Deloison et al., 2020). This applies both for "dynamic space" – for example, space used by vehicles and people in movement – and "static space", where vehicles park or people stay put for a while. In dense urban contexts, allocating more space to one use will require taking away space from another.

Demand and conflict over the use of street space will increase as urban areas house more people and activities, and space becomes scarcer. By 2050, more than six billion people will live in cities, almost 70% more than in 2015. More people living in urban areas will increase transport activity and the space requirements to meet mobility needs. The ITF predicts that urban transport activity could more than double by 2050 for both passenger and freight (Figure 1). This will put further pressure on urban street space and its allocation (Deloison et al., 2020) in dense urban contexts. This trend will also amplify potential conflicts over the use of street space and the consequences of these conflicts.

Figure 1. Evolution of urban transport activity for a post-Covid-19 recovery policy scenario (2015-50)



Source: based on OECD (2021a)

How street space is allocated and used can impact people's well-being for the better or worse. Most people living in cities need to use street space to meet their needs and desires, including accessing jobs, services, goods, opportunities and amenities. In other words, using public space for mobility is necessary for people's well-being (OECD, 2019). Conversely, when there are tensions over the use of street space, it is hard for people to achieve their goals, which ultimately may reduce their well-being (Hananel and Berechman, 2016). For example, for passenger transport, a person relying on their bicycle could have difficulties going to a pharmacy without safe street space allocation for cyclists. For freight transport, a lack of curb space for deliveries close to the pharmacy could hamper medicine deliveries or create further congestion and road safety concerns for people trying to access the pharmacy.

Tensions over the use of public space for mobility affect urban function and liveability. Congestion is a prime example of this. Congestion arises when demand for the use of one road at a given moment reaches or surpasses its capacity. This generates time losses for all street users and other consequences, such as increased stress, pollution, noise and CO_2 emissions (ITF, 2021a). Conflicts among different users of street space can reduce both real and perceived safety (ITF, 2020a).

Users of street space experience it differently according to their needs and characteristics. These differences will shape their capacity to react and adapt to conflicts and their consequences. For instance, it might be more challenging for a visually impaired person to adapt to and avoid collisions on crowded and shared sidewalks (Brown and Norgate, 2019). Likewise, a cargo-bike cyclist might have an easier time adapting to road congestion but may be exposed to increased safety risks compared to a lorry driver.

Freight activities need street space

Freight, goods distribution, construction and waste logistics all impact urban space consumption. In 2015, around 6% of all urban vehicle-kilometres travelled involved goods transport. By 2050, this percentage is projected by the ITF to increase to almost 10%, reaching 15% or more in cities in Canada, non-EU eastern European countries, the former Soviet Union and the United States (ITF, 2021). Most urban freight deliveries are motorised, with large vehicles taking up significant space while stopped and moving. Vans and other light goods vehicles account for a significant share of kilometres travelled (Deloison et al., 2020). In the United States, in 2010, the average light truck and freight vehicle took up between 10% and 20% more static street space than the average car (Office of Energy Efficiency & Renewable Energy, 2011).

Freight transport activities affect people’s well-being and the liveability of cities. Evidence indicates that lorries are responsible for almost 20% of congestion costs experienced by urban dwellers in the United States (Bouton et al., 2017). In Sao Paulo, freight transport contributes as much as passenger transport to congestion (Ewbank et al., 2020). Freight vehicles are also responsible for high levels of urban pollution. In London, for instance, freight carriers only represent 10% of vehicles but produce more than 30% of NO_x emissions (Bouton et al., 2017). Regarding road safety, heavier vehicles, including freight vehicles, are responsible for a disproportionate share of pedestrian, cycling and other micromobility and motorised two-wheeler fatalities (ITF, 2020c).

The uptake of new mobility services, both passenger and freight, e-distribution channels and light passenger mobility modes highlights tensions in street space allocation. E-commerce and increased urban deliveries by heavy-duty vehicles are directly linked to growing numbers of serious injuries and fatalities resulting from crashes. Crashes, often involving pedestrians, cyclists, and other users of micromobility, arise from the joint use of street space between various road users in unsafe ways (ITF, 2020c). In other words, road safety concerns highlight and exacerbate tensions regarding street space allocation between passenger and freight activities. E-commerce and freelance deliverers’ use of public docked and dockless bicycles also highlight other conflicting interactions between freight and passenger activities. In Paris, 16% of freelance deliverers use the city’s Velib’ public bicycle system, raising the question of how much, where and for whom public cycling infrastructure should be provided (Dablanc, 2020).

Improving well-being by managing street space use

Public authorities have an important role as “urban space managers” and can help ensure that people and enterprises move in a way that increases well-being. Authorities can set a clear and goal-oriented vision that focuses on increased well-being. Such a vision could design passenger transport systems that increase access to essential opportunities while increasing the use of sustainable modes and decreasing the adoption of less sustainable ones (OECD, 2021b). Sustainable freight transport systems that contribute to improved well-being could also be designed following this approach. However, more studies should focus on the linkages between freight transport activities, urban logistics and well-being.

Sustainable Urban Mobility Plans (SUMPs) effectively apply public action to manage street space use. These plans align public authority policies and measures to maximise well-being and decrease conflicts. SUMPs have mainly focused on passenger transport. However, they also include freight transport and urban logistics activities (Aifandopoulou, Lindberg and Rudolph, 2019). In Europe, creating Sustainable Urban Logistics Plans (SULPs) as part of the SUMP planning process provide operational guidance to coherently address freight and passenger transport flows in urban areas (Box 1) (Aifandopoulou and Xenou, 2019). By addressing freight, SULPs and SUMPs co-ordinate and orient public actions, and those of many private stakeholders, for more sustainable freight transport systems.

Authorities can intervene in four broad domains to manage urban freight and logistics flows:

1. **Where movements occur:** this can include trip origins and destinations. At the metropolitan level, authorities can influence land use and, thus, where goods are produced and stored and where they travel. At the neighbourhood or municipal level, authorities can restrict or prioritise delivery vehicle access. At the street level, they can also decide which space to allocate to different uses, including where delivery vehicles load and unload.
2. **When movements occur**: this can include restricting deliveries to periods of low demand, such as night-time, or setting specific time windows for loading and unloading.
3. **Vehicle choice:** some restrictions, such as low-emission zones, determine which vehicles are granted access to different parts of the city and thus may influence vehicle choice. Authorities may also adapt urban access regulations to allow privileged access to less space-consuming, clean or efficient goods transport vehicles. Authorities can also play an enabling role by providing infrastructure. For example, investments in cycling infrastructure can benefit cargo bikes which, in turn, may place pressure to provide more light mobility infrastructure due to potential space conflicts with existing cyclists. Charging infrastructure can also influence vehicle choice, although the impact of freight vehicle electrification on street space use is less straightforward.
4. **The magnitude of vehicle movements**: public authorities can influence the extent of freight flows and the resultant pressure on street networks. By imposing pricing or other forms of access management, authorities can help increase load factors. By incentivising load-matching platforms for shippers and transporters, authorities can impact who delivers what and the distances travelled. Authorities can even impact what gets transported by fostering other innovations, such as 3-D printing or local food farming.

These interventions are not mutually exclusive and could even reinforce each other. For instance, setting a time window for deliveries does not address which vehicles are used, where pick-ups and drop-offs might occur or how many vehicles may need to access the network during that time window. Setting up an incentive for the uptake of cargo bicycles by relaxing delivery windows for their use could facilitate uptake. This suggests that measures will have to be designed to address many, if not all, of these domains.

Box 1. The eight Sustainable Urban Mobility Plan principles for a Sustainable Urban Logistics Plan

Implementing Sustainable Urban Logistic Plans (SULPs) helps to set concrete policy actions to promote more sustainable and less space-consuming freight transport activities. They can add freight-specific guidelines and measures to more general and passenger-oriented Sustainable Urban Mobility Plans (SUMPs). These are eight principles that can help shape effective SULPs:

1. **Plan for sustainable mobility in the functional city:** optimising urban logistics requires understanding the characteristics of functional urban areas and their freight activities.
2. **Develop a long-term vision and a clear implementation plan:** SULP should provide a long-term vision for freight transport activities aligned with the city's medium and long-term vision. It should also align with other policy documents, such as land use and SUMPs. Based on these alignments, authorities should set specific, clear measures for short and medium-term action.
3. **Assess current and future performance:** SULPs should propose targets for future urban freight transport activities. These targets should be based on a realistic assessment of the characteristics, challenges and opportunities of a given city's freight transport systems. Setting targets requires obtaining and treating data from private operators.
4. **Develop all transport modes in an integrated manner:** SULPs should be built while considering multi-modal systems. This means setting the ground so that the best transport mode – both traditional and emerging – is used for each trip depending on the trip's characteristics, an enterprise's profit objectives and society's overall sustainability goals.
5. **Co-operate across institutional boundaries:** creating and implementating SULPs should involve all relevant authorities in metropolitan areas. This includes authorities from local jurisdictions that are part of the urban area. It should also integrate representations from regional and national public decision-making bodies that impact transport activities within the urban area. Cross-institutional co-operation should also be increased to allow sector-specific institutions to collaborate, such as departments working on transport and land-use policies.
6. **Involve citizens and relevant stakeholders:** creating, implementing and evaluating effective SULPs should include all stakeholders involved in or impacted by urban logistics operations.
7. **Monitor and evaluate:** developing SULPs should include methods and practices for monitoring progress towards achieving the objectives and targets set within. This requires setting up the scope of SULP evaluations and their necessary metrics and data sources.
8. **Assure quality:** all actors involved in creating SULPs should make sure that these documents properly reflect a city's freight systems and set realistic goals. SULPs can also set the ground for agreements between authorities and private stakeholders to meet the plan's objectives.

Source: based on Aifandopoulou and Xenou (2019)

The tensions of managing streets for people and freight

Authorities managing street space must address four central tensions: liveability, capacity, networks and design (Jones, 2014; ITF, 2022):

1. Liveability tensions emerge when authorities must decide what street space is for and whose needs should be prioritised for its use, be it pedestrians and cyclists, people with cars or goods delivery vans or freight trucks.
2. Capacity tensions refer to how the street space availability is allocated to prioritised needs and who makes that decision. It includes the assumptions and expertise behind those arbitrations.
3. Network tensions address the issue of how to balance street space allocation to fit the needs of the metropolitan-wide transport system while also tending to the needs of local neighbourhoods. This tension influences street hierarchies and classifications.
4. Design tensions raise questions on the physical characteristics each street should have to fit and prioritise needs. These characteristics include features like the width, materials and speed limits each road should have and how these co-exist with other networks like water and sewage, electrical and fibre-optic networks.

Public authorities must account for the interest and initiatives of many private stakeholders and arbitrate among them. Transport activities and street space use in cities happen in complex systems where the use of space by each person and enterprise is motivated by their own reasons (Gammelgaard, Andersen and Figueroa, 2017). This is true for those who directly occupy street space and those who depend on that use. For example, employers rely on their workers reaching the workplace, and shippers and clients need products to go from A to B. Actions to manage transport flows, their characteristics, and their timing will have consequences for all stakeholders – sometimes for the better and sometimes for the worse. Understanding systems, their actors and their motivations is a complex but necessary task for successfully implementing policies and redesigning systems to lead to greater well-being (Gammelgaard, Andersen and Figueroa, 2017; OECD, 2021b).

Urban areas spanning multiple jurisdictions complicate managing transport and street use. Transport activities occur at the functional urban area level, which may encompass various municipalities, regions and, in some cases, even countries (Dijkstra, Poelman and Veneri, 2019). At the same time, land use, street space and transport responsibilities tend to be split between national, regional and local authorities for passengers and freight (ITF, 2018a). Because of this, many public institutions must co-ordinate and develop coherent visions and actions for managing public space. This is especially true for urban freight.

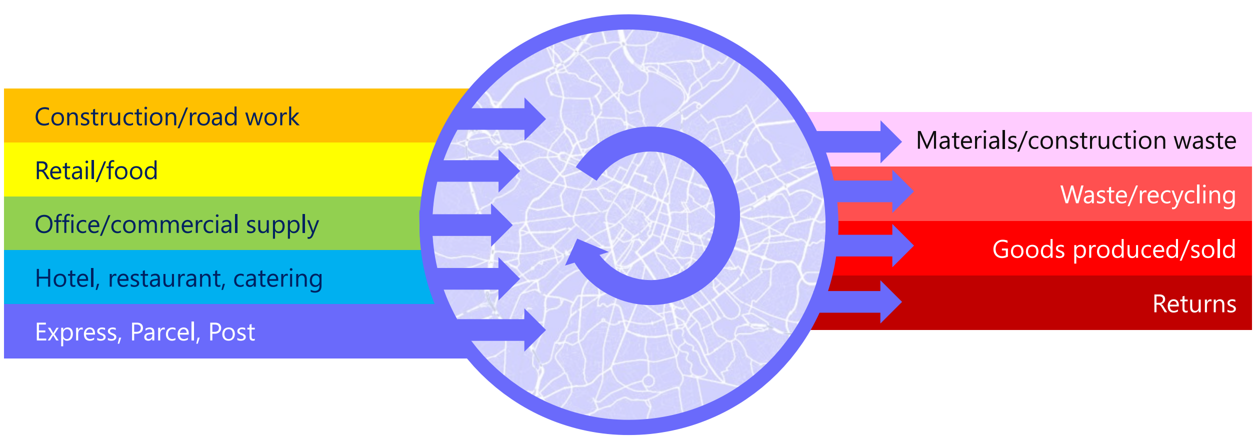
The urban logistics system

Managing urban freight movements is complex. In many cities, authorities have paid less attention to freight distribution than people's mobility. Reasons for this include the assumption that the private sector should primarily lead freight activity and that authorities should only intervene in a limited manner (for example, to ensure competition). Further, a single authority may not have sufficient jurisdiction to influence freight movements at a metropolitan scale (Cui, Dodson and Hall, 2015; Dablanc and Heitz, 2019; Lindholm and Behrends, 2012). Added to this is the challenge of understanding the freight transport ecosystem when data is hard to collect, guarded, or generated by multiple actors in incompatible or difficult-to-use formats (Zhang and Raj, 2021). The task is further complicated by the difficulty identifying and understanding, let alone managing, actors and flows across multiple goods distribution networks (Kin, Verlinde and Macharis, 2017; Zhang and Raj, 2021).

Inbound and outbound urban freight flows

Urban freight mobility is enabled by city logistics systems. City logistics refers to the means and processes that allow freight to be distributed in urban areas efficiently while decreasing negative externalities, such as emissions (Rodrigue and Dablanc, 2020). Logistics services aim at managing freight movements in cities while also responding to customers and end users' demands (Rodrigue and Dablanc, 2020). Urban logistics references the flow of goods and materials into, within and out of urban areas. These flows are neither uniform in type nor timing, affecting how they impact the use of urban space.

Figure 2. Inbound and outbound urban freight and material flows



Source: based on AustriaTech (2014); CIVITAS (2020)

There are generally five categories of inbound flows and four categories of outbound flows. These all interact within the urban area and may sometimes be generated or absorbed within the broader functional urban region. The five inbound flows (see Figure 2) are:

1. **Construction and roadwork materials:** minerals and materials used for construction and roadworks (such as sand, concrete, gravel, steel, glass, timber and pre-formed components). They are delivered via specialised, heavy-duty vehicles at infrequent intervals (for each worksite) (Janné, 2018). They are generally loaded and unloaded off-street. These flows are significant and bulky.
2. **Retail goods (including food):** all things sold in shops or stores. These also account for significant flows that are concentrated in the morning. Larger vehicles are used with scheduled deliveries over the week. Some food shipments require dedicated, temperature-controlled vehicles, while other goods (like fuels) require dedicated and adapted vehicles. Offloading and loading may take place off-street for larger shops and shopping centres. These flows also include movements linked to meal delivery. In this case, trips tend to be done with electric or fossil fuel-powered two- and three-wheelers and non-electric bicycles. Meal deliveries take place all day, mostly around restaurant business hours and late at night.
3. **Office and commercial supplies:** paper, IT equipment and other expendable supplies used in offices and commercial services. These deliveries may use smaller trucks and vans and involve weekly shipments. Offloading and loading may take place off-street for larger office buildings.
4. **Hotel/restaurant/catering:** food, linens and other supplies for the hospitality industry. These deliveries involve medium to larger vehicles with frequent (daily) scheduled deliveries concentrated in the morning. Loading may take place off-street for hotels but often on-street for restaurants. Some food shipments required dedicated temperature-controlled vehicles. Increasingly, they involve intra-urban food delivery from restaurants/food preparation facilities to consumers using small vehicles.
5. **Express, parcel and post:** smaller to medium-sized parcels and letters. These involve frequent (multiple times per day) unscheduled deliveries with a variety of small to mid-sized vehicles, including light mobility two- and three-wheelers. These deliveries account for a significant share of overall freight travel and space consumption. Most loading and unloading takes place on-street. They also include intra-urban pick-up and delivery of consumer goods to households using smaller vehicles, both from e-commerce and various shop-based deliveries.

The four outbound flows are:

1. **Materials/construction waste:** mineral and material waste from earthworks, building destruction and road maintenance. Infrequent (for each worksite) but large and bulky flows involving heavy-duty vehicles. Loading primarily takes place off-street on construction and road-work sites.
2. **Waste/recycling:** all other waste flows, including food waste, commercial and retail waste (packing), household waste and recycling. These involve scheduled municipally-tendered waste collection and bespoke waste services using heavy-duty vehicles, typically concentrated in the morning or evening.
3. **Goods produced or sold from urban areas:** goods produced and shipped from urban areas and consumer-to-consumer sales of second-hand goods. These involve a wide range of vehicles, with pick-ups typically concentrated in the afternoon.

4. **Returns:** e-commerce sales that are returned to the seller for various reasons. They mainly comprise clothes, shoes and electronics. Around 30% of all e-commerce sales are returned, generally by end-consumers to goods providers, either directly through courier services or indirectly through pick-up and drop-off points (Richpanel, 2022).

Understanding these inbound and outbound flows is essential for developing adapted space management strategies. Yet, many public authorities know little about their characteristics, including their volume, weight and timing. This is due to poor data availability and the relatively high fragmentation of the urban logistics field.

Processes and scales of urban freight and logistics

The urban freight and logistics ecosystem operates at various functional and organisational levels. One way to categorise these is by the scales at which they operate. The urban freight and logistics system can be broken down into four broad functional scales, each operating at higher geographic scales from outside of the urban area down to the street and building level (see Figure 3).

Figure 3. Urban freight flows and scales

Extra-urban logistics

First hundreds of kilometres

- Long-distance shipping of goods/materials
- National and international transport
- High load factors
- Heavy goods vehicles, rail, airplanes and ships
- Motorways and other long-distance networks infrastructure

Urban logistics

Last dozens of kilometres

- Interface between long distance shipping and urban distribution
- Regional transport
- Medium load factors; breakbulk hubs
- Heavy to medium trucks
- Regional road networks, concentration of hubs in peripheries

Urban distribution

Last kilometer ("last mile")

- From hub to curb
- Volume rather than weight constraints – mixed to low load factors
- Smaller-sized trucks and vans, cargo bikes and motorised two- and three-wheelers
- Arterials and city streets

Delivery

Last hundred metres

- From street or curb to door
- Pick-up, drop-off (PUDO) space constraints, competition for street space
- Walking, pushcarts, cargo bikes, sidewalk drones, palette loaders
- Curb, sidewalks/pavements and private spaces

Source: adapted from Cardenas Barbosa et al. (2017)

Urban freight scales

At the broadest scale is the part of the urban logistic system that operates outside the urban area, such as the first hundreds of kilometres. Extra-urban logistics covers the regional, national and international movement of goods from their point of production to the urban area. These consignments are characterised by large to extremely large vehicles and high load factors operating on inter-urban infrastructure (motorways, rail and ports). Some of these loads may continue into the urban area, but many will be unloaded, reapportioned and combined with other loads at dedicated facilities. The extra-urban logistics system is an essential part of the urban logistics system, but as its spatial impacts fall largely outside of the urban area, it is not part of the scope of the present report.

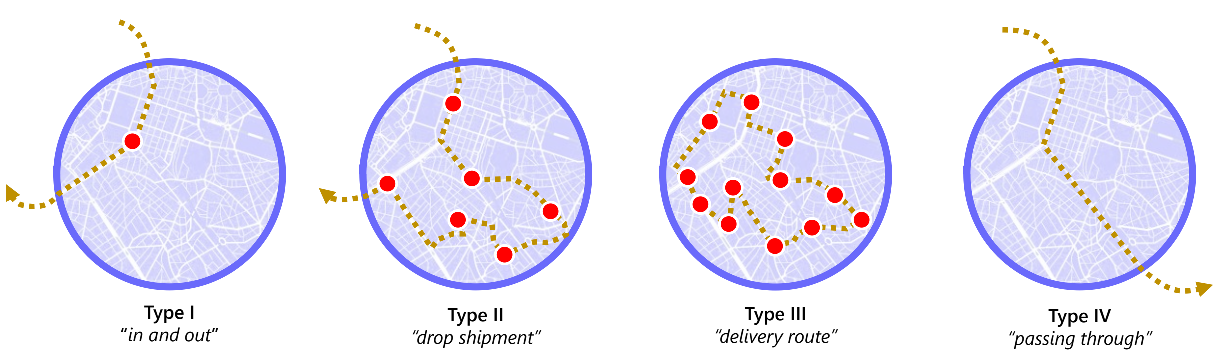
Urban logistics covers the last few dozen kilometres – essentially, all logistics activities that operate at the broader urban scale. This is the interface between extra-urban logistics activities and urban goods distribution. This level is characterised by break-in-bulk facilities (where loads are shifted from one mode to another), distribution hubs and other activities and locations essential to forming the final truck, van or cargo-bike loads for onward distribution. The scale is regional and the vehicles employed typically range from medium- to large-sized. Load factors are not as high as for extra-urban logistics, and trips are principally on regional arterials and motorways since they connect the distribution hubs generally located in the urban periphery. These can also play a role in urban logistics distribution in cities with port facilities.

Urban distribution concerns the last kilometre(s) (the "last mile") from the distribution hub to the curb. Load factors are lower still, and loads are generally volume-constrained (they "cube out") rather than weight-constrained. This is especially the case for parcel delivery as goods arrive at e-fulfilment and sortation facilities in bulk, and are broken up, picked and re-packed in lower-density final delivery cartons. Vehicles are generally smaller still, ranging from medium-sized trucks to vans and powered two- and three-wheelers and cargo bikes. Yet, some larger trucks with high load factors still operate at this scale, mainly targeting business-to-business (B2B) deliveries with bulkier goods. The main challenge at the urban distribution scale is how to route vehicles efficiently in congested urban areas. Urban distribution occurs on city streets and arterials, concentrated in areas with high commercial or residential densities. Many of the most consequential impacts of the urban freight system are felt at this level – including congestion, noise, local pollutant emissions and crashes.

Urban distribution patterns

Urban distribution patterns are not uniform, differing according to the type of goods transported, the commercial relationships between carriers and shippers and the final destination of consignments. However, there are generally three principal goods distribution patterns that deliver urban centres (Dijkstra, Poelman and Veneri, 2019) and one pattern that involves goods vehicles but no urban distribution (see Figure 4).

Figure 4. Urban distribution patterns



Source: adapted from Verlinghieri et al. (2021)

Type I trips may be trips for urban centres using the same vehicle and load used for extra-urban logistics, for example, large vehicles carrying uniform loads at high load factors. These are generally full truckload (FTL) trips that will serve one large receiver – e.g. a construction site, a large store or supermarket, an automobile or other vehicle dealership.

Type II trips combine an extra-urban centre element with multiple drop-offs or pickups in areas within urban centres. These typically comprise uniform types of goods (for example, paper, fuel and white goods) shipped by a specialised wholesaler. These drop shipments may also be made at breakbulk and sortation facilities for re-consolidation by final destination and onward distribution. Type I and Type II trips may involve larger vehicles and have longer dwell times, which is the time spent in (un)loading operations, than Type III trips.

Type III trips distribute multiple, heterogeneous goods to multiple and heterogeneous destinations. These trips may involve consolidated loads delivered to commercial retail establishments (for example, food or clothing stores), households, commercial and office locations, pickup hubs and lockers. These trips involve multiple stops, delivering a mix of single parcels at some destinations with longer stops delivering multiple parcels to office or apartment buildings.

Type IV trips are distribution trips that pass through but do not service areas within the urban centre. .These trips generate nuisances but provide no direct value to the neighbourhoods they pass through. Urban infrastructure provisions and traffic policies, such as low-emission zones and other vehicle access restrictions, have increasingly sought to disincentivise these trips.

It should be noted that for all of the trips above, points of origin and destination may be within the same broader metropolitan functional urban area and may service one or several urban centres within it.

Final delivery

Along with urban distribution, final delivery is the most important and challenging stage of urban logistics. The time a vehicle parks at the curb is significant as drivers attempt to make final deliveries to customers, particularly for parcel deliveries. One recent survey from Sweden indicates that parcel vans are parked for 41% of their route duration as drivers make final delivery by foot (Sánchez-Díaz, I. et al., 2020). Delivery concerns the last few metres – from curb to doorstep – and, though urban distribution has no value without successful deliveries, it has largely been outside the focus of urban transport policies. As with urban freight transport, more generally, this has been because public authorities have generally considered delivering goods from the curb to the doorstep wholly within the commercial and private realm, except for on-street parking.

In 2018, last-mile distribution was estimated to cost around USD 10 on average per small package (Jacobs et al, 2019). There are several reasons for this. Congestion and lower travel speeds increase the time it takes to deliver in cities and the cost of wages and consumed fuel. Costs can also be higher because of delayed or failed deliveries or difficulty and time accessing recipients. A study assessed the cost of failed deliveries of 300 retailers operating in Germany, the United Kingdom and the United States. It found that in 2021, 8% of online deliveries failed in Germany, 6% in the United Kingdom and 7% in the United States. Failed deliveries entailed costs as high as USD 17.37 in Germany (with a EUR 1.183 to USD 1 exchange rate) (Figure 5) (Loqate GBG, 2021). Growing e-commerce deliveries of various products to multiple recipients using a multitude of carriers all complicate the efficient use of public space for these deliveries.

Figure 5. Costs of failed deliveries for 300 retailers spread across the United States, the United Kingdom and Germany

Faulty fulfilment by country	Germany	United Kingdom	United States
Online orders per year	140 381	97 822	140 792
% failed deliveries	7%	6%	8%
Cost per failed order	EUR 14.69	GBP 11.60	USD 17.20
Total failed delivery cost per year	EUR 144 354	GBP 68 084	USD 193 730

Source: based on Loqate GBG (2021)

Urban freight efficiency decreases when moving from logistics activities outside of city areas towards final delivery. The last few metres are particularly difficult to service efficiently, especially in dense urban cores. There are many reasons for this, including the structural shifts in delivery patterns brought about by e-commerce. Some of these changes, such as same-day deliveries, make it harder to plan and optimise deliveries. The delivery speed required by some of these changes also contributes to shifting (un)loading operations from off-street spaces to curb space use.

Urban freight and logistics data are crucial

Data are vital for freight operators and public authorities. Shippers and logistics operators need data to improve freight efficiencies, and authorities need it for urban planning. Data can come from traditional sources, such as surveys for and from operators, as well as from more innovative ones, such as real-time data stemming from freight operations and vehicle activities (Bonnafous et al., 2016; Vigran, 2020).

Digital freight data present both an opportunity and a challenge. Stakeholders face the difficult task of determining which data will be useful. This entails obtaining the data, managing and processing it, understanding it and using it. In the freight sector, this also involves successfully combining, understanding and using data from various actors across highly fragmented supply chains. This complexity increases for the last-mile and final delivery. The lack of common methodologies or standards also raises interoperability challenges between data sets.

Public actors face specific challenges regarding harnessing data for public use (Dablanc, 2022; Vigran, 2020; Zhang and Raj, 2021):

- Know-how: many authorities lack in-house technical or human capacity to gather and use freight data.
- Co-ordination: the absence of common methodologies and reporting requirements for gathering and treating data across different public agencies creates inefficiency. Some authorities may lack the skills and capacity to handle sensitive or personal data. This applies particularly to automatic number-plate recognition (ANPR) data. Authorities also face challenges when co-ordinating efforts with private stakeholders to obtain data. This can be linked to a lack of trust from private actors – due to data privacy concerns – and because private stakeholders may not see the value of sharing data with authorities.

- **Knowledge**: many authorities do not understand how urban logistics function and what motivates the actions of its actors. This is especially the case in countries where informal freight distribution practices are more common. Lack of insight into urban goods flows can also include other areas of understanding – as in the case of urban space consumption.

Nonetheless, public authorities increasingly have options to address these shortcomings, as demonstrated by examples from Australia, Colombia, the Netherlands and the United Kingdom.

Table 1. Public sector urban freight data initiatives

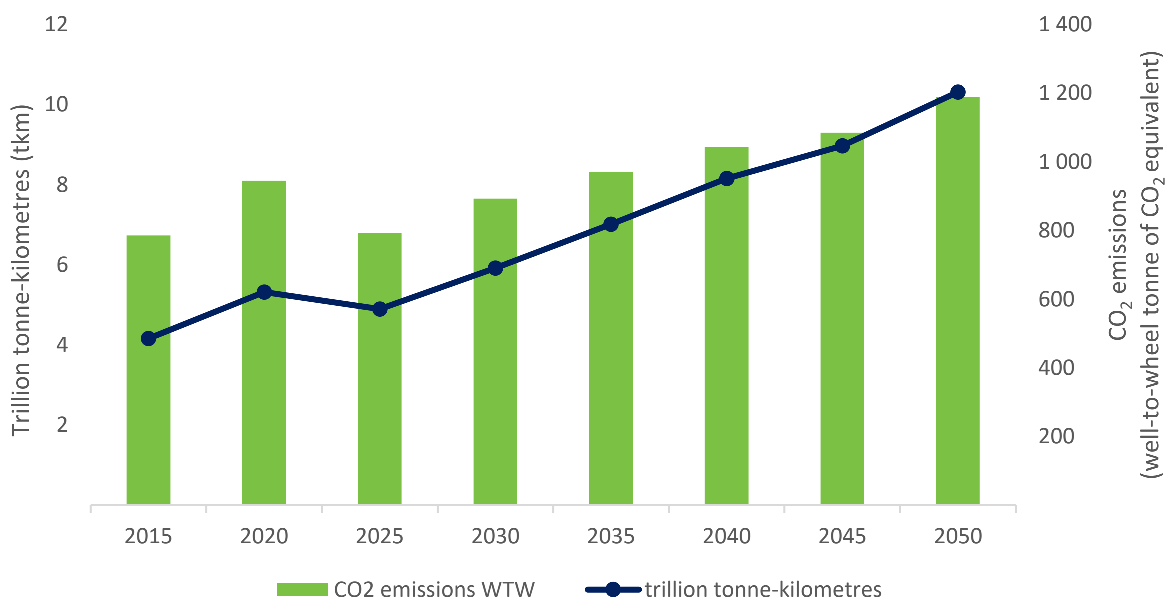
Challenge	Possible solution	Example
Know-how and Co-ordination	Creating new institutions to gather, process and share freight data	In Australia, authorities have launched a National Freight Data Hub as part of the National Freight and Supply Chain Strategy. The hub will serve as a federal-wide data-sharing platform for local authorities and businesses. The hub will be responsible for opening existing government data, setting common standards that allow businesses and authorities to share data for mutual benefits and promoting innovation and skill-building in the sector. Activities in this platform have also built trust around data privacy and data sharing with private actors, increasing the co-operation needed in the sector.
Know-how and Co-ordination	Empowering existing institutions to generate and manage metropolitan-wide data	In Colombia, municipalities in the Metropolitan Area of the Aburra Valley and the surrounding area of Medellin progressively gave capacities to a metropolitan body in charge of policy planning and implementation. It obtained responsibilities over metropolitan road freight logistics in 2002. In 2017, the metropolitan body led an extensive survey on freight origin-destination data. This was achieved thanks to co-ordination with private stakeholders via various incentives.
Knowledge	Harnessing the actions of emerging innovation leaders	Transport for London has launched a FreightLab in London, allowing authorities to incubate and support emerging startups in the sector. Some of the winning solutions in the programme's first session allowed for generating, treating and giving new insights into freight data. It included a startup aiming to improve the management of curb use for authorities and private actors operating in urban logistics in London.
Co-ordination and Knowledge	Combining aggregated automatic number-plate recognition (ANPR) data with other sets in one area	In Rotterdam, authorities use various existing data sets to plan for freight activities in the city. One data set includes aggregated data from ANPR, used to control compliance with the city's low and future zero-emissions zone and comply with the Dangerous Goods Plate Recognition database (DGPR). Other data sets include information from freight carriers' platforms to prepare for setting the zero-emissions zone.

Source: based on Adoue (2022); Australian Government (2021); Transport for London (2020b); Universidad Nacional de Colombia and Área Metropolitana del Valle de Aburrá (2017); Vigran (2020); Zhang and Raj (2021)

Accelerating e-commerce growth exacerbates the pressure on urban space

Cities will see an expansion in goods transport in the future – but not a sustainable one. By 2050, urban freight transport activities could generate 50% more greenhouse gas emissions than in 2015 (Figure 6). The explosion in e-commerce, increased delivery speeds, lower transport efficiencies and longer travel distances have set the background for unsustainable growth in urban goods transport and increased pressure on scarce urban space in cities worldwide.

Figure 6. Evolutions in global urban freight demand and well-to-wheel CO_2 emissions (2015-50)



Source: based on OECD (2021a)

Online and app-based purchases have increased parcel and goods delivery in cities worldwide. Even before the pandemic, approximately two out of three people in Europe sometimes shopped online (Lone, Harboul and Weltevreden, 2021). People living in Germany, the United Kingdom and the United States received more than 20 parcels on average in 2019 – in China, it was more than 70 (McCarthy, 2019). A shift from shop-based purchases to e-commerce could yield environmental benefits under some conditions where e-commerce distribution displays greater efficiencies and lower emissions. Yet, many e-commerce channels rarely seek to optimise environmental performance as a core objective (Burdeo Rai, 2021).

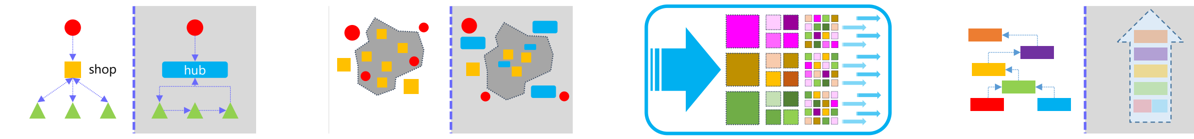
E-commerce also contributes to an increase in reverse logistics flows concerning packaging, waste and customer returns. Packaging and waste flows include processes linked to the reuse, recycling, remanufacturing or refurbishing of products and waste management. Customer returns may result from many factors, including damaged goods, products that do not meet expectations and, increasingly, apparel or other products that do not fit. E-commerce is expected to increase product returns. By 2027, customers will have returned products worth more than USD 1 trillion, implying an increased number of “backwards” trips (Rubio et al., 2019). Companies are also increasingly looking at re-using, refurbishing, recycling and remanufacturing products. Some of these activities could help decrease manufacturing costs. Citizens’ environmental concerns and environmental policies and regulations are also pushing enterprises towards adopting more sustainable practices for product returns (Rubio et al., 2019).

Meeting consumer expectations regarding delivery times generates externalities and puts pressure on city space. Increasingly rapid delivery makes consolidating freight loads into a few trips harder. Instead of one vehicle delivering many packages, many packages might need to be delivered by many vehicles. Because of consumers’ expectations, businesses are racing to deliver as quickly as possible. In the early 2000s, Amazon offered free delivery for orders, delivered in about eight days. By 2015, orders were delivered for free in two to three days (Barbee et al., 2021). By 2021, premium users were offered free next-day and even same-day delivery. These practices have shaped consumer expectations. Generally, people expect to wait less than two days to receive e-commerce orders (Barbee et al., 2021). The growth of e-commerce exacerbates the challenge of last-mile urban distribution and delivery. In some cases, last-mile distribution accounts for up to half of the total transport costs of a product (Dolan, 2021).

As a result of the Covid-19 pandemic, people have changed the ways they consume in an accelerated way. During the many lockdowns, city streets were filled with goods delivery vehicles. The ongoing effects of the pandemic have caused people to increase the amount and types of goods they buy online. In 2020, e-commerce purchases by end consumers grew by more than 20% in most European countries and more than 40% in some of them (Lone, Harboul and Weltevreden, 2021). Globally, after the pandemic, around 40% of consumers shop online for things they would have otherwise shopped for in stores (Rogers and Cosgrove, 2021). These changes have turned many B2B flows into business-to-consumer (B2C) ones (Archetti, 2021; Dablanc et al., 2022). The pandemic has also brought about new services that cater to people’s expectations for faster deliveries. Some food delivery services even offer to transport groceries in as little as ten minutes.

The rapid acceleration of e-commerce has triggered many structural changes in freight flows in urban areas. The shift from shop-based retail patterns to direct-to-customer distribution patterns is a significant trend impacting cities and how they function (see Figure 7). This shift replaces single-point delivery to shops with multi-point delivery to final destinations, which may increase or decrease the impact of goods delivery, depending on several factors. These factors include vehicle types, whether travel distances increase or decrease, trip frequency and vehicle load factors. The rise of e-commerce also impacts urban commercial real estate markets by replacing city centre retail facilities with distribution facilities in the periphery. It also pressures traditional commercial real estate (shopping centres and ground-floor shops), which may lead to vacancies and shifts in consumer shopping travel. At the urban scale, location dynamics for commercial real estate and distribution facilities are changing, and new types of e-commerce-related facilities are appearing (for example, fast delivery hubs). New facilities also include “dark” restaurants, where various enterprises cook in the same place to cater for delivery operations for their own clientele, and “dark” shops, which are not open to the public but rather serve as centres for fulfilment operations. Logistics facilities are diversifying and growing outside of cities just as specialised smaller hubs are multiplying within cities. Finally, e-commerce has accelerated trends towards dedicated third- and fourth-party logistics and delivery services, increased consolidation and vertical integration (including within delivery fleets) and the rise in platform-based business models (Logistics City chair, 2022; Rodrigue, 2022).

Figure 7. Structural changes triggered by a significant shift to e-commerce



Distribution patterns
- Shop-based to distributed consumption
- Growth in direct business to consumer distribution
- Shift from deliveries to shops to deliveries to consumers
- Emergence of multiple specialised hubs
- Shift to low latency delivery (next day to next hour)
- Emerging distribution patterns suited for light goods delivery vehicles (cargo bikes, light three-and four-wheeler vehicles)

Real estate Footprint
- Shift of real estate footprint from retail shops to distribution facilities
- Pressure on traditional retail real estate (e.g. ground floor shops, shopping centres)
- Changes in siting and location dynamics
- Emergence of "dark" stores and restaurants

Logistics facilities
- Multiplication of new logistics facilities (e.g. e-fulfilment, sortation centres, urban logistics depots, fast delivery hubs, shop-based delivery hubs, parcel lockers)
- Automation for, and application of AI to, fulfilment and inventory management

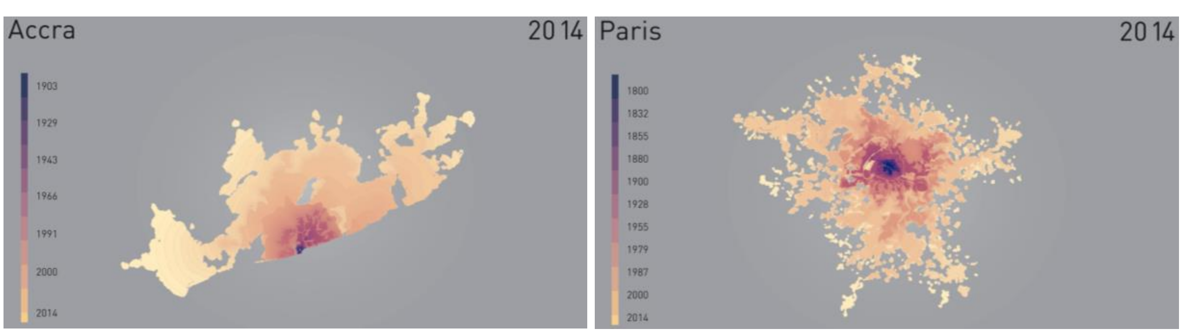
Vertical integration
- Development of third party and fourth party logistics services
- Dedicated carrier services (truck, air, non-long-distance shipping of goods/materials)
- Rise of platform-based distribution and delivery services and platform-based business models

Source: adapted from Rodrigue (2022)

Urban logistics increase pressure on cities' limited spaces

By 2100, the spatial footprint of all urban areas combined could be 1.8 to 5.9 times larger than in 2000, depending on factors such as population growth and people's lifestyles. The footprint of cities is also related to different forms of commerce and underlying economic models. The growth of urban areas occurs in both the Global North and the Global South. Between 2000 and 2010, the total spatial footprint of European cities grew by approximately 15 000 km^2, while in Africa, it increased by 17 000 km^2 (Gao and O'Neill, 2020) (Figure 8).

Figure 8. Urban expansion of Accra (Ghana) and Paris (France) up until 2014

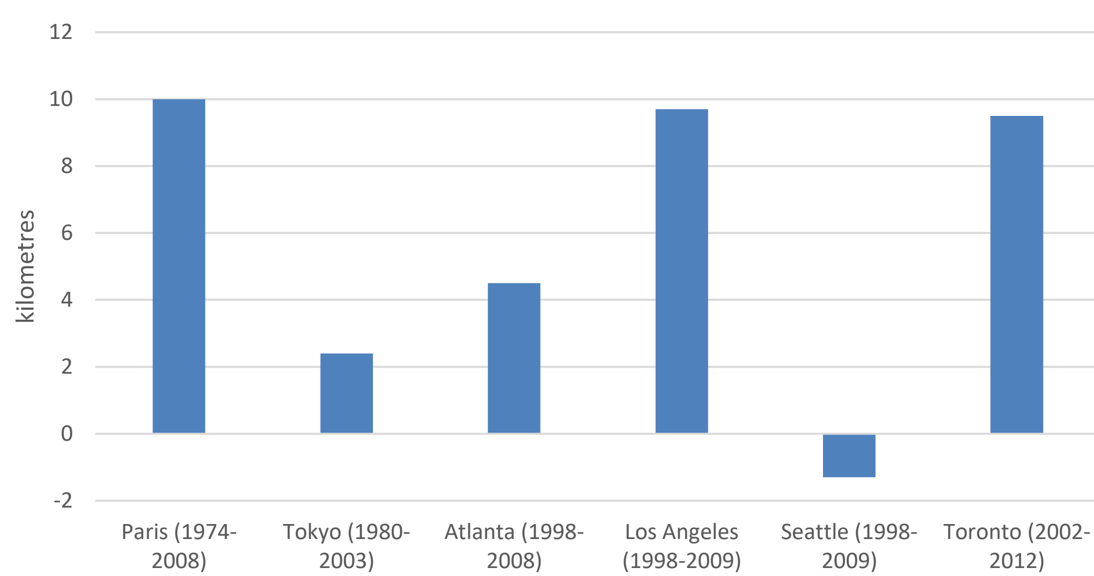


Source: UN-Habitat, NYU and Lincoln Institute of Land Policy (2016)

Some urban logistics facilities such as warehouses, distribution centres or intermodal transport hubs have moved outside cities, contributing to sprawl in many global contexts (Dablanc and Rakotonarivo, 2010; Rodrigue and Dablanc, 2022a; Robichet and Nierat, 2021). Higher real estate prices and lower space availability in central areas have contributed to this trend, along with the increase in the size of logistics facilities (Aljohani and Thompson, 2016; He et al., 2018). This is especially true for e-commerce-related facilities, including sortation and fulfilment centres. Medium-sized facilities, such as delivery stations in city peripheries, are also in high demand (Rodrigue, 2020). Land-use policies and regulations that do not consider freight activities have also played a role by decreasing the space available for industrial uses in some cities (Aljohani and Thompson, 2016). So have market uncertainties: larger warehouses located outside of cities with the capacity to serve wider areas have improved the ability to serve markets with heterogeneous and fluctuating demand, sometimes at the cost of the sustainability of trips (Andreoli, Goodchild and Vitasek, 2010).

Logistics sprawl has increased distances travelled and, in some cases, affected the sustainability of freight transport systems. Logistics spaces in various cities worldwide have moved up to 10 km away from city centres, and with them travel for urban goods distribution (Figure 9) (Dablanc and Rakotonarivo, 2010; Aljohani and Thompson, 2016). This sprawl has contributed to various externalities – increases in logistics-related travel contributed to an additional ~15 000 tonnes of CO_2 emissions per year between 1974 and 2008 for parcel distribution (Dablanc and Rakotonarivo, 2010). Negative impacts depend on cities and their characteristics and factors, such as vehicle types and the location of logistics facilities within metropolitan areas (Sakai, Kawamura and Hyodo, 2015). In Tokyo, for example, concentrating all logistics facilities within central areas or forbidding them in the same perimeter would increase travel distances for operation routes and raise CO_2 emissions (Sakai, Kawamura and Hyodo, 2019). Other consequences, such as increased noise and air pollution and lower road safety for active mobility, could occur in areas close to logistics facilities if they are within dense urban areas (Holguin-Veras et al., 2021).

Figure 9. Change in the average distance of logistics facilities from the city centre (in km)



Source: Aljohani and Thompson (2016) based on Dablanc and Rakotonarivo (2010); Dablanc and Ross (2012); Dablanc, Ogilvie and Goodchild (2014); Sakai, Kawamura and Hyodo (2015); Woudsma, Jakubicek and Dablanc (2016)

Inside cities, depots, consolidation centres, dark kitchens and stores are occupying urban space and may contribute to localised congestion. Urban logistics spaces are not new within cities. Yet, increases in e-commerce and parcel deliveries have heightened retailers' and freight operators' need for these spaces. In cities such as Paris, new hub spaces have transformed the use of existing commercial locations (Figure 10). Local stores, parking lots, former gas stations or underused areas have become inner-city logistics spaces (Dablanc, 2021). Sometimes, these transformations and increased goods-related travel in streets not designed for them have increased congestion (Marcher, 2021). New spaces tend to be leased, rather than owned, by operators and retailers. Because of this, a new inner-city real estate market has appeared, where landowners own, rent and sell these spaces for logistics (Ulliac, 2021).

Figure 10. Urban delivery hub in Paris

Source: Philippe Crist, ITF

Street and curb space are increasingly contested within cities. Delivery services find it harder to find loading and unloading spaces. In cities such as Seattle, drivers can spend around one-third of their total trip time looking for a parking spot (Dalla Chiara and Goodchild, 2020). In other cities, such as New York, companies like FedEx and UPS can pay more than USD 500 million per year on parking fines. These are often issued for unloading parcels in the middle of the road or when double parked (Figliozzi and Tipagornwong, 2017) (Figure 11). Such illegal parking contributes to congestion – especially during peak travel periods. In San Francisco, for example, double parking can increase congestion and lead to up to 20% more CO_2 emissions in residential areas (Jaller et al., 2021).

Figure 11. Delivery van parking conflicts with the public transport lane

Source: Philippe Crist, ITF

Re-allocating street space for passenger mobility may negatively impact freight transport and vice-versa unless a holistic approach is adopted. This re-allocation can have unwanted knock-on effects on freight access and goods distribution (resulting in congestion). It may also impact emissions and safety if it leads to greater travel distances. The interplay between the re-allocation of space and traffic and other impacts must be accounted for in policy and practice because ignoring these leads to unwanted outcomes. In Oslo, for example, an urban renewal project to rehabilitate the Smestad and the Brynstunnelen tunnels sought to re-allocate street space towards more sustainable modes (Caspersen and Ørving, 2020). The project involved a car-free area in central Oslo and a shift to needs-specific parking (for example, for freight for disabled users). Despite some consideration being given to freight carriers' needs, this shift contributed to negative outcomes for carriers and end receivers. Consequences included time losses, longer travel distances, congestion and worse working conditions for freight vehicle drivers. Street features used to improve the liveability of the urban environment, such as planters, trees or benches, further hampered parking and deliveries. In spaces where the increase in cycling lanes did not come with a clear physical separation between the lanes and motorised traffic, goods delivery drivers experienced higher levels of conflicts with cyclists (Caspersen and Ørving, 2020).

The Covid-19 pandemic has led to further strain on the space available for urban freight transport. The pandemic has accelerated the use of rapid delivery services for groceries, food and other products. As a result, many inner-city logistic spaces that enable these services have popped up (Dablanc, 2021). The pandemic has also forced other actors, such as small businesses affected by a customer drop, to diversify as freight delivery points. These new spaces have often been put in place without public support or co-ordination with other private actors, decreasing potential synergies and efficiencies for goods distribution and delivery. The pandemic has also accelerated the adoption of active mobility, as many cities have made temporary cycling infrastructure permanent. This, coupled with other non-mobility use of spaces for dining and outdoor shops, has further exacerbated tensions over limited street space.

Areas for action

Authorities can intervene in four principal areas to address the tensions arising in urban freight and logistics flows. These action areas are related to managing and optimising space, time, vehicle choice and the intensity of freight and passenger movements.

Managing the space where movements occur

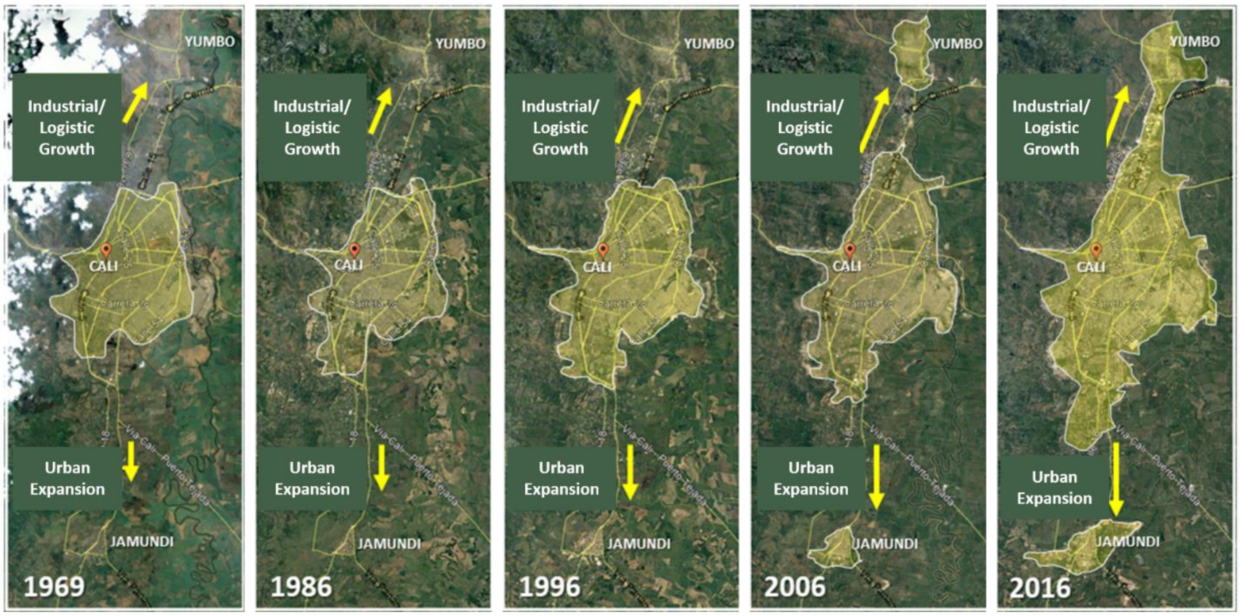
All actors can contribute towards optimising urban space in support of sustainable cities. Their contributions to urban space management must account for the use and allocation of space at three different scales: metropolitan-wide, in the urban centre and at the street level.

Public authorities can support private logistic activities by setting clear metropolitan-wide land-use planning and sustainable policy plans

The consumption of urban space by freight activities is a metropolitan-wide challenge, but it is rarely addressed at that scale. Companies put logistics facilities in places that make the most sense to optimise gains and reduce overall logistics costs (Kang, 2020; Robichet and Nierat, 2021). However, the location of these facilities does not consider the negative impacts they could have on surrounding areas or the wider region. In Cali, Colombia, high congestion levels result partly from a lack of attention to where industrial facilities developed over time. For decades, enterprises decided to create logistics facilities on cheaper land at the city's northern periphery (Yumbo), contributing to this sector's development and eventual integration with the rest of the functional urban area. At the same time, the southward expansion of the city (Jamundí) has led to significant and long-distance north-south goods distribution flows (Figure 12) (Holguin-Veras et al., 2021).

Authorities can promote Freight-Efficient Land Uses (FELUs) to orient the development of freight activities in urban areas and the location of related logistics facilities. Policies can include measures to guide the (re)location of large freight generators to specific parts of the metropolitan area. They can also seek to influence land use and the urban context around freight generators to integrate sustainably within the urban fabric (Holguín-Veras et al., 2020). Authorities can deploy measures like regulating land prices and rents and fiscal incentives that decrease the cost of renting or owning warehouses in targeted areas. Metropolitan-wide or regional land use planning can reduce inefficient warehousing sprawl and the longer travel distances they generate (Dablanc et al., 2018). Another way to achieve these objectives is by implementing Sustainable Urban Logistics Plans (SULPs) (see Box 1 above). In all cases, this requires regional governance structures or co-ordination (Holguin-Veras et al., 2021).

Figure 12. Expansion of Cali, Colombia leading to north-south goods distribution flows



Source: adapted from Holguin-Veras et al. (2021)

Private actors can reduce traffic and create better systems by deploying adapted logistics facilities

Logistics actors are deploying a wide range of urban logistics facilities. If co-ordinated and optimised across all urban logistics flows, they can better meet consumer demands and increase logistics efficiency. These facilities take many forms and have different functions. Still, all contribute to the broader urban logistics chain consisting of receiving goods from various suppliers, sorting these and redistributing them to their final destination within a city (Box 2). These facilities contribute to higher vehicle load factors and could reduce the number of vehicles used. A survey of more than 100 consolidation centres (CCs) around Europe found that these facilities could even double vehicle load factors (up to volumetric rather than weight constraints) and reduce vehicle-kilometres travelled by up to 80% for last-mile deliveries (Allen et al., 2012). The benefits of CCs vary from sector to sector. Construction is a sector that would especially benefit from load consolidation. Implementing CCs in construction sites could lead to up to 70% fewer vehicles being required for transporting freight and, thus, cost reductions for construction companies (Vrijhoef, 2018). These benefits are strongest when consolidation and redistribution merge the logistics flows of many firms and carriers. This is not typically the case, as key actors often deploy bespoke logistics facilities and distribution channels.

The cost of logistics facilities can be higher than the benefits that any single firm could derive from them. Sharing these could be a way of addressing this issue. Evidence indicates that sharing consolidation centres – including depots, fleets and operational strategies – could potentially decrease the per-firm operating costs by almost 50%. More significant cost reductions are correlated to higher levels of inter-firm co-operation. The same evidence suggests that logistical efficiency improves and distribution vehicle kilometres travelled would decrease, leading to a decrease of up to 40% in CO_2 (Nataraj et al., 2019). One reason for improved efficiency is consolidated loads and improved load factors, which reduce the number of vehicles necessary for final delivery.

Box 2. Emerging logistic facilities in the era of e-commerce

E-commerce activities have made freight operators develop complex networks of logistics facilities to optimise goods movements from the initial freight sender to the final consumer. The types of facilities, their specific characteristics and their use within a logistics system depend on the supply chain that they are found within and on the business models of participating enterprises. Rodrigue (2021) outlined the logistics facilities used in Amazon's activities, split into procurement and fulfilment, distribution and last-mile activities:

- Inbound cross-docks, neighbour ports, railyards and other major intermodal terminals are transloading facilities that handle international and domestic flows. They act as entry points for fulfilment activities, where loads are sent to e-fulfilment facilities.
- E-fulfilment centres bring together individual online orders, specialising in one particular commodity type or product size. They enable storing and redirecting goods to other areas within a wider region. Given the amounts of goods they store, they tend to be larger facilities, sometimes more than ten metres tall. They tend to have different degrees of automation within structures to facilitate the reorganisation of loads and decrease times as much as possible.
- Air hubs are facilities next to airports, mainly aimed at channelling freight (generally parcels) to and from air cargo logistics services. Hubs tend to be organised in vast networks, where metropolitan areas become key nodes for smaller, intermediate hubs.
- Sortation centres organise parcels in batches to be sent to their local destinations. These include local post offices and other facilities for last-mile deliveries. They tend to be large facilities of more than 45 000 sqm, where it can be possible to have e-fulfilment activities as well, depending on the e-commerce operator's business model. These facilities are placed in locations that balance low land costs, high road infrastructure access and wider distribution systems.
- Delivery stations are cross-docking spaces that enable parcel sorting and redirecting for local delivery routes. They tend to be located on the outskirts or within urban areas.
- Pickup locations and local freight stations allow final receivers to fetch parcels when deliveries are not made directly to the final address. They can be small shops or even places where locker banks enable customers to pick the final product.
- Fast delivery hubs stock high-demand goods and facilitate their rapid delivery, generally at the last mile. Hubs allow for almost immediate delivery after an order has been made. They tend to transform the uses of older, pre-existing facilities.

Source: Rodrigue (2020); Rodrigue and Dablanc (2022b)

Creating shared logistics facilities can be difficult, especially if this is done as a collaborative venture. One challenge is to build trust among enterprises to build co-operation for using and managing such facilities. This also includes questions on how to share the costs and savings between these enterprises and with other private stakeholders (Hezarkhani, Slikker and Van Woensel, 2019). Another challenge is the financial sustainability of shared logistics facilities. To be viable, these facilities need to reach a critical mass of clients – either enterprises or final consumers – to justify the high initial capital and operation costs (Kin et al., 2016). This critical mass of clients would also require adapting to highly complex networks, which can often mean collaborating horizontally with new stakeholders (Altuntaş Vural and Aktepe, 2021). Another pathway is for carriers and distribution channels to employ third-party logistics facilities. This can bypass some trust issues as the third party is not a direct competitor but a service provider. But it also entails losing some direct control over logistics and distribution activities by sellers and carriers.

Authorities have initiated or facilitated the creation of shared logistics facilities and funded their initial operation in several pilots. Public assistance has included funding the construction of these centres, making land available within cities and giving subsidies to enterprises to rent these spaces (Anand, van Duin and Tavasszy, 2021; Rode et al., 2021). Authorities could create further incentives so that using these shared facilities is viable beyond the pilot phase. For instance, road pricing and conditional access restrictions can help incentivise increasing load factors which, in turn, could be delivered more efficiently through shared logistics facilities. In the absence of steering or guidance, the opposite trend of multiple logistics facilities or the market dominance of one or two logistics providers dictating terms to the market can already be seen in many urban areas.

Public authorities have a role to play in managing and optimising street use for passenger traffic and logistics services

The way authorities specify the uses and characteristics of streets and road networks will help determine their contribution to urban sustainability (ITF, 2022). Authorities can help make freight contribute to, rather than erode, transport sustainability by adapting streets for safe and accessibility-enhancing use. Sustainable streets and road networks are places of both movement and urban life. They give a place and a role for all types of movements while putting people at the centre and prioritising sustainable transport modes. This includes providing places for various types of freight transport movements and designing streets that can accommodate them.

Emerging road frameworks give good examples of street design that promotes quality of life, safety and accessibility for all transport movements, including freight. One such framework is "The Good Street" approach (Immers et al., 2016; Immers et al., 2020). Under this framework, the types of vehicles that can use a given street, their size and mass and the speed they can use will depend on the characteristics and design of the infrastructure. This ensures that the size, mass and speed of vehicles circulating are relatively homogenous, contributing towards a) improving road safety and b) maximising the efficient use of street space. At the same time, the framework provides guidelines regarding which vehicle families can share the same street space and when and under what conditions they may do so safely (Immers et al., 2020). The ITF's *Streets That Fit: Re-allocating Space for Better Cities* report (ITF, 2022) includes an adaptation of The Good Street framework's four main street types. Other interesting street space design frameworks include street types for London, flex zones in Seattle and the superblock model in Barcelona (ITF, 2018c; 2022).

Authorities can control the number and size of vehicles and the conditions under which they can access curb space to increase the efficiency of overall street space use (ITF, 2018c). By increasing the availability of freight vehicles' dwell times in parking, loading and unloading areas, drivers can deliver their goods faster without congestion, especially in high-traffic areas. In San Francisco, the provision of around 30% more loading and unloading areas in commercial sectors of the city would make it easier for drivers to park and do their deliveries without adding to congestion. This could reduce travel times, and vehicle-kilometres travelled, contributing to more than a 6% reduction in CO_2 emissions (Jaller et al., 2021). Space requirements depend on freight demand, as requirements in residential areas differ for mixed or commercial areas. These requirements also depend on local characteristics. Shifting parking space from cars to freight pickup and drop-off use in areas with high car density could increase congestion without effective traffic management actions (Jaller et al., 2021).

Curb space management should be dynamic wherever possible. Adapting the function of a street section according to the time of day to fit changing mobility needs can be a successful but hard-to-achieve measure for improving space efficiency (Valença, Moura and Morais de Sá, 2021, ITF, 2018c). The use of information and communication technologies can help in balancing users' space needs across the day. In Detroit, a dynamic re-allocation of curb space to fit freight and passenger vehicle demand could reduce freight delivery parking search and dwell times by around 20% (Yu and Bayram, 2021).

Despite the potential, various challenges exist for dynamic street space allocation, such as gathering, treating and communicating the correct data. For instance, providing data on the location and status of loading and unloading zones improves space use efficiency. Most freight carriers start looking for parking spots near the delivery location, not before. Communicating available loading and unloading spaces to drivers can help reduce parking search times and travel distances (Jaller et al., 2021). Online advance booking of (un)loading spaces could also help, though this is fraught with implementation and enforcement challenges (Patier et al., 2014). In Barcelona, the Area DUM app facilitates the location of regulated parking places for (un)loading in the city. Doing so provides authorities and other stakeholders with open data on parking behaviour and needs (Dablanc, 2022).

Other actions may improve the efficiency of the last few metres of distribution. These include facilitating access to buildings and improving in-building navigation to reduce dwell times while parking. Trust between public and private stakeholders is essential for launching constructive dialogues in this area. More research is needed to understand the space impacts of actions at the last 50 metres of urban logistics.

Managing the time when movements take place

Urban distribution stakeholders can work together so that the timing of deliveries improves street space use and decreases conflicts with other users. Private stakeholders – shippers, private carriers, freight receivers and end clients (both people and businesses) – can act on their business models or delivery preferences. Authorities can act via regulation or incentives. Authorities, freight carriers and receivers can collaborate to improve city street space use.

Off-peak deliveries can bring travel time and economic savings for carriers and reduce congestion

Pilots carried out in New York, London, Paris, and Stockholm show that such programmes can lead to reductions in delivery times of more than 50% because of lower congestion and more accessible parking. Pilots have also reduced up to three-fourths of CO_2 emissions on trips (Sánchez-Díaz, Georén and Brolinson, 2016). Off-peak delivery programmes may meet opposition from citizens in the areas where they are implemented – especially at night due to concerns about noise. However, implementing noise reduction or other noise mitigation alternatives can overcome this. These measures can include training delivery staff to produce less noise when (un)loading, using electric vehicles and low-noise technologies and materials for trucks and other equipment and asking people to report excessive noise. Such policies can reduce noise levels associated with night-time deliveries (Holguín-Veras et al., 2013).

Off-peak deliveries are not always easy for or adapted to all actors. In cities such as New York, only around 5% of deliveries are made during off-peak times (Holguín-Veras et al., 2007). This is because benefits are not equally split between freight carriers and receivers, even though some actors can benefit from these programmes. This is the case if receivers are concentrated in areas with high congestion, low (un)loading space availability or access restrictions. Receiving businesses benefit less from off-peak deliveries and may even face increased costs due to added wages for receiving staff or increased security measures for ensuring staff safety at night. Some firms may be more open to the idea than others (for example, food providers such as bakers who need to receive flour early in the morning) as they rely on off-hour deliveries and might be open to broader schemes (Holguín-Veras et al., 2007). Likewise, some businesses do not need to but can benefit from these programmes, such as 24/7 stores (Holguín-Veras et al., 2005).

The most effective way to promote off-peak deliveries is to incentivise freight receivers. This can be done using monetary incentives and support to build the material and trust conditions for off-peak deliveries (Sánchez-Díaz, Georén and Brolinson, 2016). Although, monetary incentives are only a start. In a New York pilot programme, authorities gave USD 2 000 to receivers who would shift part of their deliveries to off-peak hours for six months. Some also received assistance to manage the unassisted reception of goods. This meant the programme incurred no cost for them, and the USD 2000 was only profit. After six months and the end of compensations, all receivers who had been receiving assisted freight deliveries stopped doing so. However, 90% of receiving stores that were helped to set up unassisted good receptions continued with the practice after the pilot's end (Holguín-Veras et al., 2011).

Evidence indicates that restricting freight vehicle movements during peak hours or increasing their cost does not lead to increased off-peak delivery because the balance of costs rests on the freight carrier, not on the receiver. As mentioned previously, carriers can benefit from off-hour deliveries without public support as they are generally not the ones needing to be convinced. Because receivers still expect peak-hour deliveries, restrictions can lead to contravening behaviour on the part of carriers and to added transport costs linked to fines (Sánchez-Díaz, Georén and Brolinson, 2016). Road pricing would likely also fail at delivering shifts from peak to off-peak deliveries because it is hard for carriers to signal cost increases to receivers (Broaddus, Browne and Allen, 2015). Even when such signalling is possible, staffing costs for receivers with no public support or guidance on how to set up unassisted deliveries outweigh increases in delivery costs (Holguín-Veras et al., 2007). Road pricing and other vehicle restrictions can improve road space allocation if they target vehicle or flow management but not if the desired or targeted result is to shift the timing of deliveries.

Under certain conditions, voluntary off-peak delivery programmes can benefit carriers and receivers alike. During the London 2012 Olympics, around 40% of businesses in the city used some sort of re-scheduling system for off-peak deliveries (Browne et al., 2014). In the case of (big) enterprises which undertake their deliveries, well-designed off-peak hour trips could lead to gains in productivity that could even off-set increases in costs for the receiving part of the business (Sánchez-Díaz, Georén and Brolinson, 2016). Another alternative is to put in place systems that allow carriers to deliver without the assistance of on-site staff – by having a secure and automatic reception method or by giving carriers access to store deposit areas. These systems could require initial investments for receivers or high trust between the receiver and the carrier (Holguín-Veras et al., 2013).

Increases in e-commerce must balance consumer preferences and societal outcomes

The timing of e-commerce deliveries is primarily controlled by shippers and accounts for consumer expectations and costs. Public authorities rarely intervene to manage end-consumer demand regarding space consumption consequences – except in some cases of parcel pickup point promotion and attempts to regulate activities of emerging app-based meal delivery services.

Efforts to manage the timing of e-commerce deliveries may be supported by the value consumers place on flexibility and the environment. A survey carried out by Capgemini indicated that almost three-fourths of consumers care more about having a convenient timeslot for receiving a parcel than about the speed of delivery (Jacobs et al., 2019). This focus on “at the right time” deliveries parallels a shift seen in other logistics domains away from “just in time” deliveries and highlights the value of predictability to receivers. Flexible addressing of this demand can help re-time deliveries of e-commerce parcels at times that are the most predictable and convenient for consumers and generate the lowest space and other impacts. Evidence indicates that consumers also value the environment. In 2020, more than half of e-commerce consumers worldwide were ready to change their consumption habits to help decrease the environmental consequences of their purchases (Haller, Lee and Cheung, 2020).

Communicating the trade-offs between fast deliveries and the environment can help inform consumer behaviour. In a 2020 survey of approximately 250 European residents, most respondents indicated they were ready to wait for longer, pay more or have less convenient deliveries after being shown data that outlined the environmental cost of faster deliveries (Ignat and Chankov, 2020). Shippers and carriers could benefit from greater flexibility in programming distribution and deliveries, especially when this would reduce costs and environmental impacts. They could also benefit from guidance on providing their end clients with actionable information regarding the environmental impacts of various distribution and delivery options. Educational campaigns can help enhance peoples’ environmental awareness and their understanding of the impacts of their distribution and delivery choices (Nogueira, de Assis Rangel and Shimoda, 2021). This awareness will depend on where people live, their age, gender and education level. It also depends on the products people buy (Nogueira, de Assis Rangel and Shimoda, 2021).

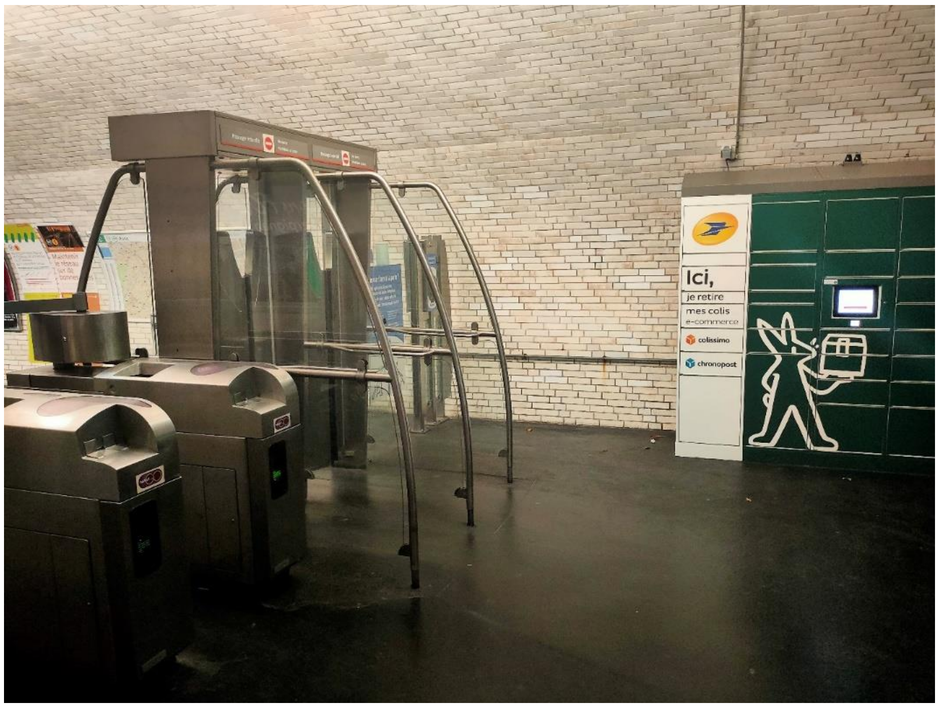
Innovative e-commerce distribution models could reduce space use and other impacts. One such solution would be to allow consumers to group all of their deliveries in a pre-determined, weekly time window. Amazon is looking at such a model with its “Amazon Day”, one or two days per week in which their regular users can decide to receive the bulk of their purchases (Perez, 2019). This service improves distribution and delivery efficiencies and, thus, the spatial and environmental footprint of deliveries. It can also reduce costs for shippers and carriers and improve business operations by having more predictable delivery slots.

Labelling and other voluntary or mandatory methods to inform consumers of impacts could help change e-commerce shipping preferences. Few efforts are made to ensure that end-receivers and consumers understand the negative impacts of rapid e-commerce deliveries, even though public authorities have tools available to promote less impactful behaviour. In other markets – such as cigarette or food sales – authorities have sought to change consumer behaviour by requiring consumer information (Harvey et al., 2016; Marzo, 2016).

Facilitating the deployment of efficient and sustainable parcel pickup points

Parcel pickup points provide consumers with flexible delivery times to improve operations and space allocation efficiencies. These points are secure places (generally lockers or local shops) where freight carriers can leave parcels for people. Lockers can be located in a public space, including public transport stations, close to where people live or travel (Figure 13). Existing shops can also serve as parcel pickup points and have proven to be a popular way for small business owners to generate additional revenue – especially during the Covid-19 pandemic. For carriers, parcel pickup points improve the efficiency of distribution. They decrease the number of failed deliveries (for example, deliveries not made because the receiver was absent) and can improve the efficiency of return parcel flows and outbound shipments by people. These factors increase the overall efficiency of distribution and reduce costs (Arnold et al., 2018). For people, parcel pickup points offer flexibility. For cities, parcel pickup points can help reduce the number of vehicles on streets and reduce the space and environmental delivery footprint of e-commerce sales.

Figure 13. A parcel pickup point within a Paris metro station



Source: Joshua Paternina Blanco, ITF

The space use advantage of parcel pickup points is only realised if people go to them using less space-intensive modes than vans or other vehicles used for home delivery. These benefits are most significant when people walk, cycle or use micromobility to access these points. If people access them using space-intensive modes, such as cars, then parcel pickup points can lead to more, rather than less, use of space. The same holds for emissions: if people pick up packages by walking, cycling or using public transport, emissions from parcel pickup points will tend to be lower than home delivery. However, emissions can be higher if people go to them by car instead. A recent study simulated a system of parcel pickup points in New York City and found that for CO_2 emissions to be lower than home deliveries, no more than one person in five should use a car to access the pickup points (Schnieder, Hinde and West, 2021).

The space consumption impacts of parcel pickup points are lower if they are close enough that people can go to them sustainably on their way to other things. If people pick up or drop off parcels on their way to work, school or other activities, then parcel pickup points do not contribute to additional trips (and space consumption). Instead, they would have cancelled trips to deliver parcels to receivers' homes. Distance is a key factor in mode choice for accessing parcel pickup points. If the points are close enough to people's home or work locations, they could access them using sustainable modes. In Graz, Austria, almost 20% of people would be ready to use low space-consuming modes instead of cars to go to a parcel pickup point on their way to do something else if the point was less than 2 km away from their home or workplace (Hofer et al., 2020). Trip chaining matters as well. In Stockholm, reducing the distance to a pickup point by 5 km would generally make it 7% less likely that a person would choose a car to pick up a parcel. However, the probability of car drivers choosing a mode other than a car to go to a parcel pickup point would drop to only 1% if they access the parcel pickup point on their way to or from work. This is because commuting trips are strongly habitual and, as such, are much harder to change (Liu, Wang and Susilo, 2019).

There is a trade-off between parcel pickup locker density and the costs incurred by carriers in servicing them. Using sustainable and space-efficient modes to access parcel pickup points hinges on how close they are to people. This implies a high density of points, especially in large cities. Servicing these is not always economically beneficial for freight carriers and even less so for smaller companies in the case of lockers. A high density of lockers requires large upfront investment costs by logistics actors (shippers in the case of vertically integrated operations, carriers or third-party locker providers). As a result, the pickup point model based on local shops has gained popularity as these do not entail upfront capital costs but only commissions paid to shop owners (Arnold et al., 2018). Nonetheless, such a system requires people's trust in the reliability and safety of goods of such a service, which could be difficult to obtain without proper communication (Altuntaş Vural and Aktepe, 2021).

Authorities can help incentivise the use of parcel pickup points to reduce negative outcomes. Authorities could give economic incentives – such as subsidies or tax rebates – to parties investing in pickup lockers in dense areas where these are currently lacking. They could help foster partnerships between carriers and local businesses so that the latter can function as pickup and drop-off points at a neighbourhood level. Public authorities can leverage incentives to help guide the deployment of parcel pickup points where they are most needed and generate the most benefits. In France's capital region, metro operators partnered up with the La Poste group to ensure that parcel pickup points could be located within metro stations, making it easy for people to pick up parcels on their schedules and as part of a public transport trip (Figure 12). Authorities can also help mitigate the impacts related to the use of pickup points.

Managing the negative consequences of click-and-collect and meal delivery services and promoting their sustainable use

Blending physical and online shopping, for example, omnichannel retail contributes to structural changes in shopping, distribution and final delivery. One aspect of omnichannel retailing – click-and-collect sales – allows consumers to buy a product online and collect it in a store at the time of their preference. Collection can be done in-store or through a "drive and collect" system outside the store. Click-and-collect services are similar to parcel pickup points in that they cater to the consumer's desire for flexibility.

They also increase the speed a person expects to receive a product. In a 2017 survey, almost two-thirds of respondents expected an item to be ready four hours after the request and most expected them to be ready for collection in the 24 hours following their purchase (Bell and Howell, 2017). Services can benefit people in less connected areas, such as rural or peri-urban communities. The use of click-and-collect in dense cities is also increasing.

Click-and-collect services reduce delivery costs and improve retailer operational efficiencies. Click-and-collect services allow companies to gain additional knowledge about their customers by collecting and monitoring their online shopping behaviours. They can also increase sales if consumers buy extra items at stores when picking up their initial orders.

Click-and-collect shopping may increase urban space consumption depending on how and when people go to collect products in stores. The Covid-19 pandemic has made people increasingly use drive-through collection services to decrease contact with people within stores (Numerator, 2020). This would tend to increase the spatial footprint of click-and-collect systems compared to other store access modes.

The spatial impact of click-and-collect would be less significant if people walked, cycled, scooted or used public transport to collect their purchases. For example, walking to a restaurant to pick up fast food instead of having it delivered at home could reduce more than two-thirds of emissions linked to the delivery of that product (Xie, Xu and Li, 2021). The actual impact of these practices is not well known, as few studies have looked at the space consumption and use of these services. More research is needed in this area.

The use of app-based food and grocery delivery services has also accelerated during the Covid-19 pandemic. This, too, has had consequences on the spatial impact of urban distribution (Ahuja et al., 2021; Dablanc et al., 2017). These services are characterised by multiple single orders with low latencies ranging from less than 30 minutes to only ten minutes. Load factors are low by design to service rapid delivery times. In many urban areas, these services have given rise to hyper-local grocery distribution hubs and food preparation centres (for example, "dark" stores and kitchens). In many cities, app-based food couriers use bicycles, e-scooters or mopeds to deliver orders.

Pressure to fulfil low delivery times can contribute to increased crash risk. In Bogota, three out of four couriers on the Rappi platform use bicycles. Almost 40% of food and grocery couriers have had crashes, and more than a quarter of these crashes involve a collision with another vehicle (Observatorio Laboral de la Universidad del Rosario [LaboUR], 2019). In Paris, almost half of food and grocery couriers use bicycles, and one out of ten use e-scooters. In 2020, almost one food and grocery courier out of four was involved in a crash while making deliveries (Dablanc et al., 2021).

Optimising space consumption through vehicle choice

Public and private actors can adjust or influence the composition of delivery vehicle fleets to optimise efficiency and space use. Freight operators and goods distribution services can select more space-efficient vehicles if doing so fits their operating and business models and yields efficiencies. Public authorities can also incentivise actors to adopt less space-consuming vehicles and fleets with the same constraints on operational and efficiency outcomes.

Private actors can adjust the composition of fleets to improve efficiency and align with public policy objectives

Vehicle size and other technical characteristics depend on freight carriers' operational needs and business models. Carriers decide on a fleet composition based on factors such as the size, weight and unique requirements of the goods they transport (such as special temperature conditions). They will also consider each vehicle's total cost of ownership – including maintenance and fuel. Other factors, such as drivers' wages and infrastructure needs for operating delivery routes, also form part of vehicle choice decisions. Carriers are interested in getting the most out of the vehicles they purchase or lease. This means that it is often in their best interests to increase load factors as much as possible. Load factor optimisation decreases the number of trips necessary to deliver a given number of goods and, thus, reduces street space use from operations.

Better matching vehicle size to vehicle loads can shrink the spatial footprint of urban distribution. If vehicles take less space while driving, use less time looking for parking and take up less space during (un)loading or if they can deliver more with fewer trips, then the spatial footprint of goods delivery will decrease. If operators' business models or practices result in less-than-full vehicles circulating, they can improve load factors or "right-size" vehicles – including smaller or non-motorised ones. Optimal vehicle size depends on operational needs and practices. Smaller vehicles are not always the right answer, and in some cases, larger, fully laden trucks can reduce the overall space use of a carrier.

Electrifying road delivery fleets may have an impact on street space consumption

Private companies are electrifying their fleets and adopting cargo bike deliveries in cities worldwide. As early as 2007, the French group La Poste launched its first call for tenders for electric vehicles. It now has the world's largest electric vehicle fleet, with more than 40 000 vehicles, 16 000 of which are commercial vehicles (La Poste Groupe, 2020). Businesses have various motivations to undertake such programmes – mainly to test public relations and market and economic benefits. Increasing consumer environmental concerns have made certain retailers adopt electrification of their fleets or providers and use more sustainable vehicles as part of corporate social responsibility campaigns. Fleet electrification also reduces noise from deliveries. In some cases, electrifying fleets and using cargo bikes have also decreased operational and delivery costs for enterprises, looking at the total cost of ownership and use of these vehicles over their lifecycle (ITF, 2020b).

Electrification may impact vehicle capacity and thus affect the space they use. Due to battery weight, electric vehicles tend to be heavier than those with internal combustion engines (ICEs). Higher vehicle weights could cause issues with maximum vehicle weight limits as the legal payload. The total weight an electric vehicle can carry could be reached faster than an ICE vehicle. In other words, if loads are heavy enough, vehicles would "weigh out" before "cubing out" (reaching their volumetric capacity). Due to this, electric vehicles could require additional vehicles or trips to transport the same quantity as an ICE-based fleet unless regulations change to adapt to electric vehicle needs. If done like-for-like, freight vehicle electrification could potentially increase overall space use. This concern applies less in urban areas with high shares of parcel deliveries than in longer distances and with heavier loads. Eventual space use increases could potentially be balanced out by increases in operational efficiencies and load factors promoted by carriers to avoid cost increases. More research is needed in this area.

Operators also need to balance duty cycles and battery charging. From a space consumption (and energy use) perspective, vehicles that can handle their entire duty cycle comprised of a completed delivery route on one charge display the highest space efficiency. Having to drive to a charging point and occupy it while the battery is recharged reduces the space efficiency of the vehicle and the duty cycle. Vehicles with a battery capacity of 42 kWh have a range of around 175km with an extra 20% buffer. This would cover a typical driving distance for urban deliveries and allow for private night-time charging (ITF, 2020b). Adapting delivery fleet characteristics and composition to delivery duty cycles is essential.

A Korean example shows how difficult it is to determine the space benefits of fleet electrification. Korea Post led a pilot project to replace 10 000 of their internal combustion engine (ICE) motorcycles with small electric vehicles. During the pilot, the higher loading capacities of electric vehicles resulted in carriers not needing to undertake daytime battery recharging. This resulted in 12.5% fewer kilometres driven distances while also giving rise to a more than 10% increase in deliveries (ITF, 2019). However, the new vehicles were larger than the pre-existing motorcycles making it harder to find adequately sized (un)loading spots. Delivery times decreased by 2%, suggesting that more time was spent searching for parking, which also likely contributed to peak-hour congestion (ITF, 2019). However, because the study did not explicitly seek to measure space consumption, it is hard to generalise this outcome. It highlights the need to account for this variable upfront.

Cargo bikes can contribute to sustainable distribution under the right conditions

Cargo bikes could replace up to half of all goods-related trips in cities and help significantly shrink delivery van fleets. Cargo bikes can carry up to 500 kg, depending on characteristics such as size and whether or not they are electrified (Nürnberg, 2019). Two-wheeled, three-wheeled, four-wheeled, and trailer-based cargo bikes can deliver all types of goods, from food to construction and from parcel delivery to retail shop provisioning (Cairns and Sloman, 2019). In European cities, various studies have shown that up to 51% of motorised trips linked to purchasing and delivering goods could shift to bikes or e-bikes (Cairns and Sloman, 2019). This includes delivery and passenger transport trips linked to the purchase or transport of goods. It is easier to shift trips from vans to cargo bikes because of a similar payload rather than away from trucks. In Paris, between 2001 and 2014, an estimated 650 tonne-kilometres per day shifted from vans towards cargo bikes, compared to only 57 tonne-kilometres per day from trucks (Koning and Conway, 2016). However, the potential to shift trips away from vans depends on delivery requirements and local traffic conditions. When congestion is low, cargo bikes tend to be slower than vans. At the same time, parking search times may be lower with cargo bikes, so their use may reduce overall duty cycle duration.

Cargo bikes can bring savings to operators, depending on the context. Cargo bikes tend to be less costly than other delivery vehicle options. Their operating costs, such as fuel, insurance, taxes and storage are also lower. Depending on their size, they can also be faster than van-like vehicles in congested urban areas with narrow streets. This makes their operation ideal for small businesses in emerging cities (Hagen, Lobo and Mendonça, 2013). In Bogota, replacing two mini trucks with three cargo bikes could decrease delivery costs by 16% (Prato Sánchez, 2021). However, in developed economies their operation could, in some cases, increase costs to operators if compared to only using vans. Depending on the vehicles, cargo bikes could have lower payloads than vans, thus increasing the number of trips required to deliver the same number of goods. Though, this could be counter-balanced by higher load factors. In certain contexts, this could increase overall travel times and salary costs. One study from Antwerp suggests that shifting from vans to cargo bikes could increase operational expenses by around 10% (Arnold et al., 2018).

Using cargo bikes for deliveries could free up street space and reduce emissions and noise. In Paris, a shift from vans, trucks and motorised two-wheelers towards bikes, electric or not, brought about a saving of almost 50% in congestion costs (Koning and Conway, 2016). Likewise, a simulation in Antwerp found that replacing vans with cargo bikes and adapted break-bulk hubs would reduce the noise, emissions and congestion costs linked to deliveries by more than 40% (Arnold et al., 2018).

Using cargo bikes may improve road safety by reducing the number of kilometres travelled by larger and more dangerous vehicles such as vans and trucks. This safety benefit largely befalls truck and van crash opponents, typically vulnerable road users such as cyclists, pedestrians, and the occupants of smaller motorised vehicles.

Due to their smaller vehicle footprint, cargo bikes require (un)loading spaces tailored to them, potentially smaller than those allocated to vans. A lack of adapted parking for cargo bike delivery reduces time and efficiency. It may lead to cargo bikes (un)loading in unsuitable places, increasing conflicts on pavements and at the curb. In Amsterdam, the lack of dedicated cargo bike parking led carriers to park cargo bikes and other light electric vehicles on cities' pavements, leading to conflicts with other users and uses (Ploos Van Amstel et al., 2018). In a cargo bike pilot in New York, authorities created "cargo bike corrals" where operators parked their vehicles while undertaking deliveries (Figure 14) (New York City DOT, 2021). When infrastructure is designed, it should consider the larger dimensions of cargo bike vehicles. Parking, in particular, should be reserved exclusively for freight purposes rather than mixed with parking spaces for passenger activities (Ploos Van Amstel et al., 2018).

Attention should be given to the amount of urban land required to make urban cargo bike deliveries work. Using these vehicles requires logistics facilities to de-consolidate loads from vans to cargo bikes. Without these spaces, carriers could end up using curb space not designed for this, potentially increasing urban street space use and increasing congestion. Authorities should consider the impact of such facilities in their planning and facilitate, when appropriate, their integration into the urban fabric. This may involve re-purposing off-street parking facilities or ground-floor real estate that has struggled to find use in the wake of the Covid-10 pandemic.

Figure 14. “Cargo bike corrals” in New York City

Source: New York City DOT, 2021

Authorities can support vehicle shift and better use of urban space through incentives and regulations

In many countries, authorities do not explicitly incentivise the uptake of more space-efficient vehicles, though many do for energy-efficient or electric vehicles. In this respect, it can be useful to tailor regulations so that they better include cargo bikes. In many cities, cargo bikes do not fit existing vehicle regulations, making it hard for operators to use them for deliveries (Ploos Van Amstel et al., 2018). It is still unclear if public charging supports the uptake of electric vehicles for goods distribution. Standardising charging infrastructure can help by reassuring operators that, if needed, drivers will be able to charge outside of depots and hubs (Taefi et al., 2016).

Authorities can encourage experimentation among logistics operators with new delivery modes and models. Pilots allow businesses to explore the feasibility and advantages of undertaking fleet and operational changes. For authorities, pilots build experience and understanding of the needs of private operators. They also allow authorities to explore the real-world impacts of proposed policies. When undertaking such pilot programmes, authorities should consider street space use. In Bogota, a cargo bike pilot allowed authorities to better understand how often drivers would use cycling lanes and the number of conflicts they would have with other users (Prato Sánchez, 2021).

Authorities can also incentivise the purchase and use of space-optimising delivery vehicles. Incentives can come in many forms, including facilitating the purchase of vehicles by enterprises through tax rebates or subsidies, as is already done for electric vehicle uptake. In France, authorities have recently launched a programme to subsidise between EUR 0.6 and EUR 2 per package delivered by cargo bikes between 2021 and 2025 in four urban areas (Ministère de la Transition écologique, 2021). Beyond vehicle-type shifts, authorities could also give incentives for carriers to review their existing business needs and consider making fleet adjustments that are more space efficient. Such incentives could, for instance, favour purchasing electric and larger trucks to consolidate freight from smaller vehicles. Incentivising sharing of fleet assets between carriers could also be a way forward.

In all cases, incentives must consider the specificities of different fleet operations and business models. In Buenos Aires, a pilot showed that subsidies for vehicle purchase are only effective if they are adapted to the operational profiles of different carriers. The pilot sought to understand the potential impact of financial incentives on one carrier if they electrified their van fleet. Given the distance they travelled daily, the pilot concluded that a subsidy would decrease the total cost of ownership between electric and diesel vehicles but that diesel vehicles would still be cheaper. For electric vans to be cost-competitive with diesel ones, electric vans would have to be driven three times more per year. This did not respond to the operational needs of the participating carrier. After the pilot, they retained a partially electrified fleet as part of their social corporate responsibility programme. However, it would not be feasible for smaller operators with limited resources to electrify their fleets to improve their public image (Garros, 2019).

Authorities can offer priority access to street and curb space to more space-efficient vehicles. Such priority access might concern roads, (un)loading bays, curbs and parking spots (Lidasan, 2011; Quak, Nesterova and van Rooijen, 2016). In Amsterdam, for instance, authorities have exempted electric freight vehicles from certain rules and codes, allowing them to park on sidewalks for (un)loading operations or driving on pedestrian-exclusive roads (Quak, Nesterova and van Rooijen, 2016).

Incentives can be combined with disincentives for less space-efficient vehicles. Many public authorities deploy different forms of vehicle access restriction schemes to mitigate the impacts of traffic. Restrictions can be implemented based on vehicle dimensions and weight, local pollutants or greenhouse gas emissions, loading capacity use or other characteristics. While such schemes typically target other outcomes, like addressing congestion, reducing emissions or improving liveability, they can also have knock-on effects on the use of street space. In London, implementing a low-emission zone incentivised the uptake of cleaner vehicles but also brought about a replacement of more than 3% of heavy-duty and medium-sized vehicles by light and smaller commercial vehicles in the city (Broaddus, Browne and Allen, 2015; Ellison, Greaves and Hensher, 2013).

Vehicle access restrictions typically aim at other policy outcomes. Nevertheless, they can contribute to more optimised use of road space. For instance, they can incentivise the use of urban consolidation centres if they offset additional costs from restrictions or facilitate the use of vehicles that escape restrictions (Lebeau et al., 2017).

Authorities should monitor the space consumption impacts of new modes and services

Electric vehicles and cargo bikes are only some examples of new goods distribution vehicles being introduced in cities. Authorities must monitor and assess the impacts of such new technologies and services on desired public policy outcomes, including efficient use of street space and safety (ITF, 2020c).

In theory, drones on the road and in the air could optimise street space use. The use of drones is an emerging solution for last-mile deliveries, on their own or jointly with the use of ground vehicles and consolidation centres. Deploying drones for goods distribution could reduce travel distances, the number of ground vehicles used and delivery times – depending on drone service characteristics and infrastructure. Using drones and freight consolidation together could reduce road vehicle trips by more than 50% while reducing travel distances. Drone use could also increase vehicle load factors up to 70% from a more typical 15% (Tadić, Kovač And Čokorilo, 2021).

In practice, drones bring many challenges to space use. Street and sidewalk drones raise questions about how to adapt existing street space. Because of their size and varying speeds, it is unclear whether they would need to circulate on sidewalks, roads or specific lanes. It is also unclear how interactions between these drones and other street users impact street space use. For aerial drones, challenges start with defining the areas, heights and other conditions in which drones can circulate. The features and location of vertiports will also impact space use.

Another new development to track is the emergence of mobile “warehouses”, which position parcels or goods closer to the final point of delivery, allowing other vehicles or couriers to optimise final delivery. Mobile warehouses allow operators to deliver more quickly and reactively to customer orders and increase operational efficiencies for delivery and returns. They could also reduce fixed warehousing rent costs.

Amazon patented a mobile warehousing system that acts as a “pickup point on the move”. Clients indicate where they would like to receive packages, and the mobile warehouse adapts their routes and indicates the most appropriate collection point accordingly (Bhatt, 2019). As with regular parcel pickup points, this model could bring issues if people go there using space-consuming modes. Mobile warehouses could also increase overall street space consumption because of larger vehicle dimensions, parking requirements and customer convenience-oriented routing.

In Paris, authorities partnered with freight operator Stuart to promote the use of cycle-based mobile warehouses circulating in pre-assigned zones. The mobile warehouse has a dedicated parking spot while smaller bicycles and cargo bikes carry out final delivery. The parking spot was assigned by city authorities after talks with operators, thus enabling better management and reducing the impacts of (un)loading operations. Because of their smaller size, cycling modes also optimise the overall street space used for each delivery (La Poste Groupe, 2021).

Optimising, consolidating and reducing freight and passenger movements

Minimising freight transport’s spatial and other impacts requires adopting a holistic perspective to cover all trips at the scale of the functional urban area. Consolidating freight flows is the first step to optimising deliveries and returns, and co-operation between stakeholders is essential. The second step is integrating passenger and freight flows whenever possible and under the right conditions. A third step to optimise freight space is fostering a circular and more environmentally-conscious economy, including local goods production, that seeks to decrease deliveries’ environmental and spatial footprint as much as possible.

Consolidating freight flows and optimising trips through stakeholder co-operation

Consolidating freight flows is central to optimising the use of street space. This goes beyond just creating consolidation centres. Combining freight flows where possible greatly improves the efficiency of the urban logistics system by ensuring that all resources in cities are optimised. In turn, this reduces wasteful and unnecessary trips and operations. Such co-ordination could require physical and digital infrastructure deployment, including logistics facilities and data-sharing networks between relevant stakeholders. It would also require shifts in behaviour, business models and public incentives. The growth of third-party intermediaries offering “consolidation as a service” on commercial terms could also help. Pushed to its extreme, this kind of co-ordination could mirror digital interoperability and result in a “physical internet” – urban and global logistics networks optimised to deliver goods in the most efficient possible way just as data packets are routed through the internet. (Crainic et al., 2016, European Commission, 2021).

Carriers already tend to optimise routes to increase the efficiencies of their operations. Collaboration between carriers regarding compatible deliveries for different routes could allow them to make the most out of each trip. This would mimic what already happens at regional scales. In Belgium, for instance, if three firms were to collaborate by sharing information and assets, they could see a reduction of around 25% in their operating costs and delivery trips (Vanovermeire et al., 2014). Such collaboration is not always beneficial for all carriers, as it sometimes can increase the costs for one for the benefit of many. In Lyon, simulations of collaboration between five freight carriers showed that only two could reduce costs significantly enough to justify their participation in the scheme (Gonzalez-Feliu, 2012).

Receivers also influence delivery optimisation by choosing their orders' timing, fulfilment delay and delivery method. However, end receivers do not necessarily see or experience the benefits of consolidating flows or even know the role they have to play (Verlinde, Macharis and Witlox, 2012). There are ways for receivers to help ensure more space-efficient deliveries. For example, suppose various shops from the same area place bulk orders of similar products from the same provider. In that case, they could consolidate their shipments and benefit from lower delivery costs per unit (Verlinde, Macharis and Witlox, 2012). However, this collaboration could raise concerns about competition since doing so could signal sensitive commercial information regarding product mix and quantities among potential competitors.

Vehicle access restrictions or curb management measures can also help incentivise the use of more space-efficient deliveries. In Gothenburg, Sweden, authorities developed a programme to allow vehicles with more than 65% occupancy rate to park for free in available spaces and, in some areas, to use bus lanes (Verlinde, Macharis and Witlox, 2012). Measures and restrictions can also target receivers. A study analysed the impact of a "delivery cap and price" potential scheme for shops in Rotterdam, the Netherlands. The analysis modelled the consequences of limiting the number of deliveries one business could receive by using conventional ICE vehicles that did not use urban consolidation centres. The results indicated that receivers asking for more consolidated flows would increase vehicle occupancy rates to 65% (Anand, van Duin and Tavasszy, 2021).

Authorities can also foster collaboration among stakeholders to facilitate the consolidation of shipments. In London, inter-stakeholder exchanges result from creating and continuously updating delivery and servicing plans (DSPs). DSPs are documents that ensure that all actors in one zone – landlords, tenants and even carriers – collaborate and have a shared vision so that deliveries to and from that area are as safe, sustainable, efficient and effective as possible. DSPs ensure that all stakeholders speak to each other and plan together. They are mandatory for all new developments, and authorities promote their creation in existing developments by highlighting their benefits for local businesses (Transport for London, 2020a).

Data exchange and load-matching platforms could further reduce the space consumed by urban goods distribution and delivery. In Turin, Italy, such a platform could improve load matching between shippers and receivers. App-serviced platforms could reduce operational costs and emissions from deliveries by more than 20% due to improved vehicle load factors and a related reduction in the number of trips carried out (Rosano et al., 2018). Some public authorities have taken a role in fostering these app-based platforms. In Lyon, France, a "Smart Deliveries" system using information from the city's monitoring centre and operational data from carriers' business systems and vehicle drivers could reduce urban freight traffic by almost 3%. It could also reduce distribution and delivery-related travel distances and travel time by around 25% and 20%, respectively (Baudel et al., 2016).

Although promising, using platform-based solutions for optimising freight flows is not straightforward. As there is no obligation to share data among logistics actors, there would need to be a major incentive from a platform scheme to ensure that most operators and receivers in one area do so. Commercial sensitivity concerns must also be overcome for potential competitors to share their data. There is an interoperability cost to sharing data when it is codified in incompatible or poorly harmonised data formats and forms. A further challenge comes from the new business models linked to platform-wide co-ordination. The emergence of a platform might favour platform managers and information and technology service providers at the expense of carriers and logistics firms who have traditionally co-ordinated urban logistics. This would mean a reshuffling of the power dynamics within the sector, a change in operational practices and new ways of charging for services (Monios and Bergqvist, 2020).

Integrating passenger and freight flows can increase space use efficiency

Combining both passenger and freight transport can improve street space use. The space efficiency benefits are, in theory, clear: deliveries done when using passenger trips that would have been made in any case could optimise flows and remove unnecessary goods delivery trips. An added benefit could come from using vehicles for the remaining delivery trips that are less space-intensive (McKinnon, 2016a).

Individuals could earn money from such a system, allowing them to at least partly cover their passenger transport costs or make an additional income source. This system could be attractive for traditional carriers because it can give flexibility to deliveries in a cost-effective way. Giving a commission to a person for delivering a parcel can be cheaper than paying for a van fleet, especially in areas where the density of demand is low. This offers a good return on investment in areas where margins might be tight. Such deliveries could also help reduce parcel returns; it is easier to ensure that a person receives their parcel where the deliverer lives or passes by regularly. Nonetheless, each shipper and carrier would need to look at the feasibility of using these systems. They would need to develop the infrastructure for assigning conveyances to individuals and the final receiver cost-effectively. They would also need to ensure that the good does not put the individual delivering it at risk, that the deliverer transports it without damaging it, and that both sides are adequately and affordably insured (McKinnon, 2016a).

Crowd-sourced shipping services function best from an efficiency and cost perspective if people can deviate somewhat from their initially planned trips to better match platform-optimised routes or if they take on additional trips (Voigt and Kuhn, 2021). Both of these actions, however, could erode gains in street space use. A further issue concerns the consolidation of freight flows. A fully-loaded van has low per-consignment space consumption due to its high load factors, so the space the van consumes is distributed among many parcels. Redistributing those consignments to passenger vehicles would reduce load factors – sometimes significantly – resulting in the per-parcel or per-consignment space use being higher than a fully loaded van. Another issue is the potential differences in loading and unloading times. People not trained for goods delivery could spend longer on (un)loading goods and final delivery than a trained professional.

Using public transport to move goods could improve logistics efficiency and potentially remove goods delivery vehicles from city streets. Authorities have partnered with freight operators in various European cities to use off-peak public transport to move goods. In Nijmegen, the Netherlands, a service was put in place to deliver parcels to the peri-urban communities using peri-urban bus services and last-mile delivery services using bicycles. The decrease in van trips due to the implementation of this service led to more than 58 kg CO_2eq daily reductions (Van Duin et al., 2019). Likewise, a study in Venice, Italy, indicated that using available space in public transport services for freight could lead to an approximately 25% reduction in freight traffic (Mazzarino and Nathanail, 2018). Yet, despite its potential, the use of public transport for goods distribution and delivery is not straightforward. Passenger and freight transport are regulated differently regarding safety, business models, public service obligations, contractual arrangements, employment guidelines and standards. This makes it difficult to run joint operations (Bruzzone, Cavallaro and Nocera, 2021).

Optimising reverse logistics and sustainable consumption trends can also help improve street space use

One way of optimising reverse logistic flows is to combine them as much as possible with "forward" flows that focus on goods delivery. This strategy would seek to maximise vehicle payloads as much as possible. Instead of getting emptier as they deliver goods along their route, delivery vehicles would take on product returns or other reverse logistic consignments, such as items due for refurbishing or recycling. In Rome, Italy, authorities developed a pilot alongside Poste Italiane and the University of Roma Tre to combine postal delivery trips with a collection of bottle caps to be recycled. The pilot aimed to reduce empty running and dedicated trips to collect bottle caps. Thanks to the pilot, every 2 kg of collected caps avoided 3.5 km of dedicated trips, and the number of bottle caps collected almost tripled (Twisse, 2020).

Waste collection can be better optimised to reduce space consumption. Waste collection can be a major source of congestion in cities. On top of this, waste management arrangements can lead to situations where buildings in the same area can have multiple waste collection providers resulting in inefficiencies and a surplus of waste collection vehicles operating on city streets. Cross-operator optimisation could lead to decreases in travel distances of more than 30% (Das and Bhattacharyya, 2015). To this end, authorities could aim to set zone-based contracts through regulations or incentives. In New York City, the shift towards a zone-based waste collection system is expected to improve the efficiency of waste collection and result in halving annual waste traffic (New York City Department of Sanitation, 2019).

Local consumption trends could help improve space efficiency under the right conditions. In Madrid, Spain, a local agriculture pilot was implemented in 2014. The programme decreased the street space consumption of food freight activity by various means. First, as they allowed participants to purchase goods directly or very close to production sites, distances travelled with large commercial vehicles decreased significantly. Second, it contributed to changes in the mobility behaviour of buyers. Participants in the scheme increased their share of walking and cycling by more than 4% between 2012 and 2017, compared to a decrease of almost 10% for those not participating. Third, participants in the pilot reduced their waste generation by almost 15% and were nine times as likely to compost their food waste compared to non-participants (Puigdueta et al., 2021). There are challenges to the wider adoption of urban agriculture because of factors such as the high costs of urban land. Nonetheless, if effectively implemented, urban agriculture activities could help meet up to 2% of global urban food demand (Stuchtey and Vahle, 2019) and, under the right conditions, could also improve street space efficiency.

Another form of "local production" – 3D printing – can improve street space efficiency. This technology can "localise" production, whether at end-users' homes, local shops or specialised printing centres, bringing it closer to consumers. 3D printing could also reduce product returns and reverse logistics flows due to the ease of customising end-products (Boon and van Wee, 2017). The space use of this emerging technology will depend on its future level of adoption. If adopted widely, a significant share of the goods flows to and within cities could be much more compact, thereby limiting freight movements (Birtchnell et al., 2013). If, as some analyses suggest, its adoption is more limited or concerns retailers and production facilities more than end-consumers, the street space consumption impacts of 3D printing are less clear (Mckinnon, 2016b).

Measuring the use of street space for freight transport

Measuring freight activities' use of street space is an important yet challenging task. This section describes the methodology behind the ITF modelling approach. It also outlines the main indicators for measuring space use, road safety consequences, and overall street performance. Finally, it describes the scenarios developed to test a combination of measures described in the previous section.

The ITF has developed a detailed simulation and optimisation approach to meet the challenge of assessing the (space) consequences of different freight planning and operations choices. This approach simultaneously tests the dynamic management of street space allocation, the deployment of new private ownership and shared mobility services, and innovations in urban freight.

The modelling for this study is based on – and expands – previous ITF urban and other modelling work. The model incorporates the planning and operation of urban freight, ranging from freight consolidation, last-mile delivery optimisation and vehicle selection. The model update is relative to the limited dynamic, demand-responsive re-allocation of street space according to street type that incorporates freight activity and requirements. A pre-existing shared simulation model for the Greater Dublin Area, Ireland (ITF, 2018b) and the upgrade introduced in *Streets that Fit: Re-allocating Space for Better Cities* (ITF, 2022) were used to test the measures and policies discussed in this report.

The modelling work outlines the consequences of street space use in a mid-sized European city based in the Greater Dublin region. The ITF generated a plausible characterisation of shared/free-floating transport supply and detailed parking availability. A plausible freight matrix for several commodity classes was estimated based on existing data generated for the Dublin region. The modelling does not depend on observed data, so this report's results should not be used to assess the results or impacts, specifically in the case of Dublin.

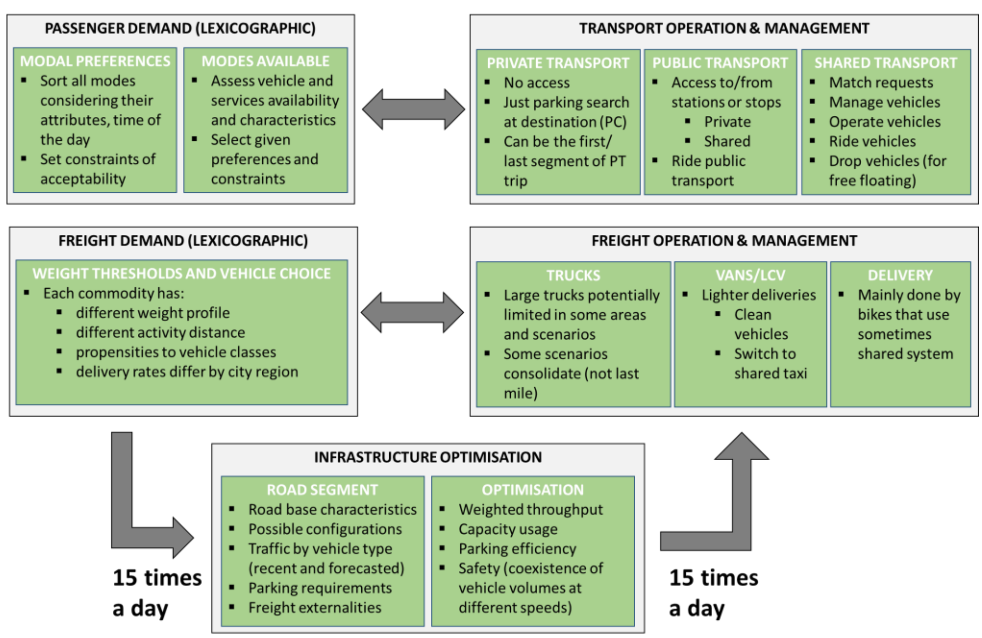
The modelling framework in this report also updates other features in previous ITF models. First, it adds the assignment of freight vehicles and the freight occupation of the street space while also considering delivery operations and their integration with shared mobility passenger solutions. Second, this model version uses a new detailed routable street network within the urban core of the studied area. This enables the capturing of detailed non-motorised vehicle flows and the availability of space for freight curb usage. This network was created and consolidated with the pre-existing network outside the city core. Finally, the model's upgrade also addresses parcels as a separate freight flow in the urban region. More details about the simulation architecture of the passenger-shared component and optimisation services approach can be found in ITF's report *Shared Mobility Simulations for Dublin* (2018b).

This report focuses on capturing the impacts of adding freight activity to the assessment. It sees how passengers and freight share urban space and how their co-existence can be improved while reducing their space consumption and other related externalities. It also seeks to capture the effects of managing street space allocation and use more dynamically expanding concepts used in the *Streets That Fit* report (ITF, 2022) to integrate freight into the mobility space management equation. The simulation does this by running an optimisation process 15 times a day. The periods of optimisation were extracted from the previous report by analysing the dynamic road allocation and observing the times of day when significant changes were introduced. This enables the characterisation of configurations that are theoretically more adjusted to the observed or predicted demand constraints according to street type across the day.

The adjusted model framework (Figure 15) comprises three key components: a lexicographic travel demand framework, which allows setting a pre-established order of mode preferences depending on availability; an infrastructure optimisation framework; and a transport operation and management framework. The model simulates how users make mode-choice decisions given available options, the expected modal attributes given the operational layout and the expected travel time given street capacity and speed specifications for each vehicle type.

The model is a sorting utility-based algorithm derived from the Global Urban Model, as used in the *ITF Transport Outlook 2021* (ITF, 2021b). The simulation sets constraints to trigger potential modal switches (meaning, the conditions under which one mode can be replaced by another). Specific modal availability and suitability depend on the time of the day and trip purpose. In practice, all travellers and vehicles operating in the city simultaneously send and receive information from a centralised dispatch algorithm that optimises vehicle usage and plans for future periods. Finally, an optimisation algorithm runs based on the registered dynamic and static (such as parking) demand on each street segment (see Figure 15). This algorithm enables changes in the capacity reserved for each vehicle type (moving or standing) and an optimal free flow speed, given the combination of expected flows. The street design profile, as well as the space attributed to each mode and the speed allowed to them, is calculated 15 times per day.

Figure 15. Adjusted model framework to account for space allocation and use of urban freight and passenger transport activities



Assessment indicators of model outputs

Two main types of indicators were used to assess the results of the simulation exercise: space consumption and safety-like measures. These are described in more detail below.

Space consumption indicators

Space consumption is calculated based on the mobility patterns comprised of the number of trips, their distribution among modes and trip duration resulting from the model. This approach is based on work and equations from Héran and Ravalet (2011). A detailed discussion of their components and rationale can be found in the Streets That Fit report (ITF, 2022).

The space consumption indicator incorporates four main components:

1. static space consumed when vehicles are not in motion (for example, parking, loading and unloading)
2. dynamic space consumed by vehicles while travelling
3. space used by travellers while waiting for vehicles to arrive (public transport or shared modes)
4. space used by travellers while travelling to and from public transport.

The space consumption indicator assesses two key aspects: (1) the total stock of space consumed while travelling and (2) the space efficiency per traveller and by passenger km.

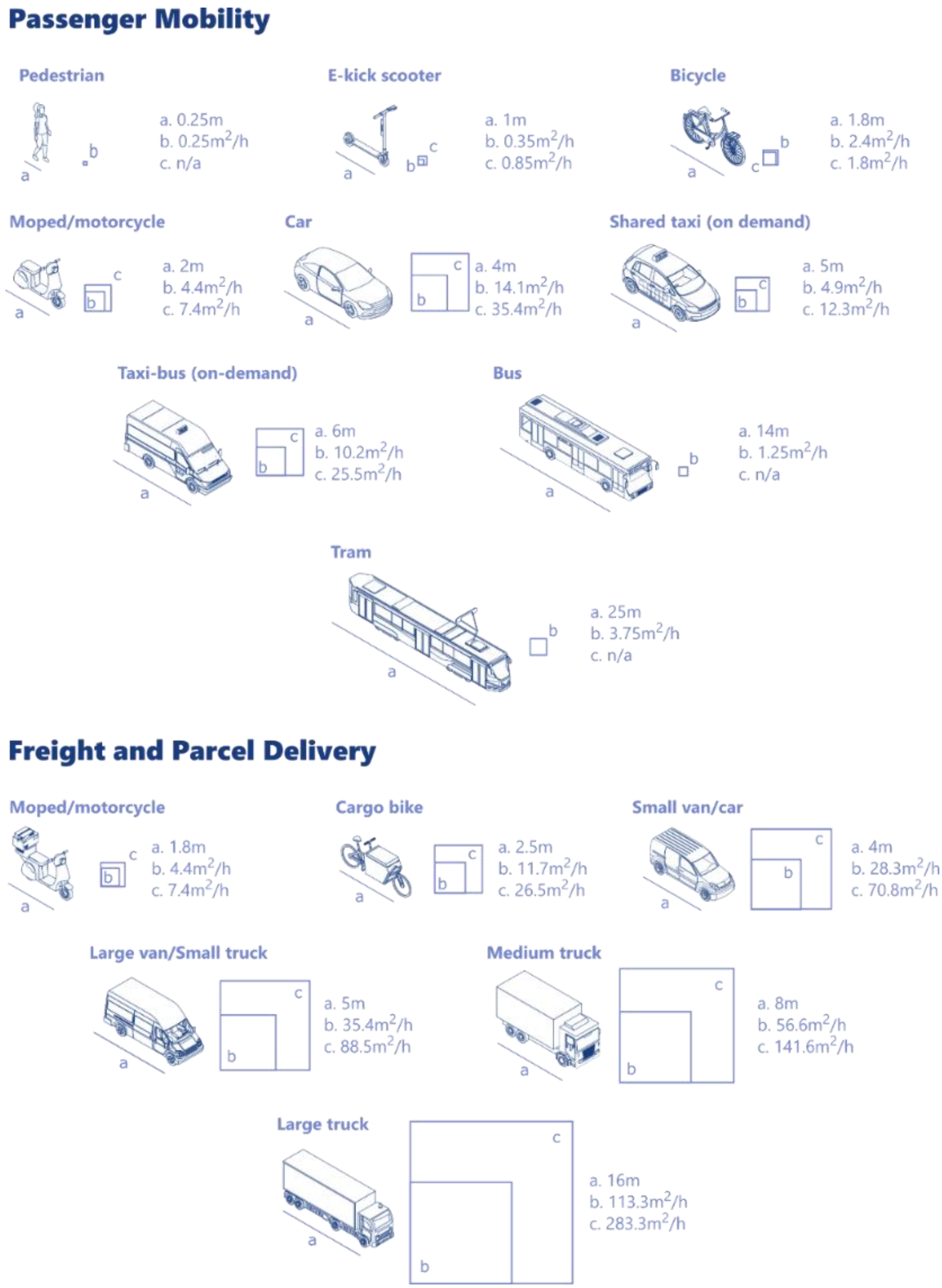
The static and dynamic consumption parameters were adapted to incorporate freight transport activities for the different vehicles used in the various scenarios. This includes the size of the vehicles and space consumed when idle in parking for on- or off-street delivery activities (Figure 15).

Proxy safety indicators

A set of new indicators reflect how safe it is to move in public space and streets. They measure the intensity of potential conflicts among different types of vehicles within the same street, especially in shared space conditions. The road conflict safety indicators were developed with five sub-components that represent the intensity and severity of conflicts between different vehicles. These are conflicts between:

1. pedestrians and freight vehicles
2. pedestrians and motorised passenger vehicles
3. pedestrians and non-motorised vehicles (such as bicycles)
4. non-motorised vehicles and freight vehicles
5. non-motorised vehicles and motorised vehicles.

Figure 16. Street space consumption parameters by mode or vehicle type



All conflicts are computed using the following equation for an interval of time t:

$$Conflict_{V_A V_{B_t}} = \sum_{i=0}^{N\ streets} V_{A_i} \cdot V_{B_i} \cdot \left(\frac{Speed_A}{Speed_B}\right)^{0.5} \cdot (1 - LS_{AB})$$

where LS_{AB} is the share of segregated movements in the street between the two vehicles. LS_{AB} is set to a maximum of 0.75 given all the intersections of friction points, although longitudinally separated.

The safety aggregated indicator is obtained by computing a log sum for each period of the day t:

$$Safety\ index_t = exp\left(\sum \ln\left(Conflict_{V_A V_{B_t}}\right)\right)^{0.25}$$

$$where\ A, B\ \forall\{\text{pedestrians, passenger motorised vehicles, non} - \text{motorised vehicles, freight vehicles}\}$$

For the total characterisation of each mobility scenario tested, a safety index score was calculated. This was derived from accumulating the median of the safety value for each 30-minute period and divided by the amount of 30-minute periods throughout the day.

A risk exposition indicator was derived for each pairwise combination of vehicle classes. It is measured by dividing the number of conflicts in a given scenario between the two vehicle classes by the number of vehicles of the most vulnerable vehicle classes.

Street performance optimisation

The simulation model developed for this report adjusts the allocation of street space to match expected demand 15 times per day. Different road classification categories were defined based on a characterisation of the Dublin road network, stemming from the work of OpenStreetMap contributors, under the Open Database License (OpenStreetMap, 2022). Rules relating to how and under what circumstances these road classes could switch were also built into the model. The linkage between road classes (and their use) and vehicle classes was roughly based on the street space classifications developed in "The Good Street" framework (Immers et al., 2016; Immers et al., 2020). The road classes used in the report are an evolution from the previous street categories available in the Streets That Fit report (ITF, 2022).

A "street performance" metric was created to measure how efficiently space is used for each street in the network. The "street performance" indicator assesses both dynamic and static space use, as well as the safety of flows that take place at the same time for a given street. The safety component of the metric refers to the probability of conflict between different vehicle types, as described in the previous section. The three components of the indicator are converted into an adimensional unit that weighs their overall combined efficiency (ITF, 2022).

Road performance values relating to capacity, speed, and traffic segregation (or lack of) were defined and used as attributes in the optimisation exercise. For each road category, the car-equivalent parking capacity was defined for every 10 metres of road length (for example, a bus stop occupies three times more space than a standard car parking space). For this study, reserved freight (un)loading capacity was designated as a share of the capacity of reserved general parking spaces for every 100 metres of road length. The values for these categories can be found in Annex C.

The simulation allows different vehicles to use different types of streets according to their dynamic in-motion characteristics. The table in Annex C displays the speed and capacity performance for each mode for a given street type if the street's initial configuration in the model, or its temporary reconfiguration, allows that mode to be used. There are two consequences to this. First, some vehicles can never occupy specific street space in the model. For instance, a car or motorised freight vehicle will never operate on steps, and a pedestrian or bicycle will never be present on a motorway. Second, the table indicates how infrastructure built for one use may handle different vehicles under a temporarily changed configuration. For example, in the model, a pedestrian zone temporarily re-designated to accept bicycle use could see up to 500 bicycles operating per hour at a maximum speed of 12 km/h. A tertiary road that is temporarily re-designated as a secondary road in the model will not see more than 800 vehicles per hour operating at a maximum speed of 40 km/h in the model. This is opposed to a "native" secondary road that can handle 1400 vehicles per hour at a maximum speed of 50 km/h. Additionally, as freight vehicles compete for curb space for deliveries, the presence of vehicles in reserved spaces, standard parking, or partially or blocking traffic is considered in the street space performance equation.

Street-type categories also act as constraints in the model regarding the geometrical changes that can be introduced to alter the original road space configuration. Each road category has a pre-defined set of other possible categories that it can be converted to based on the original geometry (see Annex C). For example, a motorway cannot become a pedestrian area in the model.

The potential street use conversion pathways discussed in this report are theoretical and help understand what efficiencies could be achieved with more dynamic adjustments of physical street space. In reality, such adjustments would have to be carefully designed and implemented so that no negative safety outcomes occur. This may limit the range of potential re-configurations that this report investigates, even under the constraints imposed in the model. In any case, such dynamic reallocation of space would require a very different road management paradigm to what exists today.

The optimisation objective function minimises space consumption when vehicles and other agents are stationary and moving. The optimisation of each street segment is solved by taking into account 19 different road typologies. It uses a "greedy optimisation" approach, where each link is optimised individually and co-ordinated with the neighbouring segments accounting for neighbourhood traffic fluidity, mode availability (access) and street geometric and functional characteristics. This allows reflection of the static and dynamic components of street space consumption. The objective function includes four main components that are converted into time:

1. **Vehicle type:** this time is weighted by flows and corrected by a factor of 2 for pedestrians and 1.5 for bicycles. This avoids overly representing cars and trucks that may present higher travel time savings by circulating at higher speeds.
2. **Parking capacity usage:** the estimated parking search time and a time penalty representing an unused spare capacity of reserved parking spaces.
3. **Freight parking behaviour:** the number of parking types multiplied by the duration of pickup/drop-off activities, with an estimated penalty for each type. This calculation addresses the location and quantity of vehicles during deliveries if a reserved (un)loading or regular space is used or if a circulation lane is blocked. It also allows vehicles to occupy space meant for other users – for instance, cycle lanes and sidewalks.
4. **Traffic safety:** the number of potential conflicts between vehicle types and their difference in free flow speeds is converted to a time-based indicator. A car-pedestrian conflict is represented by a 2-minute penalty, and other conflicts are scaled to this value.

Each road typology has a pre-defined set of compatible conversion options. Depending on whether the infrastructure is shared or not, there are different flow capacities and free flow speeds for each vehicle type. Parking capacities are assigned separately for passenger and freight vehicles (the latter requiring unloading spaces, as described earlier). Street characteristics are treated separately for motorised-based modes and vehicles (car/bus/motorcycle), pedestrians, and bicycle-based modes. In each street configuration solution, the infrastructure devoted to each of these groups can be shared, which requires lower speeds (especially for the fastest modes) or segregated. In the following section, each transport mode considered is attributed to one of these groups. Each street has an initial typology that is revised 15 times during the simulation (see Annex C). More details about the simulation architecture of the shared and passenger-free floating component and optimisation services approach can be found in (Martinez and Viegas, 2017; ITF, 2018b, 2022)

Defining freight narratives and scenarios

This work tests four different narratives of measures that address freight transport planning and management, its operations and the technologies deployed. These four narratives create ideas of potential approaches for optimising freight transport. They are actor-based and consider the potential consequences of actions taken by private actors, public authorities and freight receivers – both businesses and people. This analysis may enable differentiating the effectiveness and efficiency of optimising urban freight in various ways and accounting for their interactions.

The narratives are:

1. **Do nothing:** no measures are applied to manage and optimise freight activity.
2. **Private action:** includes measures that can be implemented voluntarily by private-sector freight operators.
3. **Public management:** authorities actively seek to reduce the space consumption of freight activities. It includes measures from the "private action" scenario, enhancing their ambition and reducing their negative impacts. It also includes new measures that public authorities could develop to optimise street space use.
4. **Combined ambition:** ambitious measures are put in place by authorities to increase their positive impact even further as a result of the support from civic society and private freight receivers. In this case, support from private freight receivers increases the implementation of potentially positive measures linked to (1) sustainable waste management and reverse logistics trends and (2) local production and 3-D printing.

These narratives encompass a level of ambition and adoption of some of the measures and policies discussed in the first section of this report to manage freight delivery times, flows, vehicles and street space use. Some of the measures discussed above, such as ground drone vehicles, could not be integrated with the existing modelling framework and were left out. The narratives are based on an "optimistic" approach that assesses all actors' potential to combine space-optimising actions. However, the feasibility and impacts of the scenario implementation depend on all actors' real-life needs and experiences. Further work is needed to contrast results with real-life examples.

Table 2. The level of implementation of each measure and policy in the tested scenarios

Measures	Do nothing	Private action	Public management	Combined ambition
Consolidation centres				
Consolidation of freight flows				
Parcel pickup points				
Integrating passenger and freight flows (private individuals doing freight transport)				
Information and asset sharing				
Fleet electrification				
Mobile warehouses				
Construction and material site-sharing				
Off-passenger peak-hour deliveries				
Click-and-collect systems in stores				
Optimised waste logistics and management				
Freight/parcel delivery/pickup app-based platform				
Three-wheelers/cargo bikes				
Urban vehicle access restrictions – temporal access restrictions for heavy-duty vehicles				
Urban vehicle access restrictions – low-emission zone				
Urban vehicle access restrictions – congestion area				
Curb management – reservable on-street loading/unloading bays				
Curb management – increased number of loading and unloading bays				
Integrating passenger and freight flows (combination of freight flows with public transport)				
Sustainable waste management and reverse logistics trends				
Local production and 3-D printing				

Strong intervention to reduce potential negative externalities of measure	Small intervention to reduce potential negative externalities	No implementation	Light implementation of potentially positive measure	Medium implementation of potentially positive measure	Strong implementation of potentially positive measure	Stronger implementation of potentially positive measure

Table 2 shows the different measures and policies tested and their level of implementation intensity in each narrative.

For each narrative, three policy scenarios are tested. The first presents a situation where, on top of the measures included in the narrative, policies further increase street space performance through higher passenger demand management and space optimisation measures. The second combines street space performance optimisation with measures that increase the uptake of shared mobility services. The third presents a situation where no measures are added to those in the narratives. This strategy allows for isolating and assessing the impacts of these different components. Table 3 presents the terminology of the narratives and their related scenarios following the implementation of added measures. The description of the policies for road optimisation and shared mobility stem from the Streets that Fit report (ITF, 2022).

Table 3. Classification of the tested scenarios

Measures	Classification	Do nothing narrative	Private action narrative	Public management narrative	Combined ambition narrative
Before any optimisation	Scenario with -	Do nothing -	Private action -	Public management -	Combined ambition -
With road optimisation	Scenario with *	Do nothing *	Private action *	Public management *	Combined ambition *
With combined shared mobility and optimisation measures	Scenario with *+	Do nothing *+	Private action *+	Public management *+	Combined ambition *+

Freight demand generation

Freight demand used in the simulation comes from the aggregated ITF Urban Freight Model developed for all European Functional Urban Areas (FUAs). For each urban area, the model generates freight activity classified in 12 commodity categories (1 to 12 in Table A2 in Annex A), six distance classes (less than 1 km, 1 to 2.5 km, 2.5 to 5 km, 5 to 10 km, 10 to 20 km and more than 20 km) and 12 vehicle typologies (ranging from freight bike to the largest high-capacity truck – 1 to 12 in Table A1 in Annex A). Detailed documentation about this model's calibration, validation and use can be found in (ITF, 2020d).

The model's origin-destination (OD) freight matrix considers the existing freight facilities in Dublin and the city's detailed land use specifications. This level of detail was available from previous studies in the city (ITF, 2018b) and increased the model's accuracy. Additionally, some features were added to enable the modelling of the selected scenarios. These include increased vehicle availability, local lockers for parcel delivery and click-and-collect pickup. For this purpose, the shared mobility centres already designed in the simulation in previous studies were also designated as parcel pickup locations. There are 344 of these for the whole study area.

The model was enhanced with a delivery generation model for the study area based on freight delivery data from London to capture current food and grocery delivery trends (Allen et al., 2021). This was operationalised based on the land use density dataset. It also considers that each household has a daily delivery generation rate that differentiates between the urban core and the suburban area, with the suburban area having a 50% reduction in generation rates. These two commodities – food and groceries – were added to the model with a daily rate of 0.034 for food delivery and 0.018 for groceries delivery. These commodities also have predesignated freight vehicles that could be used (see Annex A).

Passenger modal alternatives and freight vehicles

The simulation covers passenger and freight activity within a medium size European metropolitan area. The passenger modal evolution was already explored in a previous report (ITF, 2022) and entailed 19 different travel modes. These were categorised according to several variables (see Annex B). From a model analysis perspective, modal alternatives were grouped into four categories: shared non-motorised and micromobility, private motorised transport, public transport and shared transport. Freight operations with eight different available vehicles were added to these modal alternatives. For more details on the included modes, please refer to Annex B.

Space use impacts of freight interventions

The modelling undertaken for this report resulted in several groups of scenario narratives that implement a set of freight planning and operations. For each narrative, the modelling addresses the uptake of new forms of shared transport solutions – vehicles or services that increase vehicle load factors – and street performance optimisation.

Isolating freight activity from people's movement is challenging as they affect each other. Therefore, the modelling approach sought to track and measure freight-related mobility and its interactions with and contribution to overall urban mobility outcomes. In the analysis of model outputs, findings were generally grouped within the same family of scenarios when comparing the impact of the different freight interventions. It is noted, when relevant, the co-existence of measures targeted at passengers and the interaction of these measures with freight activity.

The impacts of introducing freight and logistics measures are first assessed in terms of each scenario's volume of activity. This is followed by a description of the modal impacts accompanying these changes and the subsequent use of space. Space consumption metrics include the total stock of space consumed while travelling and the space efficiency per delivery and by tonne-kilometres travelled. Space metrics include an analysis of the narrative and freight policies on improving space consumption within the freight sector. This involves understanding how it interacts with passenger activity and the relative scale of the impacts from the two mobility segments. The analysis also quantifies the environmental performance of scenarios accounting for CO_2 and local pollutant emissions based on previous ITF work (ITF, 2021b).

Public action and consumer awareness can optimise sustainable freight activity

Table 4 outlines the change in vehicle activity composition and freight volume by freight policy scenario. The results indicate a shift towards lighter vehicles and efforts to improve load factors. The most significant shift concerns replacing light commercial vehicles, such as vans, with cargo bikes (when range constraints permit). Moreover, imposing urban access restrictions for heavy trucks and other large vehicles results in a shift from these vehicles to medium trucks.

Increasing load factors and replacing last-mile trips significantly reduces overall trip volumes by up to 32% in the "combined ambition" narrative as compared to the "do nothing" one. The impacts of the deployed freight management measures are less significant but still considerable (a 21% reduction in "combined ambition" versus "do nothing"). This is because, in the simulation, the shift from large to smaller vehicles is offset by an increase in vehicle trips. Freight activity, measured in tonne-kilometres, is lower still at -19% in the "combined ambition" versus the "do nothing" narratives.

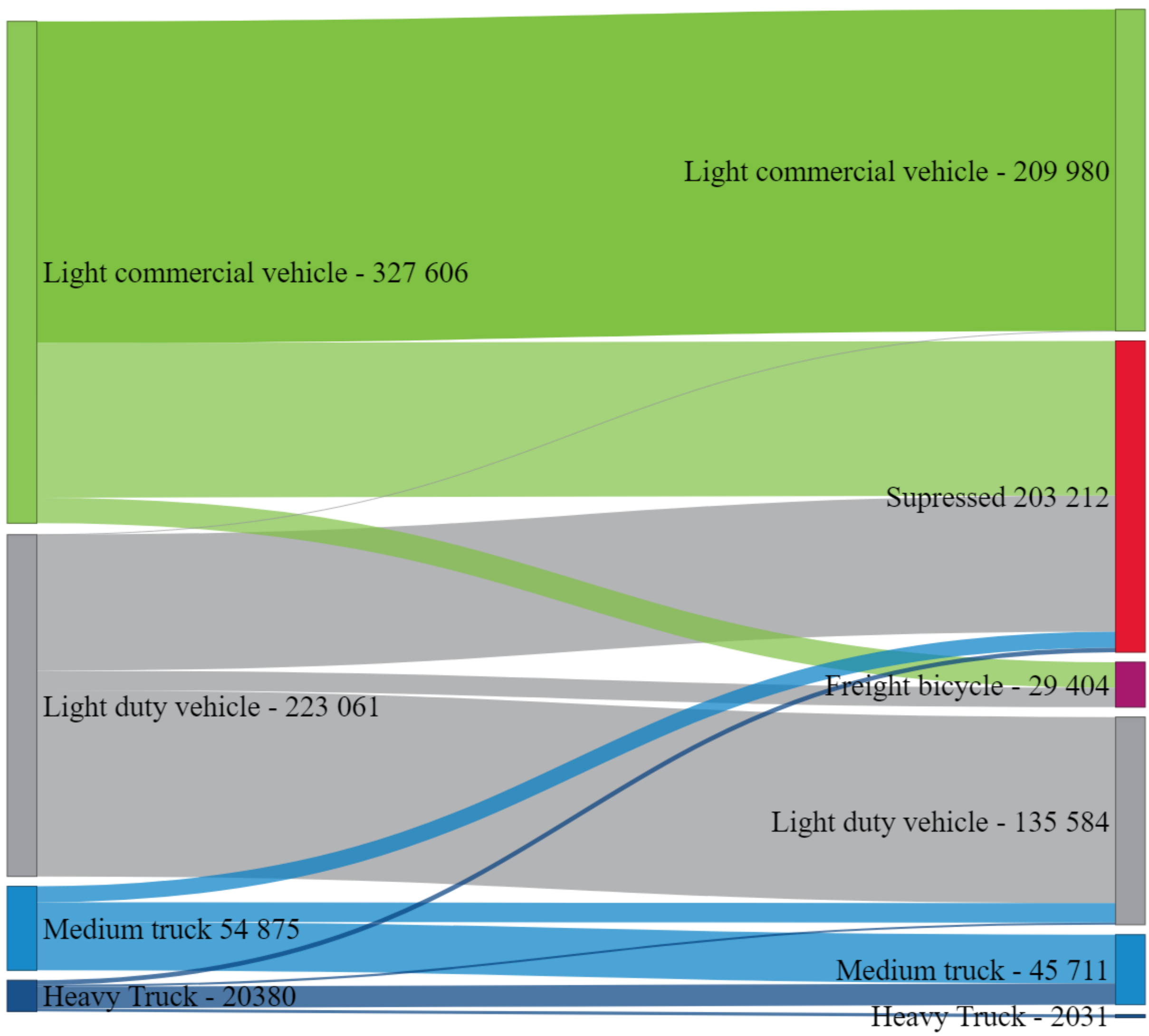
Table 4. Change in vehicle activity composition and freight volume by freight policy narrative

Indicator	Mode/Narratives	Do nothing	Private action	Public management	Combined ambition
Trips (% by vehicle type)	Freight bicycle	0%	4%	7%	7%
	Heavy truck	3%	4%	0%	0%
	Light commercial vehicle	52%	50%	49%	50%
	Light duty vehicle	36%	33%	31%	32%
	Medium truck	9%	9%	13%	11%
	Variation from "do nothing"	-	**-11%**	**-22%**	**-32%**
Weight (tonnes) (% by vehicle type)	Freight bicycle	0%	0%	0%	0%
	Heavy truck	36%	36%	7%	8%
	Light commercial vehicle	3%	2%	2%	2%
	Light duty vehicle	14%	14%	15%	21%
	Medium truck	48%	48%	75%	69%
	Variation from "do nothing"	-	**-4%**	**-14%**	**-21%**
Activity (tonne-kilometres) (% by vehicle type)	Freight bicycle	0%	0%	0%	0%
	Heavy truck	67%	67%	22%	23%
	Light commercial vehicle	1%	1%	1%	0%
	Light duty vehicle	7%	6%	7%	9%
	Medium truck	26%	26%	70%	68%
	Variation from "do nothing"	-	**-2%**	**-12%**	**-19%**

The measures in the "combined ambition" narrative promote parcel consolidation. As Figure 17 and Figure 18 reflect, the reduction in overall trips is higher than the reduction in tonnes transported, meaning that vehicles transport higher loads than under the "do nothing" narrative. This is best seen for trips and loads transported by light-duty vehicles. Almost half of these trips are eliminated following the measure. But, only around a quarter of transported loads are suppressed. Likewise, a significant share of heavy trucks is replaced by medium trucks or lighter vehicles, especially in central areas of the city. This results in more, but smaller, vehicles circulating. Importantly, those smaller vehicles can be more easily replaced by cleaner or zero-emission models.

Importantly, around 19% of light motorised vehicle deliveries, including tonnes transported by both light-duty and light commercial vehicles, shift to cargo bikes. This represents 2% of the total weight transported by light-duty and commercial vehicles. This shift concerns mostly shorter-range parcels and other small deliveries.

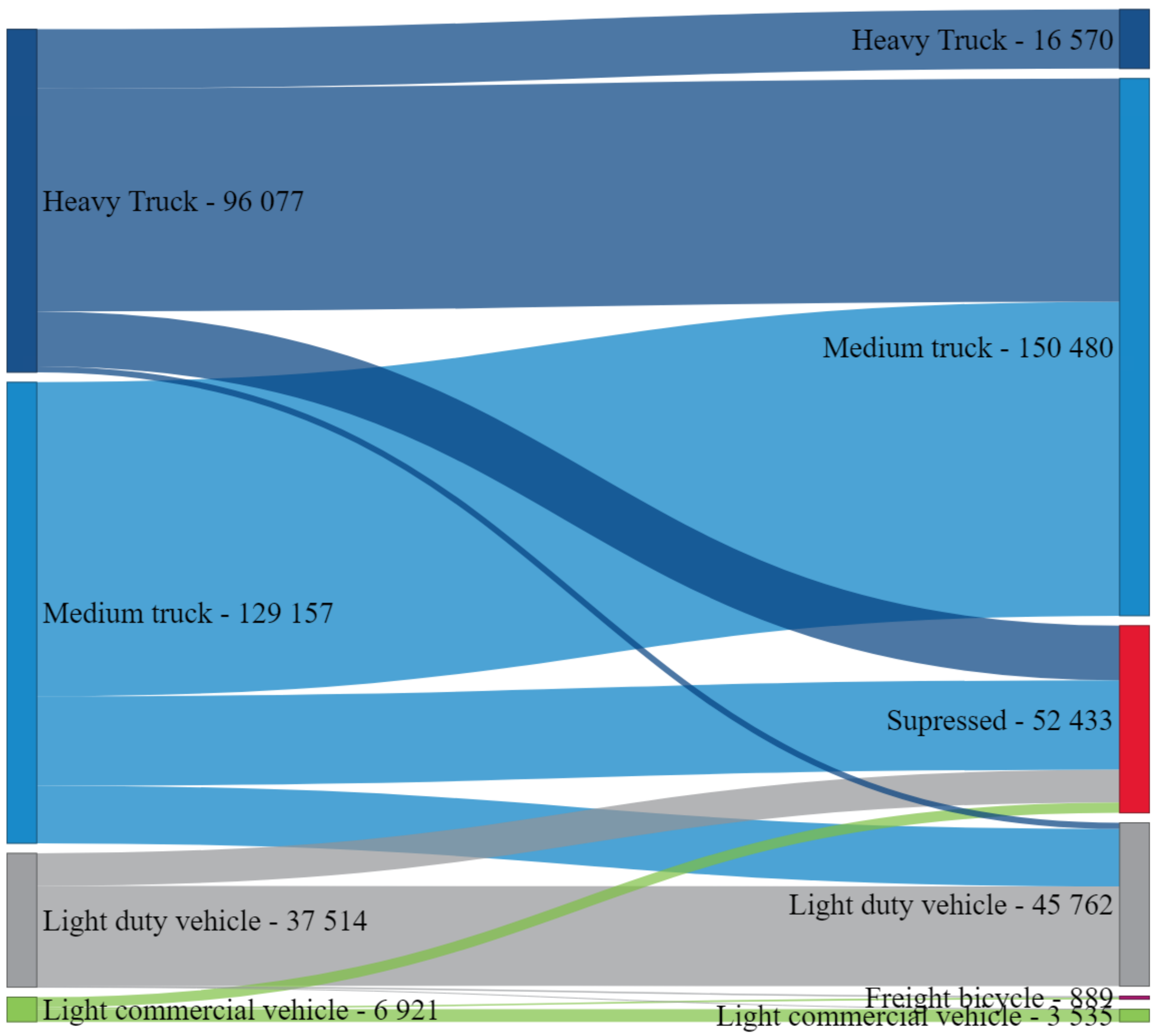
Figure 17. Vehicle switch in number of trips ("do nothing" vs "combined ambition" narrative)



Urban freight policies can reduce overall space consumption

All mobility (passenger and freight) in the baseline scenario ("do nothing -") consumed 565 km^2 for a modelled day. In the most ambitious scenario ("combined ambition *+") (see Table 5), space consumption could be reduced by 24%. For reference, the ITF's Streets that Fit report (ITF, 2022) implemented the limited and demand-responsive re-allocation of street space and broadened the number of new mobility options for travellers, reducing the overall consumption of space by around 19%.

Figure 18. Vehicle switch in transported tonnes ("do nothing" vs "combined ambition" narrative)



Regarding freight, the "combined ambition *+" scenario results in a 57% reduction of the space consumed by freight, largely due to optimised logistics and better information, but also by more conscious behaviour changes on the part of citizens to reduce the traffic and space consumption impacts of their deliveries.

In "combined ambition *+", private cars consume the most space for passenger trips (see Table 5), especially due to parking. In contrast, space consumption for freight is less skewed among motorised modes except for a steep drop in heavy truck use (replaced by medium trucks or even lighter vehicles, as shown in Figure 20).

Table 5. Space Consumption by mode and vehicle type ("combined ambition *+" scenario)

	Mode/Vehicle	Dynamic (%)	Static (%)	Average space consumed (m^2/trip)	Area ($sqkm^2$)	Δ from "do nothing -"
Passenger	Private motorised transport	4%	96%	190.25	387.82	-28%
	Public transport	98%	2%	1.66	1.54	-13%
	Shared transport	72%	28%	23.94	30.81	403%
	Private non-motorised + micromobility	31%	69%	2.53	4.44	35%
	Passenger total	**10%**	**90%**	**70.66**	**424.62**	**-23%**
Freight	Light duty vehicle	22%	78%	22.66	2.83	-57%
	Medium truck	20%	80%	47.32	2.27	-32%
	Heavy truck	42%	58%	162.24	0.27	-90%
	Freight bicycle	100%	0%	2.05	0.06	67%
	Light commercial vehicle	25%	75%	14.88	1.76	-61%
	Food and groceries deliveries	73%	27%	2.69	0.24	-35%
	Shared transport for freight	100%	0%	16.26	0.03	9%
	Freight total	**25%**	**75%**	**18.16**	**7.46**	**-57%**

Figure 19 shows the tested policy narratives' impacts on freight street space use. As mentioned previously, for each narrative, the results highlight impacts with no network performance optimisation (-), those with optimisation (*) and those with optimisation and shared services and vehicles (*+). Doing so reflects the additional improvement in space consumption in each narrative by street performance optimisation and shared mobility. The results evidence the strong role of the policy narratives in improving space consumption and how improving road performance and adjusting the street to demand throughout the day have significant benefits. Shared mobility also provides benefits, especially by reducing the conflict of parked private vehicles with freight vehicles and also by making extra freight delivery capacity available.

The basic implementation of the "combined ambition" narrative, with no street optimisation and shared services and vehicles, has similar results as "public management". However, the most ambitious configuration of that narrative, "combined ambition *+", significantly decreases space consumption when compared to "public management *+". This effect results from the types of vehicles deployed, particularly the shift from larger to smaller vehicles with higher load factors.

The re-timing of parcel delivery does not seem to significantly impact the overall volume of space consumed (a decrease of approximately 2%). The most significant impacts that stem from the dynamic re-allocation of road space are linked to speed reduction and better co-existence with slower modes.

Figure 19. Evolution of street space consumption with scenarios within the tested freight narratives

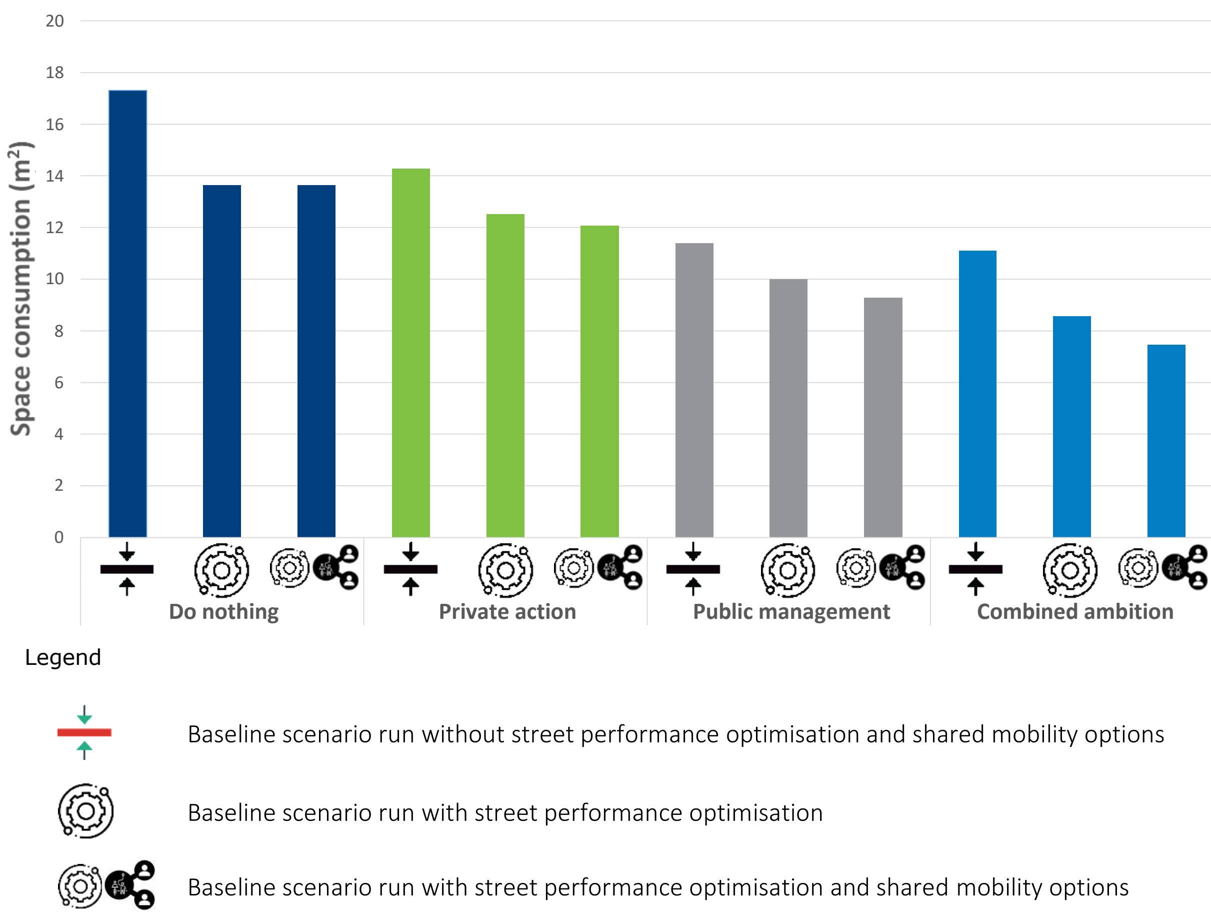
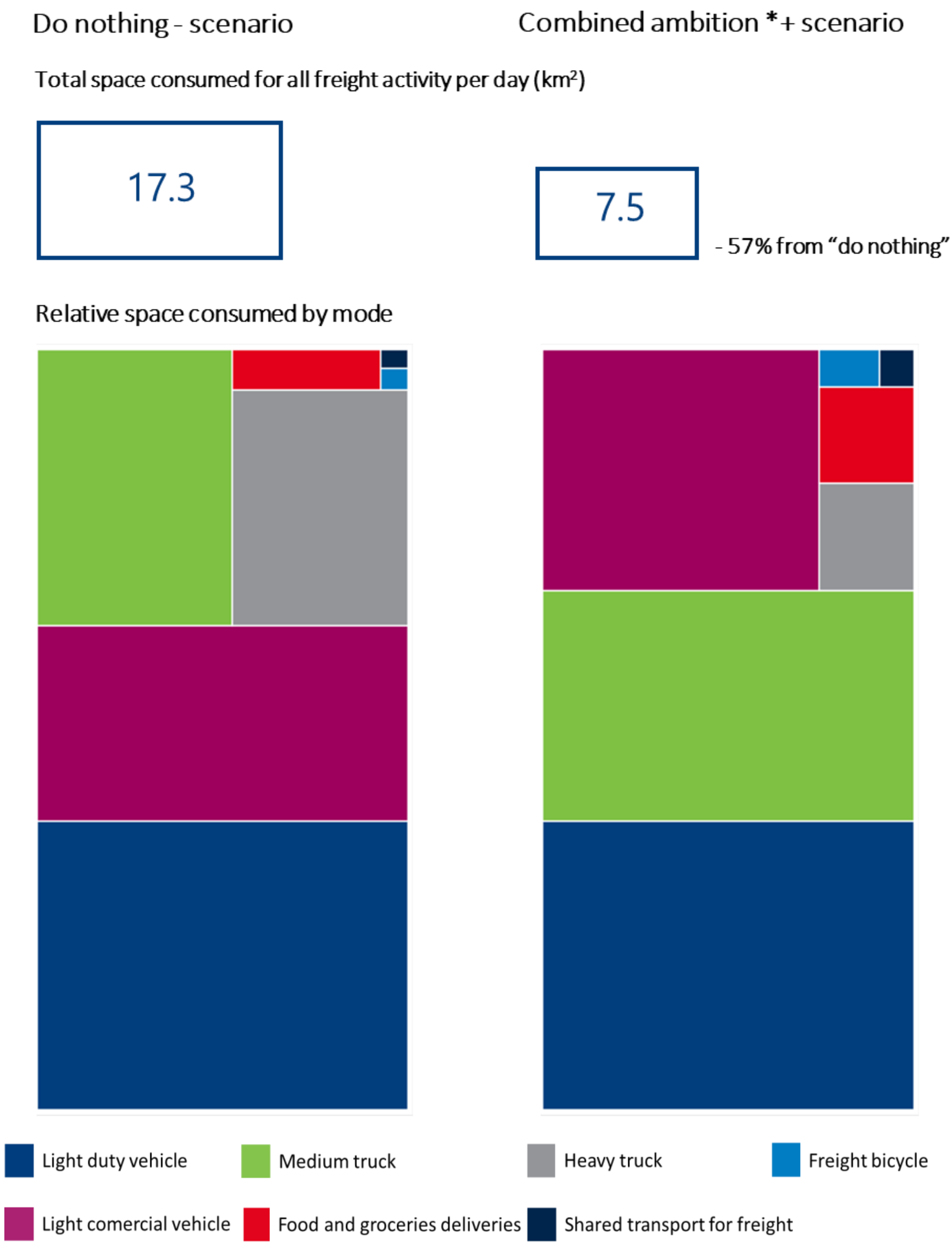


Figure 20 shows the contribution of each vehicle class to total space consumption from freight activity for the “do nothing” – and “combined ambition *+” scenarios. The latter reduces the overall space consumed by urban goods distribution and delivery by 57%.

Figure 20. Total and share of space consumed by mode per day



Street performance analysis

Street performance was evaluated for all 12 scenarios (refer to the previous chapter for a description of the street performance indicator). Table 6 shows a small variation in street performance resulting from implementing the different freight narratives. One of the lessons of this analysis is that improving street performance also improves safety and sustainability. Despite the increase in smaller and slower vehicles, improving street performance delivers spatial efficiency. The use of these vehicles, if unmanaged, might otherwise increase space consumption due to their number, diversity and slow speed.

The implementation of dynamic street space optimisation and the broader uptake of shared mobility services combined with less intensive car use generates significant improvements in the street performance indicator.

Table 6. Variation of the whole-day street performance indicator compared to the “do nothing -” scenario

Scenario	Space consumption savings linked to variations in street performance indicator (%)
Do nothing -	0%
Private action -	0%
Public management -	1%
Combined ambition -	1%
Do nothing *	8%
Private action *	9%
Public management *	8%
Combined ambition -	8%
Do nothing *+	15%
Private action *+	16%
Public management *+	15%
Combined ambition *+	15%

The impacts relating to how, where and for how long delivery vehicles stop to (un)load are important for measuring street performance. Table 7 shows that the different freight transport interventions included in the different scenarios help to reduce double parking by offering suitable alternative (un)loading options or reducing the frequency of trips and deliveries through improved load factors.

The dynamic reallocation of street space also helps to improve freight-related parking performance. Yet, as freight is a smaller component of overall transport volume in the city, optimising street space allocation for freight will only have limited impacts on overall city traffic.

Table 7. Impact on freight vehicle parking for different scenarios

Scenario	Share of time parked in reserved freight spaces	Change in overall time freight vehicles are double parked	Change in overall time freight vehicles are double parked during peak periods
Do nothing -	37%	0%	0%
Private action -	42%	-8%	-28%
Public management -	45%	-29%	-96%
Combined ambition -	45%	-25%	-96%
Do nothing *+	41%	4%	5%
Private action *+	42%	-3%	-28%
Public management *+	45%	-24%	-96%
Combined ambition *+	45%	-26%	-96%

Safety considerations

Analysing the safety indicators developed for this exercise shows a sharp decrease in potentially dangerous conflicts. This decrease stems from a combination of factors. Principally, it is through a safer coexistence of modes on the same infrastructure due to lower travel speeds or by reducing exposure to risk due to less travel by larger and heavier vehicles. Table 8 shows the overall safety indicator developed for this work that considers the volume of conflicts and concurrent flows of different vehicles in the same spaces. The results show that reducing freight traffic, especially by heavy trucks in areas with many pedestrians and cyclists, improves overall safety performance. Another positive safety outcome stems from pre-booking (un)loading bays and restricting freight movements for some vehicles or commodities during peak periods.

Table 8. Overall safety indicator of the “combined ambition” scenarios

Scenario	Change in overall safety compared to “do nothing -” (%)	Change in overall safety standard deviation compared to “do nothing -” (%)
Combined ambition -	1%	3%
Combined ambition *	-9%	6%
Combined ambition *+	-15%	7%

Table 9 presents the risk factor by pairs of vehicles, showing a sharp decrease in conflicts that involve freight vehicles. For example, in “do nothing –”, one pedestrian out of 200 may have a conflict with a freight vehicle or car, while the risk of bicycle riders having a conflict with a car is twice as high. During peak factors, all these average daily factors are magnified at least by 30% due to traffic density.

The shift to smaller and lighter freight vehicles in the more ambitious scenarios reduces freight-related conflicts, especially in the city centre, where cyclists and pedestrians are concentrated, and freight movements are more intense. Analysis of the modelling outputs indicates that optimising street performance reduces the risk indicator in peak periods. The contribution of freight-specific policies or the uptake of shared mobility services does not lead to significant variation of the risk indicator.

Table 9. Risk exposure indicator for vulnerable road users by scenario
(daily average by crash opponent pair)

Scenario	Pedestrians - freight	Pedestrians - cars	Pedestrians - bicycles	Bicycles - cars	Bicycles - freight	Peak factor
Do nothing -	0.52%	0.52%	0.20%	1.03%	0.28%	1.45
Private action -	0.53%	0.52%	0.19%	1.03%	0.23%	1.46
Public management -	0.43%	0.52%	0.19%	1.03%	0.14%	1.45
Combined ambition -	0.43%	0.52%	0.19%	1.03%	0.13%	1.46
Do nothing *	0.52%	0.52%	0.20%	1.03%	0.28%	1.33
Private action *	0.53%	0.52%	0.19%	1.03%	0.23%	1.34
Public management *	0.43%	0.52%	0.19%	1.03%	0.14%	1.34
Combined ambition *	0.43%	0.52%	0.19%	1.03%	0.13%	1.34
Do nothing *+	0.40%	0.37%	0.13%	0.51%	0.19%	1.36
Private action *+	0.39%	0.38%	0.13%	0.49%	0.15%	1.35
Public management *+	0.31%	0.38%	0.13%	0.49%	0.10%	1.36
Combined ambition *+	0.31%	0.38%	0.13%	0.50%	0.10%	1.35

Operational and environmental considerations

When evaluating different scenarios, it is important to consider the knock-on environmental impacts of measures like improving vehicle load factors through consolidation, implementing more efficient demand management, reducing empty runs and choosing less polluting vehicles.

Operational performance

The operational improvements introduced in the different scenarios are significant. Table 10 presents the load factors by weight for freight vehicles used in the different narratives compared to “do nothing”. The increase in loads is significant, except for light commercial vehicles, whose use is constrained for shipments not easily carried by other vehicles. Yet, these vehicles would become fully electric in most scenarios, reducing the environmental burden of the decrease in load factors. Out of all measures analysed, those led by the public sector seem to have the greatest impact on incentivising increased load factors.

Table 10. Load factor variation by narrative and freight vehicle type compared to “do nothing” (weight in tonnes, variation in %)

Mode	Do nothing	Private action	Public management	Combined ambition
Light duty vehicle	0.168	+18%	+39%	+44%
Medium truck	2.361	+1%	+25%	+24%
Heavy truck	4.778	+0%	+68%	+65%
Freight delivery bicycle	0.001	+100%	+100%	+100%
Light commercial vehicle	0.029	0%	-7%	-10%

The modelling also explored using shared taxis to deliver parcels when these vehicles are available and close to the pickup point. The shared taxi keeps the parcel in the car as it carries out its service, waiting to deliver the parcel only when no longer occupied with passengers. Constraining parcel delivery to times of shared taxi inactivity reduces the potential impact of this measure – in the “public management” and “combined ambition” narratives, this measure only affects 0.5% of overall freight weight demand.

The development of neighbourhood pickup points or lockers is quite effective in reducing vehicle activity for parcels. Table 11 presents the result for the different narratives showing that more than 20% of parcels are collected at designated pickup facilities. In the modelling, the share of parcels collected from pickup facilities decreases in the two publicly-led narratives compared to “private action”. This results from two factors. First, consolidating shipments in sortation centres increases the number of goods packed in any given parcel, which means that fewer parcels must be retrieved at pickup facilities for the same number of goods ordered. Second, interestingly enough, under the two publically-led narratives, pickup points go in hand with increased vehicle load consolidation. This consolidation makes it so it is better for carriers to deliver a percentage of parcels with fewer, yet better-loaded, vehicles. This can be a positive outcome logistics-wise: carriers can deliver in the most optimal way possible by combining the two alternatives, people have the alternative of flexibility and fewer vehicles fill cities’ streets.

Table 11. Parcels collected at pickup parcels facilities (%)

Do nothing	Private action	Public management	Combined ambition
0	25	21	21

Environmental performance

The environmental performance of each family of scenarios was assessed with and without dynamic re-allocation of street space (represented by a *) and the uptake of shared mobility services (represented by a +). Table 12 presents the results for the different narratives tested in this report.

While the freight sector is not the main contributor to emissions produced by urban transport activity, the results show a significant drop resulting from the freight demand management and logistic measures tested. When coupled with more ambitious truck and van fleet electrification, these measures contribute to an approximately 30% reduction in freight-related CO_2 emissions and a 10% reduction in overall CO_2 transport-related emissions.

When looking at local pollutants, the two public action scenarios significantly decrease all pollutants compared to “private action”. Reductions are disproportionally higher than reductions in CO_2 emissions.

Table 12. Environmental impacts and travel volumes by mode/vehicle by narrative

Narrative	Variable	Passenger	Freight vehicle						Summary		
			FB	FGDV	LCV	LDV	MDV	HDV	Total	Variation within freight	Variation from baseline
Do nothing	CO_2 TTW (million tonnes)	2 660.6	-	3.0	103.8	137.7	114.1	145.5	3 164.6	-	-
	CO_2 WTT (million tonnes)	676.2	-	1.2	80.5	28.8	23.9	30.4	841.0	-	-
	NO_x (thousand tonnes)	5 317.4	-	14.3	185.1	314.1	165.1	234.2	6 230.2	-	-
	SO4 (thousand tonnes)	26.6	-	-	1.0	1.4	0.7	1.0	30.8	-	-
	PM25 (thousand tonnes)	127.9	-	0.3	4.8	8.3	4.4	6.2	151.7	-	-
	VKM (millions)	20 706.4	-	176.8	611.3	710.2	181.9	172.0	22 558.6	-	-
Private action	CO_2 TTW (million tonnes)	2 660.6	-	3.0	86.3	109.4	110.7	141.8	3 111.7	-10%	-2%
	CO_2 WTT (million tonnes)	676.2	-	1.2	66.9	23.4	23.2	29.6	820.6	-12%	-2%
	NO_x (thousand tonnes)	5 317.4	-	14.3	153.9	249.5	160.2	228.3	6 123.6	-12%	-2%
	SO4 (thousand tonnes)	26.6	-	-	0.8	1.1	0.7	1.0	30.3	-12%	-2%
	PM25 (thousand tonnes)	127.9	-	0.3	4.0	6.6	4.2	6.0	149.0	-12%	-2%
	VKM (millions)	20 706.4	36.5	176.3	508.1	612.2	176.5	167.6	22 383.6	-9%	-1%
Public management	CO_2 TTW (million tonnes)	2 660.6	-	3.0	68.9	75.5	167.4	36.1	3 011.4	-30%	-5%
	CO_2 WTT (million tonnes)	676.2	-	1.2	53.5	17.2	35.0	7.5	790.6	-31%	-6%
	NO_x (thousand tonnes)	5 317.4	-	14.3	122.9	172.2	242.2	58.1	5 927.2	-33%	-5%
	SO4 (thousand tonnes)	26.6	-	-	-	-	-	-	26.6	-100%	-13%
	PM25 (thousand tonnes)	127.9	-	0.3	3.2	4.5	6.4	1.5	143.8	-33%	-5%
	VKM (millions)	20 706.4	61.2	176.5	405.9	511.0	266.9	42.6	22 170.6	-21%	-2%

Combined ambition	CO_2 TTW (million tonnes)	2 660.6	-	1.4	35.4	33.6	97.8	20.6	2 849.3	-63%	-10%
	CO_2 WTT (million tonnes)	676.2	-	0.5	14.8	14.8	24.0	4.7	735.0	-64%	-13%
	NO_x (thousand tonnes)	5 317.4	-	5.7	44.1	53.6	101.9	-	5 522.8	-78%	-11%
	SO4 (thousand tonnes)	26.6	-	-	-	-	-	-	26.6	-100%	-13%
	PM25 (thousand tonnes)	127.9	-	0.1	0.6	0.6	1.1	-	130.2	-90%	-14%
	VKM (millions)	20 706.4	49.9	167.2	328.4	420.0	206.3	32.0	21 910.1	-35%	-3%

Conclusions

This report has shed light on the urban freight space race: the challenge of understanding, channelling and harnessing the ways freight activities affect public space use in cities. Successfully addressing this challenge can improve the liveability of cities. Failing to do so could contribute to eroding the benefits of living in urban areas.

The study has shown that private freight carriers, receivers, public authorities and the general public have a role to play in sustainably addressing this challenge. All stakeholders can, in one way or another, influence the time at which deliveries take place, the street and urban space these activities require, the vehicles used for them and the intensity of freight flows. Collaboration between all relevant stakeholders will be essential so that measures can improve liveability in cities, as well as operational efficiencies. Otherwise, conflicting actions could have negative impacts, such as higher congestion and road safety concerns. Public authorities must embrace the key role of implementing measures and managing metropolitan-wide collaboration for more sustainable and space-optimised freight transport operations.

Public authorities will need to manage urban street space – and curb space in particular – while considering the needs of both passenger and freight transport users. Authorities will need to further engage with actors in urban logistics to understand their business models and use cases and monitor developments in the field. This understanding can inform how public authorities craft policies, including infrastructure development, to support sustainable urban distribution. Providing cargo loading and unloading spaces in areas with high freight demand and separated parking spaces for cargo bikes and electric vehicles are some ideas to support better use of urban space for freight activities. Allocating these and other street spaces dynamically by changing each street's use throughout the day to fit different actors' needs can optimise freight and passenger street space use – delivering benefits for all. In all cases, authorities must look at how passengers and freight actors use curb and street space to reduce tensions, such as road crashes, as much as possible.

The findings also highlight the value of extending urban access restrictions while considering freight actors' business cases and behaviour. Access restrictions can support fleet change towards less space-intensive vehicles and modes. In some instances, they can also reduce the volume of freight movements by fostering higher load factors – although this is not always the case. Access restrictions, especially time-based ones, must account for the needs of freight carriers and receivers to promote sustainable change. Otherwise, they could unwillingly bring economic losses for carriers and increase travelled distances and congestion for all city inhabitants.

Effective policies will require more data to better monitor how freight moves in cities. This is especially the case in enabling the dynamic allocation of street space. Data requirements include information on when and which vehicles move, which type of goods they carry, when and how they (un)load, and how they interact with other uses of street space. Data is also required from freight receivers – for example, knowing when stores receive their goods and the available space they have will improve public authorities' ability to plan for last-mile deliveries. Partnerships with both freight carriers and receivers will be essential for this. Fundamentally, public authorities will have to find ways to monitor the complex and rapidly evolving urban freight ecosystem. Establishing urban freight and logistics observatories are a low-regret way to ensure that authorities are prepared for evolutions in this sector.

Finally, more research is necessary to understand emerging topics relevant to urban logistics. One area of future work would be to better understand the role of measures impacting the last “50 feet” or 15 meters of deliveries. These include actions for improving dwelling times within logistics facilities and at destinations. More research could also explain the space use impacts linked to logistics operational changes related to fleet electrification of freight carriers. A final area of attention is the space impacts of click-and-collect practices, return logistics and emerging innovations such as drones or 3-D printing.

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Annex A. Freight matrix analysis

Table A1 presents the freight vehicles explored in the simulation (either in the baseline or no intervention scenarios) for freight delivery for all the commodities. Some vehicles were not used in the baseline narrative. The table also presents the estimated share of each vehicle type in overall activity from the default scenario to understand the current relevance of each vehicle in the urban freight operation.

Table A1. Vehicle classes used in the model

Code	Freight vehicles	Load capacity (tons)	VKM baseline scenario (%)
1	Van	1.500	38%
2	Medium Freight Truck	15.000	8%
3	Heavy Freight Truck	40.000	13%
8	Van EV	1.500	0%
9	Freight bike	0.125	0%
10	Light commercial vehicle	0.200	32%
11	Delivery bicycle	0.025	5%
12	Delivery scooter	0.050	4%

Table A2 presents the different commodities, how their deliveries are currently being done and how much of the total freight activity they constitute. It highlights the different vehicle codes shown in Table 5 to understand how the delivery process of different goods is currently organised, given their weight and volume characteristics. Climate-controlled goods appear to be the largest commodity in urban freight activity, followed by transport equipment (for example, vehicles or their components) and manufactured goods. Parcels, though not among the largest commodities, are growing more strongly, represent the largest share in vehicle activity, and operate in smaller vehicles (61% of all vehicle-km).

Table A2. Commodity classes used in the model

Code	Commodities	Vehicles used in baseline (% of TKM)	TKM baseline scenario (%)	VKM baseline scenario (%)
1	Climate-controlled goods	1 (46%), 2 (44%), 3 (4%), 10 (6%)	28%	11%
2	Non-fresh food	1 (50%), 2 (41%), 3 (3%), 10 (5%)	1%	0%
3	Manufactured goods	1 (17%), 2 (69%), 3 (9%), 10 (5%)	17%	4%
4	Construction	1 (19%), 2 (69%), 3 (7%), 10 (5%)	2%	1%
5	Raw materials	1 (16%), 2 (26%), 3 (54%), 10 (5%)	1%	0%
6	Paper and wood	1 (18%), 2 (69%), 3 (9%), 10 (5%)	2%	0%
7	Chemicals	1 (22%), 2 (66%), 3 (8%), 10 (4%)	8%	2%
8	Waste	1 (21%), 2 (67%), 3 (8%), 10 (5%)	9%	3%
9	Transportation equipment	1 (17%), 2 (26%), 3 (53%), 10 (4%)	28%	8%
10	Parcels	1 (45%), 10 (55%)	3%	61%
11	Food delivery	11 (94%), 12 (6%)	0%	4%
12	Groceries delivery	10 (5%), 11 (30%), 12 (64%)	0%	5%

The activity of the different commodities and their relevance in terms of trips or weight are presented in Figure A1 and Figure A2. The results show that while parcels concentrate most of the trips throughout the day, their weight contribution is quite limited. This indicates that it is the commodity that is using more resources and is less optimised in terms of activity and externalities.

Figure A1. Hourly freight demand (trips or deliveries)

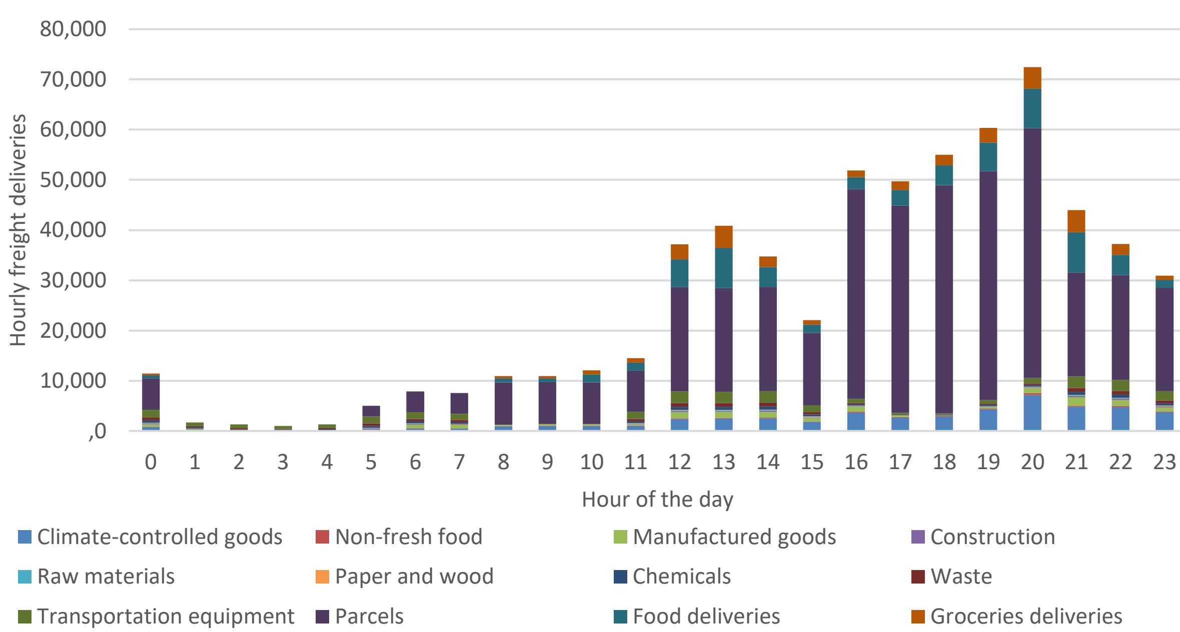
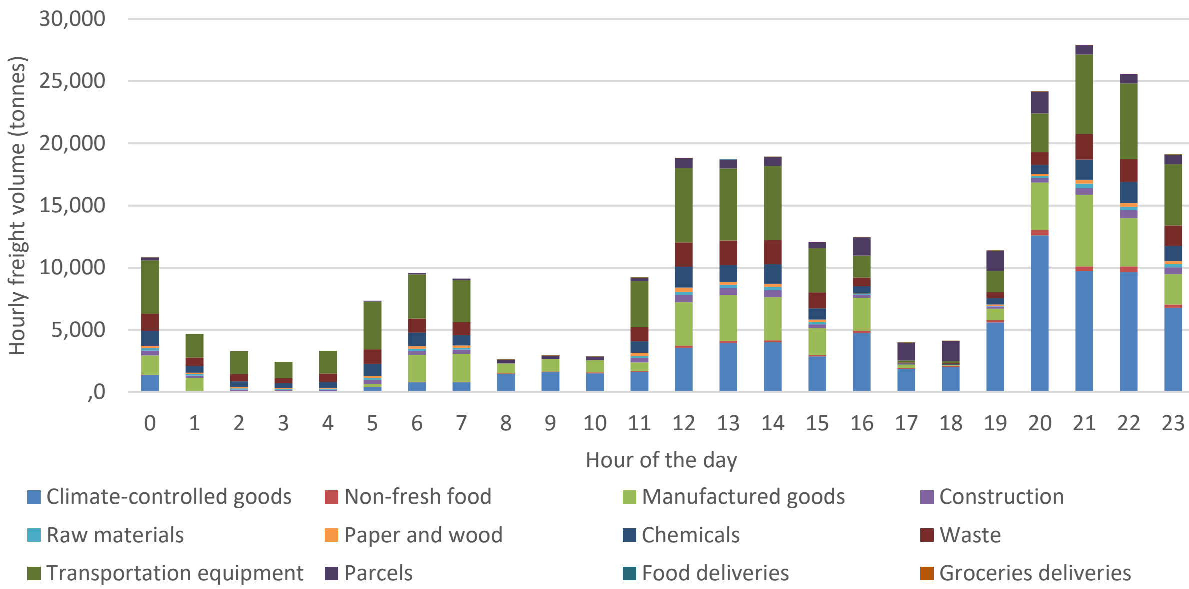


Figure A2. Hourly freight demand volume (tonnes)



Annex B. Modal alternatives in the simulation

Mode in model	Type	Description	Active or motorised	Private self-owned or shared	Sharing type	"Good street"* vehicle family	Modelling analysis group
Walk	Passenger	Walking as access or full mode from origin to destination	Active	Private		I	Private non-motorised + micromobility
Owned Bicycles	Passenger	Private non-electric bicycle as access or full mode from origin to destination	Active	Private		II	Private non-motorised + micromobility
Owned e-bicycles	Passenger	Private electric bicycle as full mode from origin to destination	Active	Private		II	Private non-motorised + micromobility
Owned e-scooters	Passenger	Private electric scooter as full mode from origin to destination	Motorised	Private		II	Private non-motorised + micromobility
Shared bicycles	Passenger	Free-floating shared-bicycle service	Active	Shared	Free-floating or station-based	II	Shared non-motorised + micromobility
Shared e-bicycles	Passenger	Free-floating electric shared-bicycle service	Active	Shared	Free-floating or station-based	II	Shared non-motorised + micromobility
Shared e-scooters	Passenger	Free-floating electric scooter-sharing service	Motorised	Shared	Free-floating or station-based	II	Shared non-motorised + micromobility
Car + public transport	Passenger	Car + public transport (e.g. park and ride)	Motorised	Private/ shared		IV/VI	Private motorised transport
Car (driver)	Passenger	Car driver from origin to destination	Motorised	Private		IV	Private motorised transport
Car - passenger	Passenger	Car passenger from origin to destination	Motorised	Private		IV	Private motorised transport

Mode in model	Type	Description	Active or motorised	Private self-owned or shared	Sharing type	"Good street"* vehicle family	Modelling analysis group
Motorcycle	Passenger	Motorcycle from origin to destination	Motorised	Private		III	Private motorised transport
Bus	Passenger	Bus as single-use or part of a multimodal trip	Motorised	Shared	Mass Public Transport	V	Public Transport
Rail	Passenger	Rail as single-use or part of a multimodal trip	Motorised	Shared	Mass Public Transport		Public Transport
Light rail transit	Passenger	Light rail as single-use or part of a multimodal trip	Motorised	Shared	Mass Public Transport	VI	Public Transport
Taxi	Passenger	Taxi passenger from origin to destination	Motorised	Shared	On-demand	IV	Shared transport
Car sharing	Passenger	Free-floating car-sharing service	Motorised	Shared	Free-floating or station-based	IV	Shared transport
Ride sourcing	Passenger	App-based ride-sourcing service with a professional driver	Motorised	Shared	On-demand	IV	Shared transport
Taxi-bus	Passenger	App-based on-demand bus (route and schedule) from origin to destination	Motorised	Shared	On-demand	IV/V	Shared transport
Feeder	Passenger	App-based on-demand bus (route and schedule) to access heavy public transport stations (rail or LRT) directly to the destination	Motorised	Shared	On-demand	IV/V/VI	Shared transport
Shared motorbike	Passenger	Free-floating motorcycle-sharing service	Motorised	Shared	Free-floating or station-based	III	Shared transport
Van	Freight	Light freight pick-up/van (3<x<5 tons)	Motorised	Private		IV	Light commercial vehicle / van
Medium Freight Truck	Freight	Medium freight truck (3<x<5 tons)	Motorised	Private		V	Truck-based freight delivery
Heavy Freight Truck	Freight	Heavy freight truck (3<x<5 tons)	Motorised	Private		V	Truck-based freight delivery

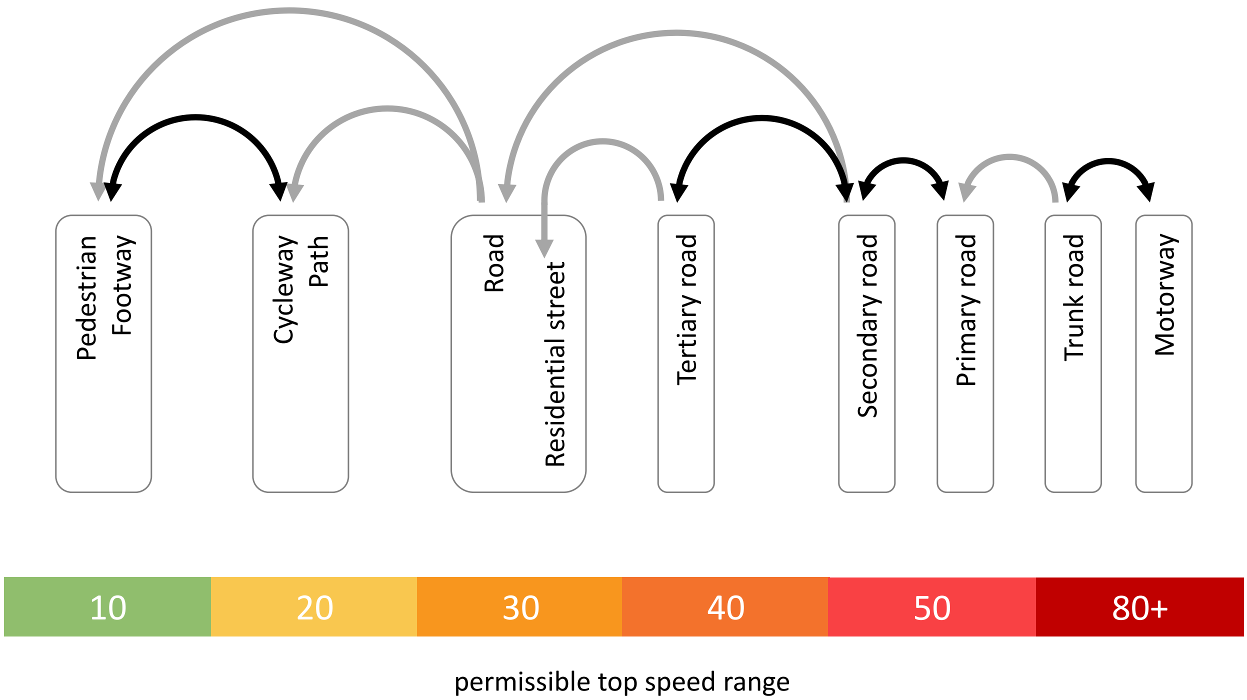
Mode in model	Type	Description	Active or motorised	Private self-owned or shared	Sharing type	"Good street"* vehicle family	Modelling analysis group
Van EV	Freight	Electric light commercial vehicle (3<x<5 tons)	Motorised	Private		IV	Light commercial vehicle / van
Freight bike	Freight	Freight bicycle (<x tons)	Active	Private		III	Non-motorised freight delivery
Light commercial vehicle	Freight	Light commercial vehicle (3<x<5 tons)	Motorised	Private/ shared	Free-floating or station-based	IV	Light commercial vehicle / van
Delivery bicycle	Freight	Conventional or electric bicycles used for deliveries	Active	Private/ shared	Free-floating or station-based	II	Non-motorised freight delivery
Delivery scooter	Freight	Light motorcycles used for deliveries	Motorised	Private		III	Light commercial vehicle / van

* Source: Immers et al. (2016; 2020)

Annex C. Street space functions and configurations

Road category	Pedestrian		Cycling		Car		Parking	Freight parking	Traffic segregation (%)
	Speed (km/h)	Capacity (person/h)	Speed (km/h)	Capacity (veh/h)	Speed (km/h)	Capacity (veh/h)	(veh/10m)	(veh/100m)	
Steps	3	500				100%	0	100%	100%
Pedestrian	5	3 000	12	500		0%	0	0%	0%
Cycleway	3	100	27	2 000		0%	0	0%	0%
Footway	5	4 000	12	500		0%	2	0%	0%
Path	5	2 000	27	800	20	10%	1	10%	10%
Track	5	2 000	27	500	20	0%	0	0%	0%
Service	5	1 000	12	500	30	25%	3	25%	25%
Residential	5	1 000	12	500	30	50%	4	50%	50%
Roads	5	1 000	12	500	30	75%	3	75%	75%
Tertiary entry	5	1 000	12	500	30	50%	2	50%	50%
Unclassified	5	750	12	500	40	25%	1	25%	25%
Secondary entry	5	1 000	12	500	40	80%	2	80%	80%
Tertiary	5	750	12	500	40	50%	4	50%	50%
Secondary	5	750	12	500	50	80%	2	80%	80%
Primary	5	500	12	200	50	100%	0	100%	100%
Trunk entry			8	1	50	100%	0	100%	100%
Motorway entry					50	100%	0	100%	100%
Trunk			8	1	80	100%	0	100%	100%
Motorway					90	100%	0	100%	100%

Figure C1. Dynamic re-configuration of road space – possible in-model conversion pathways of road typologies



Note: arrows represent the unidirectional (grey) or bidirectional (black) direction of potential change of road typology. Grouped road typologies imply interchangeability among them. Arrows to/from groups indicate potential changes of road typology to any road type in the group.

International Transport Forum

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Curbing the Impact of Freight Deliveries in Cities

This report explores ways of making deliveries in cities less disruptive and more sustainable. How goods are distributed in urban environments profoundly affects metropolitan life. Urban freight flows impact cities' economic vitality, their environmental footprint, the safety and efficiency of traffic and the ways public space is used. The report examines how new partnerships, innovative methods, the use of data and intelligent space allocation can ease the pressure on cities and their inhabitants by rapidly growing freight movements in urban areas. It also addresses whether solutions require new forms of data management, what new types of delivery vehicles might be required and how actors can co-ordinate more effectively.

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