THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Kerbside access management for freight deliveries
Conflicts, tools and implementations

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Abstract

The rapid growth of urban populations, advancements in transport technologies, and the rise of e-commerce have intensified competition for kerbside space. With demand increasing but space supply remaining fixed, access management has entailed user prioritisation and solutions to address conflicts over kerbside use by balancing supply and demand of space. In existing frameworks guiding decisions in access management, a marked bias towards specific groups of actors leads to overlooking the needs of others, with freight transport commonly excluded.

This thesis examines conflicts related to kerbside access faced by freight transport operators during last-mile deliveries, and it contributes to the development of data-driven interventions for balancing kerbside supply and demand. Using a mixed-methods approach, the research integrates qualitative and quantitative analyses utilising empirical data from London (UK) and Vic (Spain) and drawing insights from kerbside interventions worldwide.

This research advances understanding of loose couplings in kerbside access management and introduces a framework linking space-sharing conflicts to health, economic, social, and environmental implications. To address these conflicts, this research develops tools for managing kerbside space for freight transport, with an emphasis on the role of data analytics in access decisions and in estimating impacts related to Sustainable Development Goal (SDG) 11–sustainable cities and communities. It also informs urban freight policies by identifying patterns which support the institutionalisation of kerbside interventions beyond pilot phases.

Finally, this thesis provides recommendations for integrating freight transport considerations into kerbside access management. It encourages future research on analytical models to distribute space and on priorities in kerbside access which take freight access needs into account.

Keywords: Access management; freight deliveries; kerbside space; sustainable cities and communities; urban freight.

List of appended papers

This thesis is based on the research reported in the following papers:

Paper I

Castrellon, J. P., Browne, M., & Sanchez-Diaz, I. (2025). Space-sharing and kerbside conflicts in urban deliveries: A framework for understanding space allocation challenges.

The paper has been submitted for publication to an international journal. An earlier version of the paper was peer-reviewed and presented at the World Symposium on Transport and Land Use Research WSTLUR, 17–20 June 2024, Bogotá, Colombia.

Paper II

Castrellon, J. P., Sanchez-Diaz, I., & Gil, J. (2024). Smart loading zones: A data analytics approach for loading zones network design. *Transportation Research Interdisciplinary Perspectives*, *24*(101034). https://doi.org/10.1016/j.trip.2024.101034.

An earlier version of the paper was peer-reviewed and presented in a lectern session of the 101st Transportation Research Board Annual Meeting, 9–13 January 2022, Washington, DC, USA.

Paper III

Castrellon, J. P., Sanchez-Diaz, I., & Kalahasthi, L. (2022). Enabling factors and durations data analytics for dynamic freight parking limits. *Transportation Research Record*, *2677*(2), 219-234. https://doi.org/10.1177/03611981221115086

An earlier version of the paper was peer-reviewed and presented in a poster session of the 102nd Transportation Research Board Annual Meeting, 8–12 January 2023, Washington, DC, USA.

Paper IV

Castrellon, J. P., & Sanchez-Diaz, I. (2024). Effects of freight curbside management on sustainable cities: Evidence and paths forward. *Transportation Research Part D: Transport and Environment, 130*(104165). https://doi.org/10.1016/j.trd.2024.104165.

An earlier version of the paper was peer-reviewed and presented at the Transport Research Arena Conference, 14–17 November 2022, Lisbon, Portugal.

Paper V

Palacios-Argüello, L., Castrellon, J. P., & Sanchez-Diaz, I. (2025). From pilot to policy: Examining the transition towards institutionalized practices in freight curbside management. *Transport Policy*, *164*, 244-254. https://doi.org/10.1016/j.tranpol.2025.02.005.

A shorter version of the paper was peer-reviewed and presented at the 13th International Conference on City Logistics, 11–13 June 2025, Penang, Malaysia.

Notes on contribution to the appended papers

Paper I: The idea for this paper came from Castrellon, who collected the data and drafted the initial version submitted to an international conference. Browne and Sanchez-Diaz contributed to the review process and the discussion of results, which lead to a revised draft that was ultimately submitted to a journal.

Paper II: Castrellon and Sanchez-Diaz jointly developed the paper idea and collected the data. Gil contributed to data curation. Castrellon developed the models and wrote the first manuscript, which was submitted and presented in an international conference. All authors participated in the discussion of results, as well as the final editing and review which led to the paper's publication in a journal.

Paper III: Castrellon conceived the idea for the paper, analysed the data, and produced the first manuscript draft, which was presented at an international conference. Sanchez-Diaz and Kalahasthi contributed to data collection and the discussion of results. All authors participated in the final manuscript's editing and review which led to the publication of the paper in a journal.

Paper IV: Castrellon developed the paper idea, conducted the literature review, and performed the meta-analysis. Sanchez-Diaz contributed to data analysis and the discussion of results. Both authors participated in the review and editing of the manuscript, which was presented at an international conference and later published in a journal.

Paper V: The idea for the paper came from Palacios-Argüello and was further developed in collaboration with Castrellon and Sanchez-Diaz. All co-authors contributed to data collection. Castrellon and Palacios-Argüello performed coding and data analysis. All co-authors reviewed and edited the final manuscript, which led to the paper's publication.

Other publications

Other works related to this thesis have been developed and presented in the following forms:

Journal paper

Kalahasthi, L., Sanchez-Diaz, I., Castrellon, J. P., Gil, J., Browne, M., Hayes, S., & Sentís, C. (2022). Joint modeling of arrivals and parking durations for freight loading zones: Potential applications to improving urban logistics.' *Transportation Research Part A: Policy and Practice*. https://doi.org/10.1016/J.TRA.2022.11.003.

Book chapter

Sanchez-Diaz, I., & Castrellon, J. P. (2023). Freight trip generation models: Using establishments data to understand the origin of urban freight traffic. In E. Marcucci, V. Gatta, & M. Le Pira (Eds.), *Handbook on City Logistics and Urban Freight* (pp. 115–39). Edward Elgar. https://doi.org/10.4337/9781800370173.00014

Conference papers / presentations

Castrellon, J. P., Sanchez-Diaz, I., Browne, M., & Bergstad, C. (2025). The impact of bookable loading bays on stress levels of freight drivers: A pilot study. Presented at the 13th International Conference on City Logistics, 11-13 June, Penang, Malaysia.

Gateri, C., Sanchez-Diaz, I., Browne, M., Castrellon, J. P., Muriithi, J., & Kiruthu, F. (2025). Walking and freight delivery operations: Space-sharing conflicts in Nairobi. Presented at the VREF Global Summit, 26-28 May, Gothenburg, Sweden.

Castrellon, J. P. (2024). Managing street space access for sustainable freight delivery operations. Presented at the 13th Swedish Transport Research Conference STRC, 16-17 October, Gothenburg, Sweden.

Gil, J., Sanchez-Diaz, I., Castrellon, J. P., Bergstad, C., Katsela, K., & Williamson, J. (2023). Big data for identifying multi-actor streetside interaction: Towards deconflicting last-mile deliveries. Presented at the 5th VREF Conference on Urban Freight, 18-20 October, Gothenburg, Sweden.

Castrellon, J. P., Browne, M., Sanchez-Diaz, I., Cherrett, T., Crosk, J., McLeod, F., & Oakey, A. (2023). De-conflicting freight streetside operations for liveable streets: From conflicts identification to right-of-way decisions modelling. Presented at the NOFOMA Conference 2023 Logistics during global crisis, 15-16 June, Helsinki, Finland.

Licentiate thesis

Castrellon, J. P. (2023). *Using digitalisation for data-driven freight curbside management: A perspective from urban transport planning* (Licentiate thesis). Chalmers University of Technology, Gothenburg, Sweden. https://research.chalmers.se/publication/534266

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I came to Sweden five years ago chasing a dream that, at times, felt like a utopia. I often think back to an afternoon when, after a short run, Ivan and I decided to swim toward a floating platform in a Swedish lake. It looked close –within reach. But halfway there, my strength gave out, and I began to sink. My mistake: swimming too fast, too anxious to reach the end. Thankfully, Ivan (my PhD supervisor and, in that moment, my lifeguard) swam toward me, and helped me reach the platform, reminding me to move slower and more steadily. Once there, I recovered and eventually swam back to the shore, which had seemed impossible at first. On the shore, friends were waiting, encouraging me. Much like this PhD journey, it was driven by determination, sometimes it looked impossible, but I finally concluded thanks to those who supported me in critical moments.

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Terminology

The terms listed below are used in this thesis in the context of freight deliveries in urban street space.

Access management	the process of providing access to street space to users who demand it while simultaneously preserving the efficiency and safety of the movement of people and goods on streets
Couplings	connections between system elements
Loose coupling	system elements are held together by institutionalised expectations; they are responsive to external pressures but maintain their identity and independence
Tight coupling	system elements are unified by institutionalised expectations, adhere to standardised practices, and maintain strong interdependence and centralised control
Freight deliveries	activities which take place once a vehicle arrives to its destination (i.e., finding parking, parking, loading/unloading of cargo/equipment, and walking to the receiver location)
Freight kerbside management	the process of planning, implementing/assessing initiatives concerning, and controlling the use of kerbside space allocated to goods loading/unloading
Freight transport operators	fleet crew members operate vehicles and are responsible for reaching shippers/receivers' destination, loading and unloading of goods
Institutions	collective frames, e.g., governance structures, social arrangements, norms, and rules, which provide meaning to social behaviour and interactions regarding access to and use of street space
Institutionalisation process	process through which practices or behaviours take rule-like status in social thought and action
Kerb (curb)	the physical boundary between the sidewalk and the roadway
Kerbside (curbside)	the interface space of a street between vehicular movement and pedestrian activity, such that vehicles stop to facilitate modal transition to and from walking
Kerbside interventions	initiatives involving new regulations, technologies, or cultural norms which change current practices in the access to kerbside space

Liveability-freight paradox	actions fostering liveable spaces which create conditions that increase freight demand while reducing freight access
Loading zones	delimited stop areas where freight loading and unloading operations take place
Digital loading zones	loading zones equipped with technologies which provide real-time information for vehicle detection, parking space monitoring, and parking assignment
Smart loading zones	digital loading zones where data coming from connected infrastructure and mobile devices are used by public authorities, space owners/managers, and private companies to make informed decisions which enhance operational efficiency and urban liveability
Right-of-way	the legal right of a street actor to access transport infrastructure (e.g., kerbside space)
Space-sharing conflicts	imbalance in street space supply and demand which leads to two or more uses competing for the same space simultaneously, either in the present or the near future
Transport planner	public servant responsible for the planning of urban transport infrastructure to meet people's and goods' current and future demands for transport
Urban planner	public servant responsible for the planning of urban infrastructure development, including public spaces such as streets

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1. Introduction

This introductory chapter presents the background and problematisation that motivated the aim and scope of the research conducted for this thesis. The chapter concludes by describing the thesis's structure and its intended audience.

1.1. Freight in kerbside access management

Urban public space is a valuable yet scarce resource which impacts citizens' quality of life (Beck, 2009). Demand for public space relates to fundamental human needs for freedom (e.g., freedom of movement), subsistence (e.g., access to goods and work and/or study), and leisure (e.g., walking or sitting in urban spaces). Public space can take the form of green parks, where people walk and children play; it provides transport corridors which people use to move from one place to another; it attracts people to commercial areas via pedestrianised alleyways; it serves as a parking facility for private vehicles; and it acts as a platform for delivering goods and services. Because all such urban public space provides health, environmental, social, and economic value for citizens, its management is fundamental to achieving sustainable cities (Emanuel, Schipper, & Oldenziel, 2020).

Despite its local focus, the management of public space is globally relevant. The United Nations (UN) has included an explicit reference to public space actions in one of the 17 Sustainable Development Goals (SDGs) – namely SDG11, which envisions "Sustainable cities and communities, to promote policies and actions that leverage universal access to safe, inclusive, and green public spaces" (UN, 2017, p. 22). SDG11 addresses the effective management of competing demands for public space for uses which respond to human needs. Emanuel et al. (2020, p. 6) have paraphrased the UN's definition of sustainable development as involving the fair allocation of urban space whereby "one person's mobility does not come at the expense of another's mobility in the present or future generations."

Public space management becomes complex when competing demands outstrip available space. Rapid urbanisation, advances in transport technologies, and the rise of e-commerce have intensified this competition–particularly in street space, which accounts for approximately 25% of a city's total surface area and over 80% of its total public space (Rodriguez-Valencia, 2014). The challenge for transport and urban planners lies in determining who, how, and when street space is utilised, as all users claim a right to it (Lawanson, 2023).

Access management provides a structured approach to such decision-making by guiding user prioritisation based on principles such as safety, efficiency, and sustainability. Williams, Stover, Dixon, & Demosthenes (2014) defined *access management* as

> The coordinated planning, regulation, and design of access between roadways and land development. It encompasses a range of methods that promote the efficient and safe movement of people and goods by reducing conflicts on the roadway system, along the kerb, and where each mode of travel interfaces. These methods include improvements to benefit transit, pedestrians, and bicyclists, as well as context sensitive design, such as different treatments for urban, suburban, and rural settings.

A core objective of access management is to mitigate conflicts by limiting and separating conflict points, managing road use, and optimising access to properties (National

Academies of Sciences, Engineering, and Medicine, 2023). Several frameworks have informed decisions in access management, such as Liveable Streets (Appleyard, 1980), Link-Place (Jones, Boujenko, & Marshall, 2007), Complete Streets (Hui, Saxe, Roorda, Hess, & Miller, 2017), and Healthy Streets (Plowden, 2020), among others. However, these frameworks have shown a marked bias towards specific groups of actors and overlook the needs of others, with freight transport commonly excluded (Haarstad, Rosales, & Shrestha, 2023).

Freight operations require kerbside access for loading and unloading, yet this space is often contested by private vehicle parking, pedestrian walkways, public transport stops, and cycling infrastructure. Research has shown that the time a freight vehicle is parked on urban streets represents more than 40% of the time it spends in last-mile operations (Sanchez-Diaz, Palacios-Argüello, Levandi, Mardberg, & Basso, 2020) and even up to 80% in some contexts (Fransoo, Cedillo-Campos, & Gámez-Pérez, 2022), due to insufficient off-street facilities of freight receivers/senders. Given that freight vehicles typically try to park as close as possible to the delivery location, when space is unavailable (either on-street/kerbside or off-street), freight transport operators may double-park or cruise in search of a parking spot (Dalla Chiara & Goodchild, 2020).

Insufficient kerbside supply to meet freight demand for space –i.e., supply–demand imbalance– leads to unsustainable impacts by urban freight, including its contribution of 15% of greenhouse gas emissions (GHG) (Hammami, 2020) and 50% of particulate matter (PM) (De Marco, Mangano, & Zenezini, 2017); in addition, it makes freight the 3rd-greatest cause of urban congestion (Lopez, Gonzalez-Feliu, Chiabaut, & Leclercq, 2016) and results in the inefficient last-mile, which adds costs to supply chain operations (Gevaers, Van De Voorde, & Vanelslander, 2011).

Integrating freight considerations into kerbside access management has the potential to addresses supply–demand imbalances and the corresponding effects. According to Mitman, Davis, Armet, & Knopf (2018), this integration requires: i) an assessment of conflicts between freight and other kerbside users over space access, coupled with ii) an understanding of kerbside demand patterns for freight operations, and iii) the design and implementation of interventions for an effective management of space. Together, these three elements form the foundation of this research and are described below.

i) Conflicts over kerbside space access. Kerbside space serves a wide range of urban functions: Allen & Piecyk (2022) identified over 160 distinct uses of kerbside space, including goods loading and unloading. Although kerbside space is sometimes ignored in daily activities on streets, issues arise when access is constrained. The results of tensions in kerbside space access are called *space-sharing conflicts* (Markkula et al., 2020), which refer to supply–demand imbalances for kerbside space which lead to two or more uses competing for the same space simultaneously.

The consequences of these conflicts are often framed in terms of road safety and particularly collisions, given the traffic-oriented bias of kerbside planning and regulation (Dumbaugh & Li, 2010); for instance, freight-related interactions have been examined through the lens of movement impact (Conway, Cheng, Peters, & Lownes, 2013; Pokorny, Pritchard, & Pitera, 2018). However, when the access, place-making, and environmental functions of streets are considered, the effects extend further, impacting congestion, economic inefficiencies, environmental degradation, and public health concerns.

Addressing this broader perspective requires engaging with questions of spatial distribution (i.e., ROW allocation at the kerbside level) and considering how different users –and freight in particular– contribute to and are affected by space-sharing conflicts and the strategies to solve them.

ii) Understanding freight demand for kerbside space. Freight-related conflicts over kerbside space arise when delivery demands require freight vehicles to access specific urban areas at the same times and locations as other users also demanding access. Besides the identification of tensions with other users, kerbside access management for freight requires an understanding of the underlying demand patterns.

Freight operations at the kerbside are the result of a complex collection of interactions among shippers (senders), carriers, recipients, terminal operators, public agencies, and citizens (Holguín-Veras, Amaya Leal, & Seruya, 2017). These interactions are part of the *urban freight system* which encompasses supply chains involved in the movement of goods to, from, and within urban areas as well as the transport services, infrastructure, and regulatory environments enabling this movement (Ogden, 1992). Relationships and service models within supply chains introduce variability in kerbside demand in terms of delivery times and frequencies, vehicle types and sizes, goods characteristics, parking durations, loading equipment, and adjacent land use (commercial, industrial, residential). This heterogeneity poses challenges for designing access strategies.

iii) Interventions for balancing freight kerbside supply and demand. Once conflicts and demand patterns are understood, managing kerbside access requires interventions to improve space availability and solve tensions over the kerbside.

There is a varied range of kerbside interventions worldwide (Jaller, Rodier, Zhang, Lin, & Lewis, 2021; Wahid, 2020) aimed at effectively managing space through traffic segregation, access regulation, pricing, temporal reallocation, and demand-responsive management. The physical infrastructure which enables most freight kerbside access interventions is commonly referred to as *loading zones* or loading bays.

The provision of designated loading zones (LZs) is one of the most common and promising tools for reducing the negative impacts of freight activities in dense urban areas (Comi, Moura, & Ezquerro, 2022). Manzano Dos Santos & Sanchez-Díaz (2016) found that lack of kerbside availability is the main obstacle to efficient urban freight from the carriers' perspective. In a survey conducted by Holguín-Veras, Amaya, Sanchez-Diaz, Browne, & Wojtowicz (2020), 17 of the 56 studied cities had implemented LZ-related initiatives as part of their mobility plans, with both practitioners and the public recognising these interventions as effective at improving urban mobility. In Europe in particular, De Marco et al. (2017) found that 24 of the 70 European cities examined in their study had implemented LZ-oriented initiatives. However, the implementation of LZs and related technologies has remained at the level of temporary trials, rather than becoming permanent practice. Better understanding of the factors influencing the adoption of LZs and technologies over the long term is needed in order to address implementation challenges and reap the benefits of conflict reduction, last-mile efficiency, and urban sustainability seen in pilots.

Addressing kerbside supply–demand imbalances by incorporating freight considerations into access management can contribute to urban liveability by reducing transport-related externalities and improving the efficiency of last-mile deliveries. However, a better

understanding of the three elements discussed above –conflicts, freight demand, and intervention design and implementation– is needed to support the development of frameworks and tools for managing kerbside space vis-à-vis freight operations. The next section assesses the research problem, focuses on the kerbside supply–demand imbalance for freight, and presents the research gap leading to the formulation of the thesis's focus.

1.2. Kerbside supply–demand imbalance for freight deliveries

Supply–demand imbalance of kerbside space is at the core of the problematisation of access management for freight deliveries in urban areas. Expanding knowledge about this imbalance would help in understanding the root causes of space-sharing conflicts related to freight; this understanding, in turn, contributes to the design of interventions which have the potential to solve this problem while meeting sustainability targets.

Ionita, Pomp, Cochez, Meisen, & Decker (2018) stated that supply–demand imbalance is the result of insufficient knowledge about freight demand for space, a lack of monitoring of kerbside occupancy levels, a lack of differentiation in regulations between freight and private-car parking, and the so-called *big-no data paradox* (Gonzalez-Feliu, 2019), or the non-existence of analytical practices after investments in parking technology collecting vast amounts of data.

To the elements identified in Ionita et al. (2018), the literature has added other factors which contribute to the kerbside supply–demand imbalance. One is the fixed allocation of kerbside space, which limits the flexibility to adapt its use in response to varying needs throughout the day or week. Another element is the lack of comprehensive impact assessments; most existing studies focus primarily on last-mile delivery efficiencies, meaning further exploration is needed of the benefits for urban communities, including environmental, social, and health aspects (e.g., SDG11 targets). Moreover, with regard to coping with the imbalance problem, the high fragmentation in access regulations (due to the lack of coordination among public agencies with overlapping responsibilities) increases the complexity of decision-making processes. This fragmentation not only limits the effect of potential solutions (Lindholm & Behrends, 2012) but also blurs power and control structures for managing the access of public space for freight (Akgün & Monios, 2018).

Figure 1 presents the definition of the research problem and details the aspects studied in each component (i.e., supply, demand, and their balance).

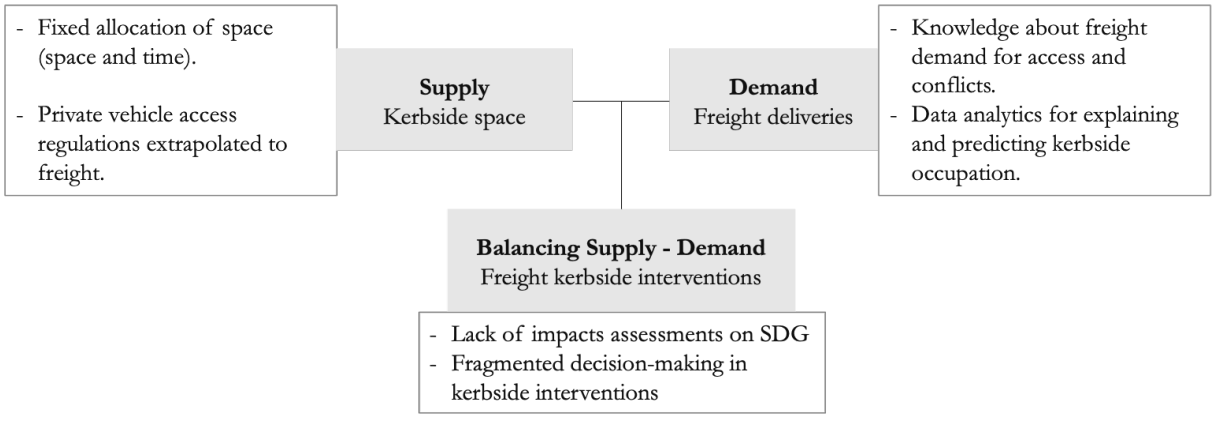

Figure 1. Elements of the kerbside supply–demand imbalance for freight deliveries

Supply: kerbside space

The supply component (left side of Figure 1) is related to the allocation of kerbside space. Decisions in this regard are contentious, since any proposed solution is likely to face opposition from one or more actors, and conflicts intensify in cases when actors are ignored during the allocation of kerbside space (Conway et al., 2018). For instance, frameworks for addressing street allocations prioritise access to street space using the principles of liveability (i.e., liveable streets) (Sanders, Zuidgeest, & Geurs, 2015), health (i.e., healthy streets) (Plowden, 2020), or flexible accommodation of various demands (i.e., flexible streets) (OECD, 2018), as well as complete streets (Hui et al., 2017). These frameworks often result in prioritising space for walking, cycling, and public transport, while restricting access for freight vehicles. Thus, the implemented interventions promote commercial and social activities which increase foot traffic and economic vibrancy –factors which, paradoxically, raise demand for freight deliveries.

This contradiction was described by Williams & Carroll (2015) as the *liveability–freight paradox*, wherein efforts for more liveable urban environments simultaneously stimulate freight activity while limiting its access. At the same time, reallocating parking spaces to become LZs might improve delivery efficiency but could also reduce parking availability for shoppers, potentially impacting local businesses negatively.

Research has focused on developing innovations to improve kerbside supply for freight, such as location of LZs, definition of LZs' size, and service coverage (Aiura & Taniguchi, 2005; Alho, de Abreu e Silva, de Sousa, & Blanco, 2018; Comi et al., 2022; Dezi, Dondi, & Sangiorgi, 2010; Letnik, Peruš, Božičnik, & Mencinger, 2019; Muñuzuri, Alho, & de Abreu e Silva, 2019; Pinto, Lagorio, & Golini, 2019; Tamayo, Gaudron, & de La Fortelle, 2018). Such studies have revealed how transport planners face dilemmas in choosing between various options for kerbside use and allocating scarce space to satisfy the demands of freight delivery. The benefits of space allocation for freight have been quantified in terms of time spent cruising for parking, traffic, delivery time, and cost for freight companies (Butrina, Girón-Valderrama, Machado-León, Goodchild, & Ayyalasomayajula, 2017); nonetheless, singular, static allocations of the kerbside for freight have the risk of resulting in overcapacity of infrastructure at specific times of the day or week at the expense of other users' needs for space. Thayne & Andersen (2017) reflected on the implications for sustainability of having kerbside space with singular fixed purposes and consequently admitted that such practices have unwanted side effects because they ignore street dynamics at different times of the day, week, or year.

With regard to access regulations, freight-focused studies have contributed to current understandings of the factors which influence durations and LZs' occupancy (Low, Duygu Tekler, & Cheah, 2020; Regal-Ludowieg, Sanchez-Diaz, & Kalahasthi, 2022; Schmid, Wang, & Conway, 2018). The data sources for these causation analyses have primarily been surveys or direct observation involving counting the number of freight vehicles and their time spent at the kerbside. However, data limitations –in terms of the types of commodities delivered and the types of vehicles– from observations beyond specific pilot projects and reference companies continue to present a challenge to unlocking generalisable estimations of parking durations and thus designing improved access regulations for freight.

Demand: freight deliveries

With regard to knowledge about kerbside demand for freight deliveries (right side of Figure 1), Jaller et al. (2021) highlighted that understanding and modelling freight demand for kerbside space is one of the most common challenges in access management for freight deliveries, for two major reasons: data scarcity and limitations in modelling techniques. As to the former, space demand for freight deliveries is usually estimated based on data representing stated preferences from surveys, instead of probed data about delivery operations (Allen, Browne, & Cherrett, 2012; Muñuzuri, Cuberos, Abaurrea, & Escudero, 2017). As to the latter, modelling the demand has involved attempts to adapt approaches from private-car parking without recognising that freight is influenced by different factors, including economic activity, city zone, and vehicle type (Schmid et al., 2018). Ignoring the stochastic behaviour of parking demand has also been identified as a limitation of methods in past research (Jaller et al., 2021).

Econometric models are the prevailing method for modelling parking demand (Campbell et al., 2018; Dalla Chiara & Goodchild, 2020; Gardrat & Serouge, 2016; Jaller, Holguín-Veras, & Hodge, 2013). However, as pointed out by Jaller et al. (2021), such models present a major problem: the assumption of either static or deterministic demand. For that reason, it remains necessary to improve modelling for estimations of freight parking demand by incorporating its stochastic nature.

Input data for estimating space demand for freight deliveries has also been the focus of several studies which have produced frameworks for data sharing and digital solutions in parking operations (Comi et al., 2017; McLeod & Cherrett, 2011; Mor, Speranza, & Viegas, 2020; Patier, David, Chalon, & Deslandres, 2014). Most of these data-sharing frameworks are based on booking systems, which present problems with implementation due to the unwillingness of freight transport operators to use them and legal frameworks circumscribing the possibility of booking public space. Moreover, such implementations have been represented by pilot projects involving specific companies and city zones, which has limited the generalisability of the results and raised data representativeness issues.

The use of data provided by connected infrastructure and mobile devices provides the possibility to access variables not typically available to transport planners, including parking arrival and departure times by location, type of commodity, and delivery vehicle. Such technology also offers access to probed data about freight delivery operations –data which are expected to give more accurate estimates of demand than survey data, given the availability of population-based data instead of data from random samples. Although research has examined implementations of freight parking systems using such technology in several cities (Letnik, Mencinger, & Peruš, 2020), data analytics and insights into data-driven decision-making in access management for freight deliveries remain in an early stage of development (Comi et al., 2017).

Balancing supply–demand: freight kerbside interventions

With regard to balancing kerbside supply and demand (bottom side of Figure 1), although some studies have quantified the impacts of specific kerbside interventions on the metrics defined in Butrina et al. (2017), there is a lack of comprehensive studies which have assessed the impact of these interventions on SDG11 targets, i.e., the average global share of urban space allocated to streets and open public spaces, the participation of civil society in urban planning and management, mean levels of fine PM emissions, and the

development of urban public policies. Although these metrics evince the societal value of kerbside management, most existing studies tend to frame benefits in terms of operational efficiencies for freight deliveries, largely from the perspective of private actors in the freight sector.

This focus has left a gap in urban freight literature regarding the public sector perspective (Lindholm, 2012), for instance in shaping kerbside access strategies. Rodrigue (2020, p. 290) noted that "planning for freight movements remains in its infancy," underscoring the need for more robust frameworks to inform urban planning which considers freight. Similar concerns have been raised in urban studies literature (Haarstad et al., 2023). Although the private sector perspective in developing interventions (e.g., routing models, last-mile delivery strategies, consolidation centres, and micromobility solutions) have contributed significantly to the field of urban freight, academic contributions from the public sector perspective remain limited. This prompts further exploration in the study of kerbside management from the perspective of the public sector.

Moreover, technological solutions (like dynamic kerbside management systems, bookable LZs, and censored LZs, among others), while promising, have in some cases stopped after the pilot phase: they fall short in the deployment phase, fail to become permanent over time, or face difficulties when trying to extend to other parts of the city (Sista & De Giovanni, 2021). Research has identified several barriers to scaling up pilots, including a mismatch of actors' interests and perspectives, a lack of supportive laws or policies, unclear business models, inadequate resources such as staff and expertise, and inconsistent monitoring and evaluation (Nesterova & Quak, 2016). However, there is still limited understanding of what drives freight kerbside interventions from pilot stages to sustained implementation.

Table 1 summarises the research problem, previous contributions, and gaps in research regarding each component of Figure 1. This thesis seeks to provide an understanding of the gaps in research shown in Table 1 and to contribute through the development of knowledge, including frameworks and tools for bridging the listed gaps.

1.3. Aim and scope

The aim of this thesis is to advance knowledge on kerbside access management for freight deliveries through the study of space-sharing conflicts and the interventions to address them.

To achieve this aim, this research centres on the empirical context of freight operations at the kerbside in urban areas, involving activities which take place once a freight vehicle arrives at its destination (i.e., finding parking, parking, loading and unloading of cargo or equipment, and completing the delivery).

This thesis is structured according to three main components. It first examines space-sharing conflicts related to kerbside access faced by freight transport operators during last-mile deliveries. Then, it develops data-driven interventions for addressing conflicts –e.g., by balancing kerbside supply and demand of kerbside space– and assesses the interventions' impact on cities' SDG11. Finally, the thesis explores the factors influencing the implementation of interventions as permanent practices for managing kerbside space for freight.

Table 1. Summary of the research problem and gaps

Elements of the supply–demand imbalance	Problem addressed	Topic of previous contributions	Gaps in research
Supply: Kerbside space	Conflicts over kerbside space access	Freight-related interactions concerning the access for kerbside space	Traffic-oriented bias of kerbside planning and regulation, which often overlook freight in space allocation decisions
		Location of LZs, definition of sizes, and service coverage	Lack of tools for flexible and data-driven regulations which enable the dynamic use of space according to the temporal and spatial variabilities of demand
		Kerbside access regulations for freight deliveries	
Demand: Freight deliveries	Understanding freight demand for kerbside space	Models of private vehicle parking durations and analysis of factors influencing parking durations	Limited understanding of factors which influence the kerbside demand for freight deliveries Lack of data analytics tools supporting decisions to improve kerbside access for freight deliveries
		Kerbside digitalisation for freight deliveries, e.g., booking or check-in systems and sensors	Need for improved demand modelling which considers the stochastic nature of demand patterns based on automated data collection and analytics
Balancing supply and demand: Freight kerbside interventions	Interventions for balancing freight kerbside supply and demand	Impact assessments on last-mile delivery efficiencies for freight companies	Limited quantification of the impact of kerbside interventions on urban sustainability
		Identification of factors which support or hinder the adoption of interventions in urban freight, e.g., consolidation centres and micro-hubs.	Limited understanding of factors influencing the permanent adoption of kerbside interventions

For the first component, the thesis explores the interactions between freight transport operators and other kerbside users, identifying and analysing the nature and impacts of space-sharing conflicts as well as the implications of space allocation decisions for freight transport operations.

For the second component, the thesis develops data-driven tools to support kerbside access management for freight deliveries. These tools seek to improve the understanding of demand patterns and support the design of supply-side solutions which facilitate last-mile deliveries while contributing to the achievement of SDG11.

For the last component, the thesis analyses the implementation of kerbside interventions introduced through pilot initiatives. It investigates the factors which influence whether these pilots are successfully institutionalised or fail to transition into permanent practices.

Access management is the central topic of analysis. Figure 2 displays the actors involved and the spatial boundaries considered in the development of the thesis. As shown, access

management is the mechanism through which different users –including pedestrians, private cars, freight, public transport, and cyclists– interact with street space adjacent to developed land. These interactions are shaped and regulated by traffic departments which comprise kerbside technology providers and enforcement agents to manage access to the available space.

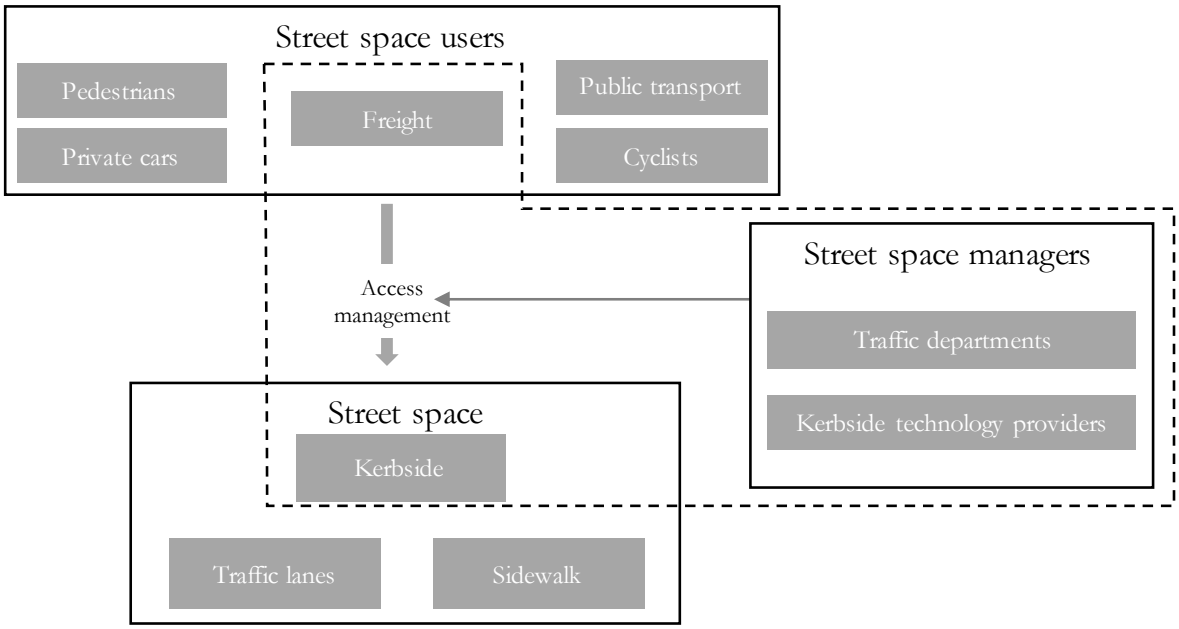

Figure 2. Research scope

The focus of the research, indicated by the dotted line, is freight access to the kerbside. This entails analysing the kerbside space demand by freight operations and how the supply of space is managed, with attention to conflicts, demand patterns, and interventions, including those driven by technology implementations. The study also develops tools to inform the decisions of street space managers in granting this access, particularly in terms of conflict assessment, space allocation, parking regulations, and technological interventions.

Elements outside the dotted line, such as other street space users (e.g., pedestrians, cyclists, public transport, private vehicles) and other spatial segments of the street (e.g., traffic lanes and sidewalks), influence access management to different extents based on the context. While they are not the primary focus of this research, they are included in the analysis when relevant to freight access and kerbside interactions.

In this thesis, understanding freight access to kerbside space acknowledges –but does not focus on– broader elements of the urban and urban freight systems. For example, sender–receiver relationships and supply chain relationships in general within the urban freight system influence kerbside demand patterns. In addition, land use affects the intensity of interactions between freight and other street users. At the same time, decisions made in kerbside management can also impact the functioning of these broader systems (e.g., changes in routing plans due to time access constraints). While these broader dynamics fall outside the direct scope of this thesis, their influence is recognised and addressed in the discussion section, particularly in terms of how they interact with elements within the defined research boundaries.

1.4. Document navigation and intended audience

This thesis describes the research conducted through the author's doctoral study, including the licentiate phase. Accordingly, various parts of the licentiate thesis titled "Using digitalisation for data-driven freight curbside management: A perspective from urban transport" have been incorporated into different sections of this document.

The target audience of this thesis includes but is not limited to researchers and practitioners interested in urban freight, urban planning, and access management. The thesis's topic may also be of interest to users and developers of data analytics applications in urban contexts. The outcomes of the research are expected to inform transport and urban planners at public authority bodies, who should be the main users of the findings; however, the results are also relevant to private actors, because they provide insights into the impacts of decisions about the kerbside on the efficiency of last-mile deliveries.

In what follows, Chapter 2 describes the conceptual background used to approach the research problem. Chapter 3 presents the research process, design, and strategy implemented to meet the thesis's aim. The outputs of the research conducted for the thesis –namely, five journal papers– which contain the results used to answer the RQs are summarised in Chapters 4 and 5. Then, Chapter 6 discusses the results, contributions to both theory and practice in view of the gaps highlighted in Table 1, and reflections about both the limitations of this research and further research. Chapter 7 articulates the conclusions.

2. Conceptual background

This chapter presents the key concepts from practice and theory which underpin the development of the thesis; some definitions are drawn from the licentiate thesis which preceded this dissertation (Castrellon, 2023). The chapter begins by framing access management in the context of urban freight and the topic of balancing supply and demand for space. It then introduces freight kerbside interventions and examines the role of data analytics in the design and impact assessment of the interventions. The chapter also outlines the theoretical perspective through which the adoption of these interventions is analysed. It concludes with a summary of the addressed concepts and a presentation of the research questions which structure this thesis.

2.1. Access management in the context of urban freight

Urban freight is the field of reference used for the development of this thesis. *Urban freight* comprises the movement of goods (as distinct from people) to, from, within, and through urban areas (Ogden, 1992). It is a complex, heterogeneous collection of interactions among shippers, carriers, recipients, terminal operators, public agencies, and citizens (Holguín-Veras et al., 2017). Ogden (1992) asserted that, by definition, urban freight is more than the movement of goods from origin to destination: it also looks to minimise, or at least reduce, the total social cost of the urban movement of goods.

In line with Wandel, Ruijgrok, & Nemoto (1992), the urban freight system can be described as consisting of three layers –supply chain, transport, and infrastructure– which are connected by two interfaces: supply chain-transport and transport-infrastructure. Freight deliveries in urban areas are situated at the latter interface –labelled here the 'freight delivery interface'– where freight interacts with urban infrastructure (e.g., roads, kerbsides, sidewalks). This interface is where freight operations transition from motorised transport to on-foot deliveries to reach the delivery recipients/generators.

Access management operates at the freight delivery interface and addresses how traffic flows connect to adjacent land uses, with the aim of reducing conflicts among competing users. At the freight delivery interface, access to kerbside space for parking, loading, and unloading is shaped by the interactions among three core components:

- Actors: Including local authorities, freight transport operators, receivers, enforcement agents, and technology providers.
- Infrastructure: Physical and digital components of the kerbside, such as loading zones, sidewalks, sensors, and signage.
- Rules: Regulatory instruments that govern access, such as time windows, parking duration limits, pricing mechanisms, and vehicle size restrictions.

This thesis focuses on the management of these components (i.e., kerbside access management), their interactions, and their alignment –or misalignment– with the broader objective of the urban freight system: delivering goods efficiently while minimising social and environmental costs. The analysis examines how access management at the kerbside addresses supply–demand imbalances, supports operational needs, and contributes to urban sustainability.

2.2. Kerbside access management

The *kerb* is the physical boundary between the sidewalk and the roadway. By extension, the *kerbside* is a public transport infrastructure traditionally used as the interface between vehicular movement and pedestrian activity, such that vehicles stop to facilitate modal transition to and from walking (Marsden, Docherty, & Dowling, 2020). Current needs for space have gone beyond the traditional use to incorporate a broader range of purposes, including for on-street parking zones, loading and unloading goods, seating for restaurants and cafés, and play areas for children.

Given such diverse demands, kerbside management requires decisions regarding the allocation, use, and monitoring of kerbside space to satisfy citizens' needs for accessibility, mobility, and the enjoyment of public space. DeBow and Drow (2019) defined *kerbside management* as the collection of concepts, techniques, and practices which effectively allocate the use of the kerbside. Apart from allocating kerbside space, kerbside management includes integrating fragmented data, monitoring the use of the kerbside, communicating and enforcing rules about kerbside use, and reporting the performance of the kerbside (DeBow & Drow, 2019).

Building on this foundation, this thesis introduces the concept of *kerbside access management*, which includes the allocation and monitoring functions mentioned in DeBow and Drow (2019) but expands the scope to include conflict management. In this context, conflicts denote space-sharing conflicts as a result of the simultaneous interests of different actors in using the same portion of street space. For instance, freight deliveries require timely and proximate access to buildings and businesses, but this demand competes with other users (e.g., cars, buses, bicycles, pedestrians), thereby creating operational and regulatory challenges.

Kerbside access management has gained relevance due to the growing intensity and variety of demand contrasted with the relatively fixed supply of kerbside space (Marsden et al., 2020). However, local authorities frequently lack tools to support their decision-making, relying instead on ad hoc processes or regulation designs driven by lobbying and political influence from specific groups in society (Wahid, 2020). For instance, in Butrina, Le Vine, Henao, Sperling, & Young's (2020), p. 5) report on interviews with local authorities in the United States, some participants admitted that making decisions about kerbside access is "more of an art than a science."

Loose couplings in kerbside access management for freight

The fragmented and loosely coordinated nature of kerbside access management, particularly for freight, echoes patterns identified in the freight transport system. Browne, Dubois, & Hulthén (2022) found that loose couplings, particularly in road transport, were characterised by fragmented responsibilities, weak coordination, and limited adaptation between system elements (e.g., infrastructure and vehicle operations) –especially compared to other transport modes, such as rail or aviation.

Originally introduced by Weick (1976), the concept of *loose coupling* indicates elements with weak interconnection and limited responsiveness to one another; systems with loose couplings among their components experience an absence of regulations, disconnection of structures from tasks, and a lack of goal consensus (Ingersoll, 1993). In the case of kerbside access management, loose couplings are reflected in the way different stakeholders share a common space –i.e., kerbside space– while pursuing divergent goals. Although various

actors (such as public agencies, freight transport operators, and other road users) interact under shared urban objectives (e.g., SDG11 targets or street liveability), they often operate independently and pursue priorities which conflict with one another. These misalignments contribute to inefficient space use, regulatory gaps, and conflicting decisions, especially where freight deliveries are involved.

Weick (1976) observed that in loosely coupled systems, rules may be violated, decisions often go unimplemented, and outcomes are unpredictable; technological innovations may fail to deliver intended efficiencies, and oversight mechanisms lack the authority or coordination needed for systemic improvement. In kerbside access management, such dynamics are evident in the liveability–freight paradox, where interventions aimed at improving environmental and mobility outcomes may inadvertently worsen freight performance, or vice versa.

According to Orton and Weick (1990), research on loosely coupled systems focuses on identifying which elements are loosely connected, understanding the causes of these weak links, examining the domains on which couplings occur, and assessing their consequences. Browne et al. (2022) argued that such analysis is critical for urban freight, pointing out the need to further elaborate and identify loose couplings so as to address mechanisms which, e.g., coordinate access to and improve the utilisation of the scarce resources at hand. They suggested that tightening these couplings –through policy, data integration, or governance reforms– can lead to more sustainable transport.

This thesis responds to that need by exploring the nature of loose couplings in kerbside access management and the implications of these couplings for freight deliveries. In this thesis, 'loose couplings' refer to the misalignment between the overall purpose of the urban freight system –i.e., efficiently delivering goods to receivers at minimal social cost– and the functioning of the components of the freight delivery interface (i.e., actors, kerbside infrastructure, and access rules). This leads to the first research question:

RQ1 – How does the misalignment between the urban freight system's goal and the components of the freight delivery interface affect kerbside access for freight?

To guide this analysis, the thesis draws on Ingersoll's (1993) approach for the identification and analysis of loose couplings. Originally applied in education research but transferable to other contexts, this approach includes three key areas of inquiry: i) identifying the goals and functions of actors involved in the system; ii) evaluating organisational structures –here, how kerbside space is allocated and the operational impacts on freight deliveries; and iii) understanding power dynamics and control mechanisms, including how decisions are made, enforced, and adapted over time. These dimensions provide a lens for analysing the implications of loose couplings on freight deliveries, thereby informing the identification of interventions which can improve coordination and contribute to urban sustainability.

In this way, research on loose couplings extends beyond identifying points of disconnection: it also seeks to define mechanisms for tightening these couplings where needed. In the context of this thesis, such mechanisms take the form of *freight kerbside interventions*, or actions intended to improve coordination, reduce conflict, and enhance the integration of freight needs into kerbside access management. The following section presents the concepts guiding the exploration of these interventions.

2.3. Freight kerbside interventions

Freight kerbside interventions involve the introduction of rules, technologies, infrastructure works, operational changes, or procedures for managing freight access to kerbside space. The main purpose of these interventions is to balance supply and demand with the intention of mitigating space-sharing conflicts.

Actors promoting freight kerbside interventions can exist at different levels (individual, organisational, and societal) and differ in nature (public or private); here, this thesis adopts a public sector perspective. Specifically, it addresses the role and actions of public space managers, particularly transport planners, in the design and development of interventions which are necessary to manage access to kerbside space for freight deliveries.

Kerbside interventions include traffic segregation, access regulation, pricing, temporal reallocation, and demand-responsive management (Jaller et al., 2021; Wahid, 2020). Traffic segregation interventions, such as San Francisco's Vision Zero initiative and Chicago's Loop Link project, redesign street infrastructure to protect vulnerable road users. Access regulations have been implemented in cities like Gothenburg, where parking is prohibited during peak hours and strict limits are placed on vehicle dwell times for loading and unloading. Pricing strategies include the use of digital permits and dynamic pricing, as seen in Washington, DC's pay-by-cell system for commercial vehicles and in San Francisco's SFpark programme, which adjusts parking rates to reduce cruising and increase turnover. Temporal reallocation of freight activity has also been adopted in several contexts, particularly through off-peak delivery programmes or alternate-day travel restrictions. Cities such as New York, London, Barcelona, Bogotá, and Los Angeles encourage deliveries during night-time hours (typically between 7 p.m. and 6 a.m.) to reduce conflicts with passenger traffic and improve kerbside availability. In São Paulo, access is restricted based on licence plates, allowing trucks to operate only on designated days. Finally, demand-responsive systems in cities such as Vienna and Lisbon use real-time data and digital tools to allocate kerbside space dynamically, seeking to match supply with fluctuating freight demand while minimising traffic disruption.

Loading zones are the physical infrastructure enabling most of the freight kerbside access interventions described above. Loading zones (LZs) are defined as on-street areas reserved for vehicles needing to load and unload freight (Dezi et al., 2010). LZs are meant to satisfy the demand for goods access from residential, commercial, and industrial establishments. The management of LZs involves decisions about location, size, and usage (Alho et al., 2018) and includes technological evaluations to choose fixed and mobile devices which support the coordination, monitoring, and enforcement of the use of LZs (Wahid, 2020). LZ management also responds to regulations about accessing time, pricing strategies, and enforcement (Nourinejad & Roorda, 2017). Thus, kerbside interventions via LZs can be grouped into four types: urban space allocation, data-sharing on LZ availability, parking limits/duration management, and enforcement.

Although recent research has focused on the managerial aspects of freight operations at the kerbside, Muñuzuri et al. (2017) highlighted the lack of robust planning tools with sufficient data on demand, which are needed to design and manage LZs. Digitalisation enabling data-driven interventions has been identified as a way to overcome that obstacle (Comi, Schiraldi, & Buttarazzi, 2018).

Data-driven kerbside interventions

Advances in sensors, computer vision technology, mobile apps, geolocation services, and data analytics algorithms present an opportunity to amass and analyse large amounts of data on the use and availability of kerbside space, particularly LZs. Since becoming available, increasingly large amounts of data on adjacent spaces (e.g., offices, shops, and residential complexes) have also demonstrated benefits in estimating demand for kerbside space. Today, such new technologies for digitalising the kerb and monitoring its use are increasingly replacing costly traditional methods of data collection, including surveys, direct observation via space inventories, and traffic counting (Jaller et al., 2021).

Public investments in various forms of static technology (e.g., cameras, in-ground sensors, and Bluetooth and RFID readers) have also overcome the limitations of traditional observation-based estimations of kerbside occupancy vis-à-vis the frequency and size of the samples observed as well as the accuracy and representativeness of the data collected. Static technologies also support enforcement activities by providing data about the misuse of the kerbside (e.g., illegal parking) and prepare cities for up-and-coming users, including autonomous vehicles, which will need to exchange data with the built environment in order to operate (Zhang & Wang, 2020).

At the same time, various forms of mobile technology (e.g., app-based systems providing booking, payment, and check-in and check-out services) have unlocked the possibility of gathering detailed data, which is typically unavailable to local agencies, including the type of user, their purpose for occupying the kerbside, and when they arrived and departed. Such technologies also benefit freight transport operators by providing them with reliable information related to current and forecasted availability of parking spaces (Zhang & Thompson, 2019).

Beyond connectivity, using big data generated from implemented technologies and even sharing such data are powerful means of translating information into decisions which improve kerbside management. However, the linkages between such data and decision-making still need to be examined (Comi et al., 2017; Butrina et al., 2020). Seeking to overcome that challenge, Lin, Rivano, & le Mouel (2017) proposed a construct for considering the digitalisation of the kerbside, with three macro-components:

- *Information collection*, which refers to decision-making and developments in the sensing and connectivity of parking information (e.g., parking meters, ground sensors, and crowdsensing);
- *System development*, which refers to software and data analytics used to predict unoccupied parking spaces and the scalability of digital kerbside management; and
- *Service dissemination*, which refers to parking regulations, pricing, parking enforcement, and the behaviour of freight transport operators.

According to Lin et al. (2017), with those macro-components in place, urban planners can make data-driven decisions which are able to enhance kerbside access management.

Data-driven decisions denote the managerial practice of basing decisions on data analyses instead of intuition (Provost & Fawcett, 2013). The aforementioned technological advances have given rise to research opportunities regarding the development of data-driven decision-making to improve kerbside access management based on probed data showing the use and availability of the kerbside. Huang (2003) applied a data-driven

decision-making approach for urban transport which incorporates supply- and demand-related data linked to the system's performance and impacts. Based on Huang (2003), Figure 3 presents a data-driven decision-making approach for kerbside management, specifically for freight parking operations at the kerbside.

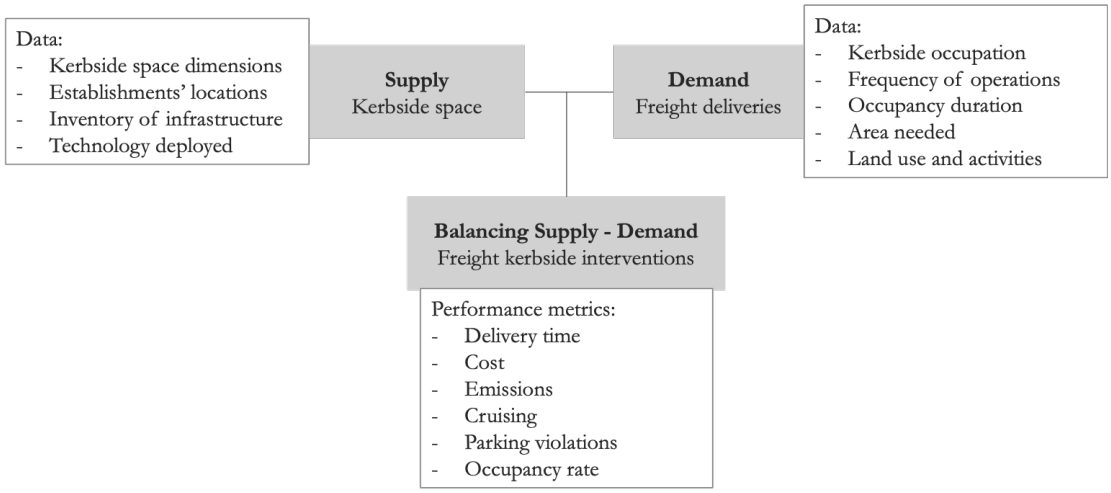

Figure 3. Data-driven approach for kerbside access management

In line with the data-driven approach shown in Figure 3, interventions at the kerbside – i.e., space allocation, regulations on durations and access, technologies, and enforcement– are aimed at balancing supply and demand through digitalisation-based decisions –i.e., decisions based on supply- and demand-related data, measured in terms of their effect on delivery times, emissions, occupancy rates, cruising, costs, and parking violations (Diehl, Ranjbari, & Goodchild, 2021; Meyer, 2016). Those performance indicators for kerbside access management are ultimately associated with sustainability impacts, namely the metrics of SDG11–Sustainable Cities and Communities.

SDG11 has four specific metrics which guide the implementation of actions in the public space: (i) the average global share of the urban area allocated to streets and open public spaces; (ii) the participation of civil society in urban planning and management; (iii) mean levels of fine PM; and (iv) the development of urban public policies. The research for this thesis investigated the role of kerbside access management interventions for freight in meeting these targets.

Accordingly, the second research question (RQ2) explores the design of interventions and regulations for managing access, the tools which support their development, and their alignment with SDG11. The question is formulated as follows:

RQ2 – To what extent do data-driven kerbside interventions for freight contribute to achieving the targets of sustainable cities and communities?

RQ2 is motivated by the need to understand the factors shaping kerbside supply and demand for freight deliveries, as well as the role of data-driven decision-making in freight kerbside access management.

Advances in technology have enabled the collection and analysis of high-resolution data on kerbside operations, which offer stronger support for decision-making. This research leverages such data, using methods like machine learning to estimate parking demand and optimisation models to assess supply in order to evaluate and enhance freight-related kerbside decisions. The research also identifies how these data-driven interventions

improve operational management and align with the broader objectives of SDG11; specifically, the impacts of freight kerbside interventions are assessed through metrics such as public space allocation, participatory planning, air quality (e.g., PM emissions), and the formulation of inclusive urban policies.

The implementation of kerbside interventions has often run into challenges, particularly regarding the permanent adoption of tested practices or technologies. This forms the basis of the third component of the thesis, which investigates the factors influencing the adoption of interventions after their design and pilot-testing phases.

2.4. Implementing kerbside interventions – an institutional approach

Kerbside pilots have become a common means for assessing kerbside interventions facilitating freight deliveries, as they provide a realistic setting and reveal the foreseeable and unforeseeable obstacles/benefits of the interventions (Ranjbari, Goodchild, & Guzy, 2023).

Pilots in kerbside access management for freight are extensively documented in the literature (Letnik et al., 2020). For example, in Lisbon, Portugal, city authorities installed parking meters and loop vehicle detection sensors on the ground at LZs to monitor occupancy levels and enforce kerbside regulations. A similar trial was implemented in Seattle, USA, with the purpose of providing real-time and forecasted parking information to freight transport operators (Dalla Chiara & Goodchild, 2020). In Lyon, France, a pilot called 'Loading Bay of the Future' assessed the effectiveness of booking systems in reducing double-parking, congestion, and emissions. Vienna, Austria, implemented 'i-Ladezone' for LZ monitoring and control, to prevent unauthorised kerbside use (BESTFACT, 2013). In Vic, Spain, the introduction of an app-based solution called 'Parkunload' provided a tool for LZ access control by requiring freight transport operators to notify the beginning and end of their operations at LZs (Kalahasthi et al., 2022).

Reported pilots differ in terms of their duration, leading organisation (academia, local government, tech company, national government, NGO, or private retail/transport company), project origination (research projects, public tenders, or supranational project calls), and the technology implemented (cameras, ground sensors, mobile apps, and parking meters). These aspects of pilot project design are crucial, as they influence the potential success of scaling up (Sista & De Giovanni, 2021). Additionally, these pilots involve different organisations, given the public–private nature of urban freight: the member compositions of pilots differ from place to place, but they most often include local/regional authorities, freight receivers/generators, transport companies, technology companies, transport infrastructure providers/managers, and academia.

While pilots have provided insights into the initiatives' impacts on city sustainability, expansion beyond their initial scope has been limited (Quak, Lindholm, Tavasszy, & Browne, 2016). Some projects faced difficulties when trying to extend to other parts of the city, or when turning pilot insights into permanent practices. Research has identified several barriers to scaling up these pilots, including a mismatch of stakeholders' interests and perspectives, a lack of supportive laws or policies, unclear business models, inadequate resources (such as staff and expertise), and inconsistent monitoring and evaluation (Nesterova & Quak, 2016). However, knowledge of what drives kerbside interventions for freight from pilot stages to sustained implementations is still limited.

Institutionalisation of kerbside interventions

Borrowing from the field of organisation studies, this part of the thesis used the lens of institutional theory (INT) to examine adoption of interventions in access management to kerbside space for freight deliveries. INT provided conceptual foundations for making sense of the institutionalisation processes of kerbside interventions.

Institutions are at the core of INT. Djelic & Quack (2008, p. 300) defined *institutions* as "those collective frames and systems that provide stability and meaning to social behaviour and social interaction and take a rule-like status in social thought and action." According to this definition, institutions represent formal or informal rules and systems which enable action, including legislation, regulations, or cultural norms and customs; institutions often involve normative obligations but also facts which lead to actions being perceived as legitimate (Meyer & Rowan, 1977). As stated in North (1990), institutions are the game's rules, and organisations are the players. Representatives of institutions come in the form of symbolic systems, relational systems, routines, and artifacts (Scott, 2001).

Stough & Rietveld (1997) provided examples of institutions within transportation systems, including the provision of transport infrastructure, management and regulatory practices, system governance and structures for stakeholders' involvement, market dynamics, and technology adoptions, among others. However, the concept of institutions has had different connotations in transport literature, with some authors defining them exclusively as the government agencies which regulate or manage transport systems (Fossheim & Andersen, 2022). This thesis aligns with the definition of institutions from organisational institutionalism (Djelic & Quack, 2008), conceptualising them as the rules which govern actions in access to kerbside space.

Although a significant stream of research in INT takes organisations as the unit of analysis, the constructs of INT also help explain phenomena at different levels, from individuals to entire societies and specific groups within them (Greenwood, Oliver, Sahlin, & Suddaby, 2008). The group of involved organisations or individuals who in the aggregate constitute a recognised area of institutional life (i.e., actions guided by institutions) is defined as *organisational field*. Concentrating on organisational fields enables understanding the decision-making processes among organisations which have different goals but interact with each other to accomplish a specific task (Wooten & Hoffman, 2017)– as seen in loosely coupled systems. Thus, this thesis conducts the analysis of institutions at the field level. Here, the organisational field consists of the actors at the freight delivery interface, including public space managers (i.e., transport planners, enforcement agents, and technology operators), street users related to freight (i.e., freight transport operators, freight receivers/senders), academia and NGOs involved in kerbside interventions.

These theoretical lenses informed the third research question, which sought to identify factors influencing the institutionalisation process of interventions:

RQ3 – What factors influence the institutionalisation of kerbside interventions for freight deliveries?

RQ3 guides the study of the *institutionalisation process*, defined as the process through which interventions take rule-like status in social thought and action (Meyer & Rowan, 1977). Transitions from ideas or trials to established practices are influenced by factors that introduce change, which cause the organisational field adopt structures considered rational

and legitimate, which in turn lead to the formation of institutions. Although some of these factors were discussed in Tolbert & Zucker (1996), DiMaggio & Powell (1983) provided a general categorisation of these factors, grouping them into coercive, normative, and mimetic isomorphic forces. *Coercive isomorphism* refers to changes driven through influences exerted by those in power (e.g., government mandate) or by cultural expectations in the society (Thoenig, 2011). *Normative isomorphism* denotes forces which cause actors to conform in order to be perceived as engaging in legitimate activities. *Mimetic isomorphism* denotes when changes occur due to actors imitating the actions of successful competitors in the industry, to replicate the path of the latter's success.

In the context of kerbside access management for freight, coercive isomorphism denotes regulatory and spatial pressures, such as national transport policies, restrictions on public space access, increased delivery demand due to urbanisation, and the scarcity of LZs –all of which shape freight deliveries (Rose, Mollenkopf, Autry, & Bell, 2016). Normative isomorphism includes societal expectations and advocacy, including demands from the public and NGOs to regulate freight activity in support of environmental goals or to prioritise active modes of mobility (Akgün & Monios, 2018). Mimetic isomorphism occurs when local authorities replicate policies from other cities or other transport modes to regulate freight access (Akgün & Monios, 2018; Janjevic & Ndiaye, 2014).

In this way, RQ3 guided the exploration of factors arising before, during, and after pilots of kerbside interventions which supported or hindered their institutionalisation process. The factors were categorised into coercive, normative, and mimetic forces.

2.5. Summary of the conceptual background

Three concepts supported the formulation of the research questions guiding the knowledge generation about kerbside access management in the context of urban freight.

First, the concept of loose couplings provided the basis to explore misalignments between the goal of the urban freight system and the components of the freight delivery interface.

Second, the data-driven approach helped examine the extent to which data-driven kerbside interventions can support the management of freight-related supply–demand imbalances and contribute to sustainable urban development.

Third, the concept of the institutionalisation process was used to understand the forces of change in the introduction of kerbside interventions –and with it, the identification of factors influencing their adoption as established practices.

The triangulation of the problem (supply–demand imbalance), the empirical focus (access management in urban freight), and the conceptual background (loose couplings, data-driven decision-making, and institutionalisation process) informed the three research questions which structure this thesis:

- RQ1 – How does the misalignment between the urban freight system's goal and the components of the freight delivery interface affect kerbside access for freight?
- RQ2 – To what extent do data-driven kerbside interventions for freight contribute to achieving the targets of sustainable cities and communities?
- RQ3 – What factors influence the institutionalisation of kerbside interventions for freight deliveries?

3. Methodology

This chapter begins with a general overview of the research process before presenting the research designs, strategies, and methods used to address the RQs. Thereafter, research quality considerations are discussed in terms of reliability, replicability, and validity.

3.1. Research process

The research process employed for this thesis (see Figure 4) operationalised efforts to achieve the research aim and answer the RQs. In the process, the delineation of three studies helped to break down the general focus of the research into work packages with specific research strategies, designs, and outputs (in the form of paper publications).

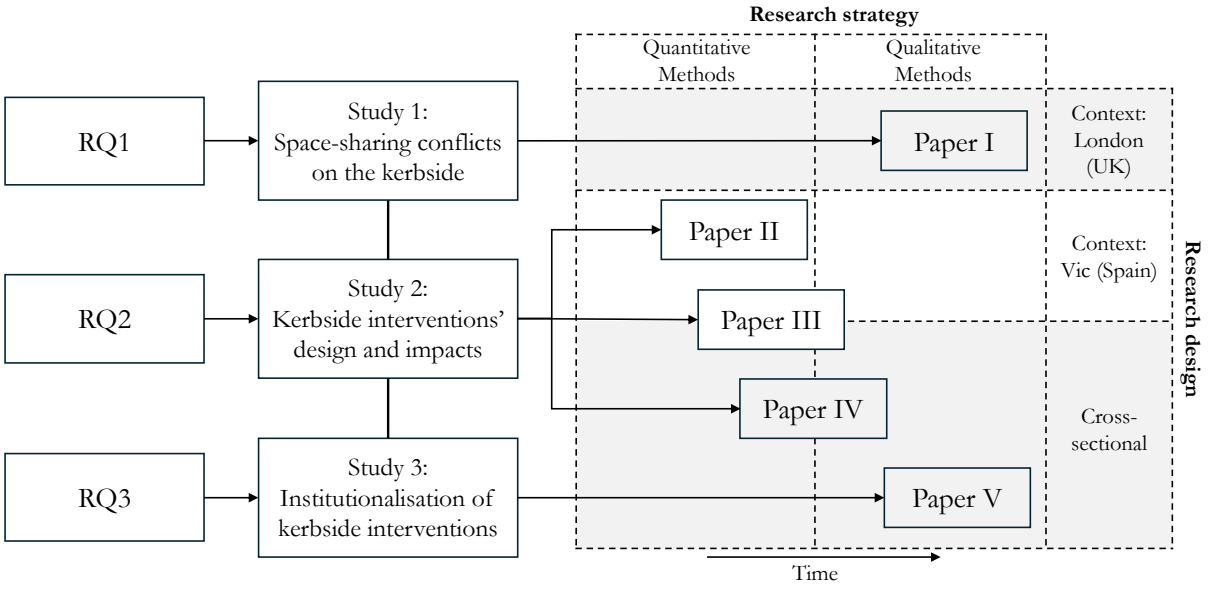

Figure 4. Research process

Study 1, "Space-sharing conflicts on the kerbside", explored the conflicts over sharing kerbside space between freight and other users of the space; it involved gathering empirical data from the West End of Central London (UK). Qualitative methods –namely interviews, direct observation, and a workshop– were used to collect the data used to identify and analyse loose couplings in kerbside access management for freight. Couplings were assessed in terms of freight-related interactions; for example, the interactions between freight and street regulations, freight and pedestrians, and freight and private cars (among others) were examined, with a focus on contrasting goals and the implications of allocation decisions for freight transport operators. This analysis provided the input for answering RQ1 (reported in Paper I), leading to a proposed framework for kerbside conflict assessment and reflections on ROW allocation approaches coping with these conflicts.

Study 2, "Kerbside interventions' design and impacts", focused on understanding the supply–demand imbalance of kerbside space for freight deliveries and the development of interventions based on data analytics. The results yielded quantitative and qualitative data which were used to answer RQ2 (regarding the design of kerbside interventions and their alignment to SDG11 targets). The city of Vic, Spain was selected as the context due to availability of probed data for freight operations at specific LZs, which enabled the implementation of quantitative methods to explain kerbside supply and demand.

Additionally, a systematic literature review supporting the exploratory approach assessed the impact of kerbside interventions on SDG11. The outputs of Study 2 consist of three papers which present the results of kerbside supply assessments (Paper II), of modelling and predicting freight parking durations (Paper III), and of a meta-analysis extracting impact quantifications from a systematic review of literature (Paper IV).

Study 3, "Institutionalisation of kerbside interventions", explored factors supporting or hindering the institutionalisation process of kerbside interventions using a cross-sectional design. Interviews with actors involved in kerbside pilots worldwide provided the data to answer RQ3. The output of Study 3, Paper V, elucidated how freight kerbside pilots are influenced by their structure and the forces of change –i.e., coercive, normative, and mimetic– in either an evolution to established practices or non-adoption.

Although the diagram of the studies in Figure 4 shows a sequential deployment of the research, chronologically the doctoral project followed a non-sequential structure due to differences in the timing of data availability, field work, and the conceptual reflections which created iterations between practice and theory. For instance, Papers II and III were motivated by practice concerns regarding how to improve decisions about the kerbside with probing data from freight parking, but during the study, conceptual questions emerged related to space-sharing conflicts with other users (Paper I) and the impacts of decisions on SDGs (Paper IV), as well as an improved understanding of why some initiatives were permanently adopted and some not (Paper V).

3.2. Research design

This thesis built on a mixed methodological research design –i.e., incorporating qualitative and quantitative methods– and collected empirical data from two cities: London (UK) in Study 1, and Vic (Spain) in Study 2. Additionally, the cross-sectional research design in Studies 2 and 3 complemented the data collection with interviews and secondary data from more than 30 cities worldwide.

3.2.1. Contexts of study

Context selection was based on the convenience of data availability, the participation of cities in funded projects (by Vinnova, the Volvo Research Educational Foundations, and Transport – Chalmers Area of Advance), and the criterion of extreme/deviant, which aims to obtain information on unusual conditions which may be especially problematic or especially good in a more clearly defined sense (Flyvbjerg, 2006).

West End of Central London (United Kingdom)

The high confluence of people, freight, and services made the West End of Central London a relevant context for identifying space-sharing conflicts. Additionally, collaboration with the Central London Freight Quality Partnership (CLFQP) –a freight transport partnership between the public and private sectors seeking to improve the sustainability of freight in London (Allen, Browne, Piotrowska, & Woodburn, 2010)– facilitated access to information and the problematisation of streets by the thematic working group dedicated to examining these conflicts since 2022 with a focus on freight interactions at the kerbside.

Seven streets at the West End of Central London were included in the study (Figure 5). The West End hosts some of the most popular areas of the city, attracting locals and tourists to approximately 3,000 pubs and bars, 2,500 restaurants, 2,000 shops, and 100 museums

and cinemas, at streets and places such as Oxford Street, Regent Street, Covent Garden, Soho, Mayfair, and Piccadilly (Allen et al., 2018). Besides vibrant commercial activity, the mixed land use makes it home to 60,000 residents and the host of 522,000 jobs (for an average of 800 jobs per hectare) and 200 million visitors per year. The West End accounts for 15% of London's total gross value added (Greater London Authority, 2018).

Figure 5. Geographical scope for Study 1 –Paper I

Field visits to the selected streets and interviews with members of the CLFQP were conducted to collect data about the intensity of freight activities and the occurrence of conflicts on the kerbside (see description in Section 3.3.1). The data assessment process culminated in the development of a framework which identified conflict triggers and reactions of freight transport operators that contributed to space-sharing conflicts. To ensure the robustness and applicability of the framework, a workshop was conducted (see description in Section 3.3.1) with representatives from industry, the public sector, and academia, with the primary goals of validating the proposed framework and collecting data about conflicts' implications for freight, which informed the answer to RQ1 (see Section 5.1).

The City of Vic (Spain)

For the research conducted in Study 2 for Papers II and III, the context was determined to be the geographical area of the historic centre of the City of Vic, Spain, the capital city of the *comarca* of Osona in the province of Barcelona. This city was selected due to its pioneering experience with implementing digital devices to manage LZs in the historical centre as part of the Z-DUMA initiative. This initiative entailed implementing a parking regulation which allocates dedicated space for freight deliveries at the kerbside. With the utilisation of mobile app technology provided by Parkunload®, the regulation aims to digitalise the management of the kerb and make better decisions based on data analytics.

The city provided data about all freight parking operations which occurred between July 2018 and December 2019 at eight LZs, defined a priori by the city's Office of Mobility (see Figure 6). The data contained information from more than 103,000 operations on the duration of freight vehicle stays at the kerbside, as well as commodity type (commercial, construction, food, installation and maintenance, transport and parcels, local commerce, or other), vehicle size (light vehicle [<3.5 T], van, truck [≥3.5 T], or private car) and vehicle technology (high-emissions, medium-emissions, low-emissions, hybrid, or electric). Data on those features were collected through a check-in/check-out app-based system run by Parkunload®; freight transport operators had to check in every time they parked in an LZ and check out upon leaving. In addition to the mobile app, Bluetooth sensors were installed

on parking signs to detect the presence of vehicles, which made the data regarding, e.g., parking durations reliable.

Figure 6. Geographical scope for Study 2 –Papers II and III

Data about kerbside infrastructure (LZs' dimensions and access to roads), establishments' locations, and their economic activity complemented the parking dataset provided by the city of Vic. Specifically, the data contained geometric details about the LZs, including length and width in metres, distances between LZs, and capacity in terms of parking stalls. Data on the managerial aspects of the LZs were also collected via interviews with municipal public servants and representatives of the technology provider (see description in Section 3.3.1).

Meanwhile, regarding the relevant establishments, the data covered 348 establishments located within a maximum walking distance of 200 m from each LZ. All such establishments were in the city centre (black dots in Figure 6) and consisted of retail stores, restaurants, and hotels, among others. The walking distance between the establishments and the eight LZs was accessed using Google Maps API 4.4.5 in Python 3.7.10. The total area (m^2) of those establishments and the economic activity were collected from OpenStreetMap and manually augmented with data read from Google Maps. The analysis of those data and parking operations are described in Section 3.3.2.

Taken together, the collected qualitative and quantitative data fed the data analytics to expand the understanding of relevant interactions among the variables. This research design contributed primarily to Study 2, which generated data for assessing kerbside supply and demand for freight parking operations as well as on the role of data analytics in designing kerbside interventions (e.g., LZs equipped with digital technologies), informed by the experience of the city of Vic with the Parkunload® solution.

3.2.2. Cross-sectional design

Per Bryman & Bell (2015), a *cross-sectional design* refers to the collection of data at a single point in time but from more than one observation in order to examine patterns of association between a set of variables and the unit of analysis. Such a design was useful at different stages of this research for collecting data from multiple cities to answer the RQs which drive this thesis. In particular, the cross-sectional design supported the collection and analysis of data on global experiences with and approaches to kerbside access management for freight through various methods –including interviews, a systematic

literature review, and a meta-analysis (see Section 3.3)– which contributed to both Studies 2 and 3.

In Study 2 – Paper III, the cross-sectional design was used to collect data from primary sources about the use of technologies to track freight parking operations at the kerbside and the managerial implications, from the perspectives of distinct stakeholders (see Section 3.3.1). These managerial implications were also discussed and synthesised in a framework for smart loading zones (SLZs) in Paper II (see Section 5.2).

In Study 2 – Paper IV, the cross-sectional design supported the collection of data on documented experiences around the world –31 cities in all– regarding the relationship between kerbside management initiatives and metrics for SDG11. Quantified performance measures of freight kerbside management (delivery times, emissions, occupancy rates, cruising, costs, and parking violations) were linked to the metrics for SDG11 using a meta-analytical approach (see Section 3.3.2), and general associations among the variables guided the discussion which informed the answer to RQ2 (see Section 5.2).

In Study 3 – Paper V, the cross-sectional design was useful in exploring experiences from stakeholders participating in kerbside pilots worldwide. In total, 17 cities were included in the study, which involved semi-structured interviews (see Section 3.3.1) providing insights into success and failure factors during the pre-pilot, pilot, and post-pilot phases of kerbside interventions. Data analysis led to the identification of factors supporting and hindering the institutionalisation processes of these interventions through coercive, normative, and mimetic forces, informing the answer to RQ3 (see Section 5.3).

3.3. Research strategy

The research for this thesis comprised quantitative and qualitative methods to analyse probed data from parking operations provided by the City of Vic and data collected via semi-structured interviews, a workshop, direct observation, and a systematic literature review. The two types of methods made complementary contributions to the development of the research.

Qualitative methods were used to identify key constructs, relationships, and elements relevant to kerbside access management for freight. These insights heavily informed the research process described in Section 3.1. For their part, quantitative methods provided data on the magnitude and direction of the variables' interactions and enabled the formulation of prescriptive solutions, such as optimisation strategies (Paper II) and policy scenarios (Paper III). The process was not linear but cyclical: findings at each stage were re-examined to ensure contextual and theoretical relevance and robustness, which is why the papers presented in this thesis are not ordered in a chronological sequence.

This back-and-forth interaction went beyond the application of standard techniques to available data: it involved the construction and refinement of knowledge by integrating empirical observation and data-driven reasoning into conceptual frameworks and the developed tools.

3.3.1. Qualitative methods

The qualitative approach consisted of three methods: interviews, workshops, and field observation.

In the identification of loose couplings in Study 1, qualitative methods supported the data collection and analysis through interviews, a workshop, and field observations. Qualitative methods have been prominent in other studies seeking to identify loose couplings (Elken & Vukasovic, 2019). By contrast, in this study, qualitative methods were utilised to provide an understanding of conflict triggers, reactions of freight operators, and actual conflicts. Additionally, qualitative methods were used to comprehend the freight implications of ROW allocation approaches (as addressed in Section 5.1).

In Study 2, the exploratory component of Paper III was aimed at gaining insights from transport planners, freight operators, and researchers on the managerial aspects of freight kerbside operations. Data from semi-structured interviews explored participants' perceptions of kerbside supply and the role of digital technologies in improving the performance of operations.

In Study 3, semi-structured interviews were conducted with stakeholders who were leading or actively participating in various kerbside pilot phases (pre-, during, and post-pilot). An initial set of cases was identified through website screening, whereafter the stakeholders of the pilots were contacted for interviews to obtain detailed information. The final case selection was based on the pilots' maturity level, namely pilots which went through monitoring, evaluation, and possible continuation processes.

Interviews – Studies 1, 2, and 3

Interviews were conducted online (except those in Study 1) and lasted 25–105 minutes. The interview protocols are given in **Appendix A** and vary according to the focus of each study and the stakeholder role. Interviews were assessed using NVivo® version 20.5.0. For Study 1, the coding structure was generated from the collected data; the codes which emerged corresponded to conflict triggers, freight transport operators' reactions, and a characterisation of space-sharing conflicts identified from the data. For Study 2 and Study 3, structural coding was employed to identify the relevant codes provided by the data analysis (Saldaña, 2021). Codification is shown in **Appendix B**. Table 2 summarises the information about the number of participants for each study and their roles.

Table 2. Interview participants

	Transport planners	**Freight operators / companies**	**Kerbside technology provider**	**Experts (academia /consulting)**	**Total**
Study 1 (London) Members of the CLFQP kerbside working group	4	3	1	2	10
Study 2 (5 cities) Vinnova's project members and participants referred by the project's steering group	6	2	1	1	10
Study 3 (17 cities) Kerbside pilot participants	4	-	5	10	19

Workshop – Study 1

In Study 1, a workshop was conducted to validate the findings from interviews and field observations, particularly in relation to the conflict assessment framework. Eleven people participated, representing industry (7), the public sector (3), and academia (1). The number

of participants is consistent with recommendations from previous studies on urban planning regarding holding small groups with deep and expert views of the discussed topic (Valença, Moura, & Morais de Sá, 2023). The purpose of the workshop was two-fold: first, it allowed the collection of participants' perceptions about the occurrence of conflicts and their causes; second, it stimulated discussions about the implications of space-sharing conflicts for health, society, economy, and environment.

Field observation – Study 1

In Study 1, direct observation through field visits provided data for assessing infrastructure supply and identifying conflicts on the selected streets. Direct observation of urban conditions has been reported as a useful tool for conducting spatial ethnography and for collecting insights about spatial patterns and the interactions among users of public space (Kim, 2015). Part of these visits included joining a delivery operation (ride-along), which involved observations and counting interactions with other users –namely pedestrians and cyclists– during loading and unloading activities.

During the field visits and ride-along, two freight associations affiliated with the CLFQP actively contributed to the data collection process. They provided insights into the demand for freight operations on the selected streets and highlighted conflicts which impede their operational efficiency.

3.3.2. Quantitative methods

A quantitative design was implemented in Study 2, to explore significant factors in the demand and supply of kerbside space for freight operations and to develop machine learning tools for data analytics to inform the design of kerbside interventions. A meta-analysis of reported effects provided estimations of streetside interventions in terms of SDG11 metrics.

In the design of kerbside interventions in Study 2, two data analytics methods – prescriptive and predictive– were implemented, with the use of freight parking records from Parkunload® from Vic. In the case study, prescriptive methods supported the analysis of supply concerning LZs' allocation, while predictive methods helped to clarify the dynamics of parking durations and the most influential demand factors which enable informed regulations on parking duration. Finally, a meta-analysis was conducted to quantify the effects of freight kerbside management interventions on SDG11 metrics, drawing from the results of a systematic literature review.

Prescriptive methods

Prescriptive methods, defined as data analytics procedures which provide optimal solutions to a specific problem (Appelbaum, Kogan, Vasarhelyi, & Yan, 2017), supported the assessment of LZs' supply conditions in Study 2. The methods considered variables such as the area of establishments, their economic activity and location, estimated demand for freight parking demand, walking distances from the LZs to the establishments, the availability of parking infrastructure, and the road network. In a two-step procedure, first the interactions between spatial and demand variables were captured by way of a greenfield analysis; second, LZs' locations were optimised based on the available parking spaces. Paper II contains a detailed explanation of the procedures and algorithms, which are summarised below.

The greenfield analysis involved applying an LZ location problem using a continuous and unrestricted space in the studied zone of the city. Clustering algorithms grouped establishments based on a weighted distance criterion (namely, walking distance multiplied by an establishment's freight demand) either from a central theoretical point in each cluster –that is, *k*-means– or from the surrounding neighbours –that is, DBSCAN. After several iterations, the algorithms converged to a set of establishment-inclusive clusters whose centroids represented hypothetical locations for LZs. The walking distance between a centroid and grouped establishments met a maximum length defined by a coverage constraint (e.g., a walking distance of 75 m). Table 3 summarises the greenfield analysis's data needs, models, and outputs.

Table 3. Summary of the greenfield analysis

<table>
<tr><th>Input data</th><th>Model</th><th>Output</th></tr>
<tr><td>Location of establishments</td><td rowspan="4">Clustering models used to compare performance to identify the best algorithm (i.e., k-means or DBSCAN) based on urban morphologies</td><td>Number of potential LZs</td></tr>
<tr><td>Walking distance between establishments</td><td rowspan="2">Approximate location of LZs</td></tr>
<tr><td>Spatial information from the study area (e.g., maps and roads)</td></tr>
<tr><td>Parking demand:
- Vehicle arrival rates
- Parking durations
- Economic activity of establishments
- Area of establishments</td><td>Establishments' allocation to potential LZs represented by the centroid of each cluster</td></tr>
</table>

Source: Paper II

Freight kerbside demand was computed following Equation 1, in which τ_{jt} is the number of parking stalls required by the establishment *j* at time *t*. Equation 1 was derived from Little's law of queueing systems applied to parking operations (Tavafoghi, Poolla, & Varaiya, 2019). Moreover, λ_{kt} represents the arrival rate calculated with parking data from the LZ, *k*, at time *t*; μ_c corresponds to the specific parking duration computed for the economic activity, *c*, to which establishment *j* belongs; θ is the acceptable kerbside service level which public authorities expect (85% is the most widely used); and WA_j^k denotes the weighted factor for the proportion of the area that establishment *j* occupies among all establishments in the same cluster, *k*. The weighted factor is included to account for the number of establishments served by a freight vehicle per stop.

$$\tau_{jt} = \frac{\lambda_{kt}\mu_c}{\theta} WA_j^k \quad (1)$$

Because the pre-identified centroids of the clusters could be located at unfeasible locations, the second step adjusted the results of the greenfield analysis by determining the optimal number and size of LZs as well as feasible locations for them, depending on kerbside features and available infrastructure. Integer linear programming was used to determine the minimum number of LZs and the number of parking stalls needed to satisfy the demand for parking at each hour throughout the day. The model was run using the extended educational license of Lingo® 18.0.56. Table 4 summarises the data-intensive needs, models, and outputs of the assessment of location allocation.

Because the City of Vic had already defined the locations and dimensions of LZs needed to satisfy the parking demand from more than 340 establishments in the city centre, the results from the optimal location-allocation analysis were contrasted with the current

situation to identify conditions of over- or undersupply of LZ infrastructure within different windows of time.

Table 4. Summary of the analysis of optimal location allocation of LZs

Input data	Model	Output
Number and location of LZs (from greenfield analysis) and a list of feasible locations close to the centroids of clusters	Integer linear programming for the LZ location-allocation problem	Optimal number of LZs
Walking distance between LZs and establishments		Optimal location of LZs
Parking demand (Equation 1)		Optimal number of parking stalls per LZs

Source: Paper II

Predictive methods and multivariate analysis

On the demand side of Study 2, quantitative methods were applied to predict parking durations and LZ occupancy levels based on significant variables which explain variability in durations. Two approaches guided comparisons in duration analytics and LZ occupancy predictions: queueing models and predictive machine learning (ML) algorithms. The former used the arrival and departure times of freight vehicles as input data to estimate probability distributions of birth–death processes, while the latter used parking duration as the response variable and the attributes of parking operations (vehicle type, commodity, weather conditions and time of the day, week, month, or year) as covariates. Based on the predicted durations, an occupancy profile was constructed for the LZs in the case study, and error metrics were used to determine the models' accuracy based on a comparison of predictions and observations. Paper III contains a detailed explanation of the implemented procedures and algorithms, which are summarised below.

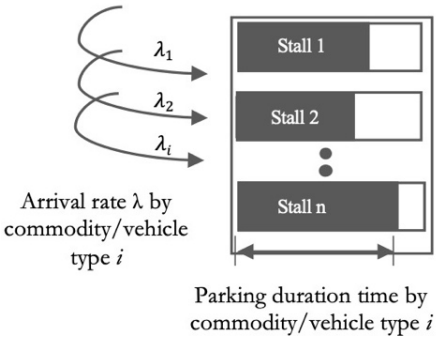

Figure 7. Queueing modelling approach for freight parking operations
Source: Kalahasthi et al. (2022)

In the queueing modelling approach (see Figure 7), freight parking is understood as a stochastic process, with probabilistic vehicle arrival and departure rates to and from parking stalls representing servers in a time-varying $M(t)/G(t)/n$ queue –i.e., non-homogeneous Poisson processes. $M(t)$ represents the Poisson process, defined as discrete events which happen at a random rate of λ. $G(t)$ is the time-varying cumulative probability distribution of parking durations (μ). The model considers a multi-server system because n multiple parking stalls per LZ independently provide parking space services in parallel on a first-come, first-served basis. The number of occupied stalls $N(t)$ is a Poisson random variable

with a mean $\eta(t)$ which results from assessing the functions $M(t)$ and $G(t)$. For instance, in the stationary case, with λ and μ as constants, occupancy estimations follow $\eta = \lambda\mu$ by way of Little's law.

In the ML approach, a set of algorithms for forecasting parking durations were tested. Generalised linear models were the baseline with which regression trees, gradient-boosting machines, and neural networks were compared. The decision variable was parking duration based on the features vector $\mathbb{X}$, which contained 59 explanatory variables related to two numerical variables (feels-like temperature and precipitation) and dummy variables representing six categorical variables (vehicle type, vehicle emissions type, professional activity, LZ, hour of day [1-hour bins from 6:00–18:00], day of the week and month), all obtained after data pre-processing and dimensionality reduction. In addition to predicting durations, ML algorithms were also employed to evaluate the importance of the factors contained in $\mathbb{X}$, which were ranked according to the significance of their associations with the variability in parking durations.

Computed parking durations were the input for the arrival–departure timestamps needed to estimate occupancy rates per unit of time *t*, as expressed in Equation 2, in which $n_p(t)$ is the number of active freight parking operations in the LZ p at time t, and $C_p(t)$ is the number of parking stalls available at LZ *p* at time *t*.

$$Occupancy_p(t) = \frac{1}{C_p(t)} \sum\nolimits_p n_p(t) \quad (2)$$

The models' accuracy and explanatory power were assessed using metrics including the coefficient of determination R^2, the mean absolute error, the root mean square error, and the symmetric mean absolute percentage error. The dataset was split into training (80%) and testing (20%) sets, of which the latter was the base for the evaluation of accuracy (i.e., forecasted vs. observed). The best ML algorithm was the one with the least error achieved.

Lastly, the forecasted occupancy levels from queueing models and the best ML algorithm were compared using a validation dataset composed of observed parking data which was not used in the training–testing process. The selected method was the one with the least mean absolute error in estimating occupied parking stalls per hour at each LZ.

Meta-analysis: Balancing supply and demand

Meta-analysis is a technique for extracting the necessary quantitative data to conduct a statistical synthesis of multiple studies (Xiao & Watson, 2017). In the research for this thesis, the systematic literature review entailed searching for published work reporting performance measures for freight kerbside interventions. Because effect metrics vary from one case to another, the statistics of the reported studies were collected and transformed to comparable scales (e.g., elasticities or percentage of change). In essence, the data extraction considered the percentage of change in performance measures of freight kerbside management factors and linked them to the metrics for SDG11.

The systematic literature review was built on the following search query: ("freight parking" OR "loading zone" OR "loading bay") AND ("curbside" OR "curb side" OR "kerbside" OR "street") AND ("impact" OR "effect") AND ("sustainability" OR "sustainable development" OR "environment") AND ("urban" OR "city"). To avoid sample bias (i.e., publication bias), the Google Scholar database was used to access grey literature, including unpublished reports, thesis, preprints, and white papers; publications

from the Web of Science, ProQuest, and Scopus databases were included as well. The search process was conducted in April 2022 and updated in June 2023.

The filtering of the first query results consisted of selecting published works based on information in the title and snippet; only works which contained the keywords connected coherently to aspects related to the research conducted for this thesis were selected. The screening process eliminated 143 duplicated results and revealed 375 records which matched the research interest. After the deletion and exclusion criteria shown in Figure 8 were applied, 57 records were included for data extraction. The list of references is available at https://dsw.chalmers.se/projects/d69106a2-6a4b-42d5-9a47-5185b9f7f621.

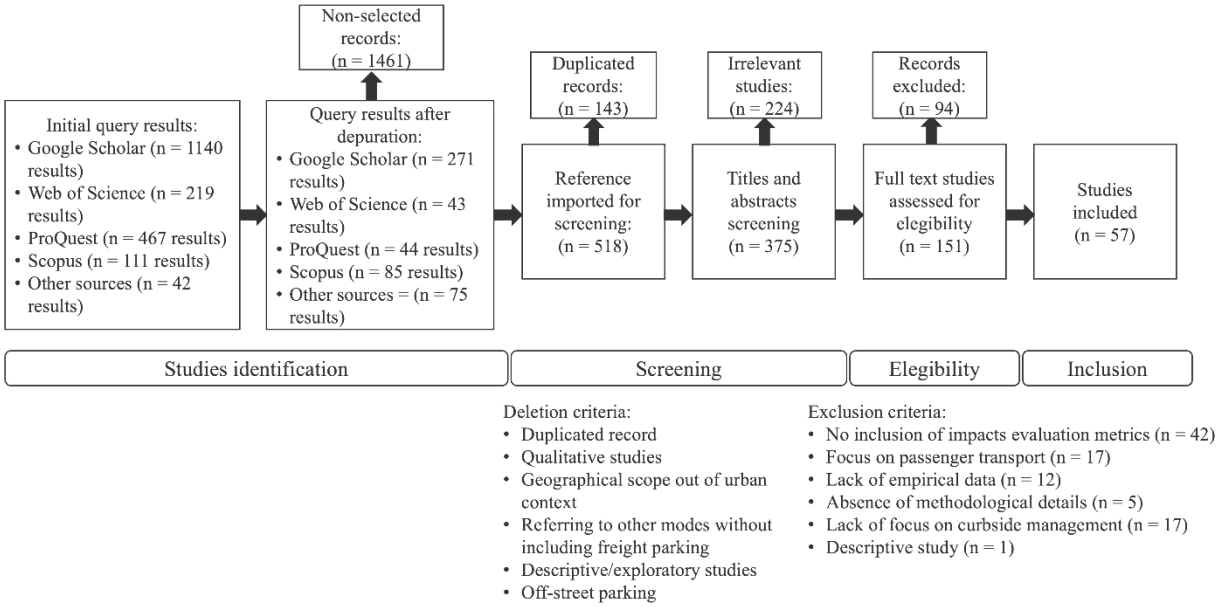

Figure 8. PRISMA diagram of the systematic literature review
Source: Paper IV

Published works were selected based on the possibility of accessing quantitative results on delivery times, costs, parking violations, emissions, kerbside occupancy rates, and cruising for parking as indicators of the performance of kerbside management. In addition to the summary statistics, the systematic literature review also collected information about the country, city, and zone of study, as well as the data collection methods and assessment tools (e.g., microsimulation and optimisation). Performance measures were assigned to the corresponding SDG11 metrics based on each paper's aim and practical implications.

3.4. Research quality

Bryman & Bell (2015) defined three criteria for evaluating research quality: reliability, replication, and validity. *Reliability* refers to the consistency of the results across reiterations of the same study. Relatedly, *replication* refers to the possibility of the research's replicability by other researchers using the same data and documented methods. *Validity* refers to the integrity of the conclusions of the research and the transferability of the results.

With regard to reliability, the quantitative approach of this thesis involved using different algorithms and optimisation models which are subject to variation according to the modeller's view, the software's characteristics, and/or data randomness. Detailed documentation of the implemented models' parameters and hyper-parameters coupled with the technical specifications of the software used to run the models mitigated reliability risks. Randomness also had to be considered, because some variables were probabilistic in nature.

The probability distributions of the assessed variables with the corresponding estimators of maximum likelihood and deviation metrics were also documented. At the same time, ensuring reliability in the qualitative approach was possible by ensuring that the interview protocols were consistent in each study and followed the same template according to the actor's role. Recording the interviews also helped to reduce the risk that the researchers overlooked any information. Two researchers were present throughout the interviews, which facilitated discussions after each interview to avoid interpretation bias.

With regard to replicability, Bryman & Bell (2015) suggested that procedures must be documented in detail so that replication is possible. In addition to documenting the models in the papers, all of the algorithms, the optimisation model, and the systematic literature review's process and results were uploaded at https://github.com/jpcastrellont/freight_curbside_operations.git, to satisfy this quality criterion and to encourage transparency and replicability in the use of the quantitative tools. However, real data from the case study were not uploaded, due to confidentiality agreements and compliance with the General Data Protection Regulation (GDPR).

Validity can be categorised into internal and external validity. *Internal validity* refers to whether a study provides enough elements to answer its RQ(s) to an adequate degree (Säfsten & Gustavsson, 2020). The mixed qualitative–quantitative approach to address the RQs in the research conducted for this thesis provided complementary contributions to solving the research problem; it also motivated a triangulation process to assess the findings' suitability and validity according to the perspectives of actors interviewed or participating in the workshop as well as the results from reference studies in the literature. In the quantitative approach, the use of multiple data sources (e.g., weather conditions, parking operations, and establishment data) together with the comparison of methods (queueing models vs. ML algorithms) helped to ensure robust internal validity, rooted in objective performance evaluations; beyond that, the statistical measures for evaluating the models' explanatory power and the variables' significance were constantly assessed, such that decisions about model selection prioritised the best performance and conceptual validity. In the qualitative approach, the triangulation of sources and respondents' validation of the data after the dissemination of the analysis of the interviews, workshop, and direct observation mitigated the risks of poor internal validity.

External validity refers to the generalisability of results (Säfsten & Gustavsson, 2020). Throughout the five appended papers, transferability is a key topic of discussion. Given the variability of urban conditions, it is challenging to generalise results from either quantitative models (based on case data) or qualitative studies (based on actors' perspectives of specific contexts). Nonetheless, data attributes and analytics procedures implemented in the research can be transferred to other studies and contexts, as discussed in Section 6.4.

Use of Artificial Intelligence (AI) Tools. AI-based writing support tools (specifically ChatGPT by OpenAI and Copilot by Microsoft) were used to assist in the writing and revision of this dissertation. These tools supported such tasks as improving clarity, refining academic language, and restructuring selected sections based on author-provided inputs. No AI tools were used in the optimisation, ML algorithms, interviews, coding, and literature reviews included in the appended papers. All content and interpretations remain the responsibility of the author.

4. Summary of the appended papers

This chapter summarises the papers included in this thesis, with a description of their focus, the methodological approach, their major findings, and their contributions.

4.1. Paper I: "Space-Sharing and Kerbside Conflicts in Urban Deliveries: A Framework for Understanding Space Allocation Challenges"

Paper I's aim was twofold: to analyse freight-related space-sharing conflicts, and to explore the implications of these conflicts related to the value provided by streets to freight operators in health, social, economic, and environmental terms. The paper presents reflections on potential ROW allocation approaches which mitigate adverse effects.

Data gathered from seven streets in the West End of Central London, UK, revealed tensions between transport modes, space uses, and freight delivery operations, which served as input for defining the framework and assessing value implications for freight operators experiencing space-sharing conflicts. The data collection process encompassed field visits, interviews, and a workshop with public and private stakeholders.

The research contributes to the analysis of freight parking operations and their interactions with other users by offering a multi-actor perspective. Furthermore, the research contributes to urban planning by providing insights for ROW decisions which include the freight perspective.

4.2. Paper II: "Smart loading zones. A data analytics approach for loading zones network design"

Paper II investigated the elements of design which urban transport planners consider when allocating kerbside space for freight operations. Paper II's aim was twofold: to propose a conceptual approach to studying and developing SLZs, and to develop a data analytics approach for designing SLZ networks which determine the number, location, and size of LZs under stochastic freight parking demand.

The paper took a data analytics approach to designing LZ networks using the context of Vic, Spain. To define SLZs, literature on kerbside management was grouped into a three-level framework for addressing strategic (long-term), tactical (midterm), and operational (short-term) decisions regarding LZs' infrastructure, regulations, and information and communication technology (ICT). The paper focused on the strategic decision-making level, specifically on designing LZ networks.

Paper II's contribution is the definition of the concept of SLZs and their management. It provides tools for urban and transport planners who are constantly challenged by the trade-offs between land use optimisation due to scarce public space and the demands for service provision (i.e., establishments' needs for freight accessibility). The utilised modelling approach for designing LZ networks enables urban transport planners to reconcile this trade-off using accurate data about when and how much space is required for parking for freight operations.

4.3. Paper III: "Enabling factors and durations data analytics for dynamic freight parking limits"

Paper III aimed to identify factors which enable dynamic parking duration limits in parking regulations and to assess data analytics tools which support the design of these regulations, based on an explanatory analysis and estimated forecasts of freight parking durations and LZs' occupancy levels.

Qualitative methods (semi-structured interviews) were conducted to collect data to identify factors enabling flexible LZ management. A quantitative approach (generalised linear modelling) was used to assess the significance of variables which influence freight parking durations and to evaluate analytical tools (queueing models and ML algorithms) for their accuracy in forecasting freight parking durations and LZ occupancy levels. Data for the quantitative approach came from the context of Vic, Spain.

Paper III contributes to the field of freight parking by elucidating factors underpinning successful implementation of dynamic regulations based on demand conditions and revealing how data analytics can support the definition of dynamic parking limits which facilitate flexible kerbside management. Formal representations from queuing theory and ML were employed and tested in the studied context; as a result, insights on their use and parametrisation are another contribution of the paper. Tailor-made regulations can be designed by applying these models to specific contexts and areas of cities.

4.4. Paper IV: "Effects of freight curbside management on sustainable cities: Evidence and paths forward"

Paper IV aimed to explore how kerbside management interventions can make freight parking practices sustainable by reviewing reported quantifications of performance measures and linking them to SDG11 metrics.

A meta-analysis was performed to explore the effects of kerbside management on the realisation of SDG11 through a systematic literature review. Aside from the Key Performance Indicators (KPIs) of freight parking operations (i.e., delivery times, emissions, occupancy rates, cruising, costs, and parking violations), data on empirical data, context(s) studied, and methods reported in the 57 works reviewed were also collected.

Paper IV contributes by identifying how beneficial or detrimental freight parking interventions are for cities' sustainability and by quantifying the effects of kerbside management on the achievement of the UN's SDGs.

4.5. Paper V: "From pilot to policy: examining the transition towards institutionalized practices in freight curbside management"

The aim of Paper V was to understand the success and failure factors which influence the institutionalisation process of kerbside interventions for freight deliveries. To achieve this, the paper analysed cases from various cities worldwide which have implemented kerbside pilots, using the lens of institutional theory.

Nineteen semi-structured interviews were conducted with actors who were leading or actively participating in the pre-, during, and post-pilot phases. The case selection was based on the pilots' maturity level—i.e., pilots which went through monitoring, evaluation, and possible continuation processes.

The findings support recommendations and guidelines for the development of future pilots, which is useful for planners seeking to generate long-term kerbside policies which solve freight-related space-sharing conflicts.

4.6. Summary of papers' contributions

The types of the contributions of each paper are summarised in Table 5. Conceptual or theoretical contributions involve new or improved definitions of existing constructs or concepts. Methodological contributions consist of the development of novel methods to study the problem under investigation. Contributions to research into practice/utilisation include insights which practitioners can use to approach the solution of practical problems.

Table 5. Summary of papers' contributions

	Type of contribution		
	Conceptual / Theoretical	**Methodological**	**Research into practice / Utilisation**
Paper I	Framework for assessing space-sharing conflicts involving freight operators.	-	Considerations about freight access needs and impacts on sustainability for ROW allocation decisions.
Paper II	Definition of SLZs and decision-making framework informing the design of kerbside interventions.	Machine learning in analytics tools for freight delivery data.	Data analytics supporting decision-making in the allocation and management of kerbside space.
Paper III	Factors explaining freight demand for kerbside space.	Comparison of modelling tools for estimating parking durations and forecasting LZ occupation.	Data analytics for the design of flexible regulations concerning kerbside access for freight deliveries.
Paper IV	Operationalisation of the SLZ framework with measurable indicators for impact assessment	-	Quantification of effects of kerbside interventions on sustainable development goals.
Paper V	Factors influencing the institutionalisation process of kerbside interventions.	-	Recommendations for institutionalising freight kerbside interventions.

Beyond the individual contributions of the papers presented in Table 5, this thesis offers a structured approach to kerbside access management for freight deliveries (see Section 6.4). It delineates key areas of action which researchers and practitioners can adopt as a guide to advance the field and to further develop the concepts introduced in this work.

5. Results

This chapter presents the analysis of the results drawn from the papers included in this thesis. The presentation of the results follows the sequence of RQs which address the research aim. As presented in Chapter 2, the RQs are:

- RQ1 – How does the misalignment between the urban freight system's goal and the components of the freight delivery interface affect kerbside access for freight? (Section 5.1)
- RQ2 – To what extent do data-driven kerbside interventions for freight contribute to achieving the targets of sustainable cities and communities? (Section 5.2)
- RQ3 – What factors influence the institutionalisation of kerbside interventions for freight deliveries? (Section 5.3)

The chapter concludes with a summary containing the main findings of the research in relation to the problem of kerbside supply–demand imbalance for freight deliveries.

5.1. The misalignment affecting kerbside access for freight

RQ1 motivated an analysis of loose couplings –i.e., the misalignment between the overall purpose of the urban freight system and the functioning of the components of the freight delivery interface. To investigate this misalignment, the thesis adopts Ingersoll's (1993) approach, focusing on three main areas: (i) assessing the extent to which interactions among the components of the freight delivery interface align with –or diverge from – the purpose of the urban freight system; (ii) exploring how these interactions impact freight delivery operations; and (iii) analysing the mechanisms through which allocation decisions can be made and enforced. The research identified how loose couplings undermine both the efficiency and the sustainability of freight deliveries. Understanding the implications of these loose couplings is a necessary step for developing interventions which improve coordination and help to better balance supply and demand of kerbside space for freight deliveries.

Urban freight system goal vs. realities at the freight delivery interface

The empirical findings from the selected streets in Central London, reported in Paper I, revealed loose couplings between the overarching objective of urban freight and the realities of kerbside space allocation and use. These loose couplings were found in conditions associated with the built environment, high and competing demands from several street users, and access regulations.

In the context of this thesis, the 'built environment' refers to the physical design and features of the street, including the arrangement of lanes, the presence and placement of bike lanes and racks, street furniture, loading zones, the street hierarchy (e.g., through routes), and disruptions caused by construction works. These conditions often constrain delivery operations and lead to reactions from freight operators which affect efficiency and urban liveability. For example, dedicated bike lanes located between receivers' locations and the kerbside, street furniture obstructing the access to receivers, and insufficient or poorly located loading zones restrict the space available for (un)loading goods, thereby forcing operators to spend additional time cruising for parking or to park illegally or at inconvenient distances from their destinations. Temporary changes in the built environment, such as

construction works or street redesigns, introduce additional uncertainty and further limit access.

At the same time, the kerbside is a site of intensely competing demands. Multiple users –including freight operators, private vehicles, taxis, public transport, service vehicles, cyclists, and pedestrians– demand limited kerbside space, especially in commercially active streets. High demand from these diverse actors lead to safety risks and overlapping demands for space from household parking, taxi zones, and freight (un)loading needs, as well as service vehicles and construction activity occupying kerbside areas. As a result, freight operators double park, circle in search of space, or (un)load in unauthorised areas, actions which in turn generate congestion and operational delays. These pressures are amplified during peak periods, which increases the likelihood of conflicts and spillover effects on adjacent streets.

In addition to these physical and demand-driven pressures are the complexities introduced by access regulations. Access regulations in kerbside management comprise the rules, restrictions, and enforcement practices which determine who can use the kerbside, when, and under what conditions. The analysis revealed that fragmented, inconsistent, or poorly communicated regulations –e.g., conflicting signage across administrative boundaries (e.g., boroughs), time-restricted access windows, and selective enforcement– significantly affected the efficiency of freight operations. In the London context, each borough has its own set of kerbside regulations, which means that freight operators must navigate non-standardised rules as they transit through different boroughs during a day. The absence of harmonised and clearly communicated regulations undermines effective planning and hinders operational efficiency, thereby contributing to broader inefficiencies within the urban freight system and reduced liveability in urban environments.

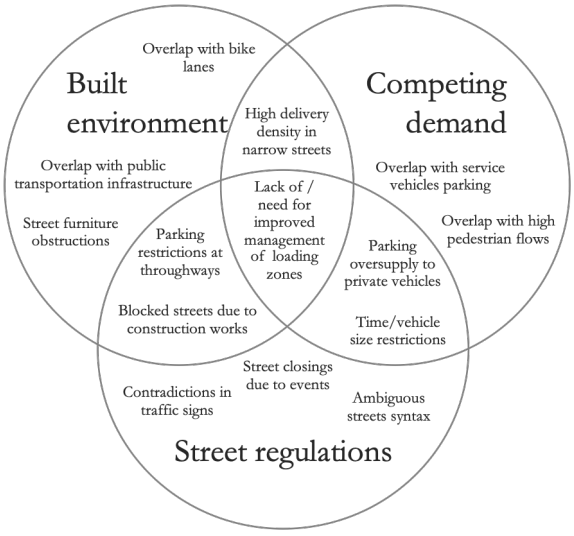

Figure 9. Tensions between freight and other users, grouped by conflict trigger
Source: Paper I

The identified loose couplings result in tensions in the interactions between freight and other users over the access to kerbside space, making it difficult to reconcile the goal of efficient freight delivery with the observed conditions of kerbside access. The analysis addressed in Paper I described freight-related interactions and tensions, clustered by component of the freight delivery interface; Figure 9 summarises the findings, labelling them as 'conflict triggers' in the freight access to kerbside space, given that they serve as

the root cause for freight operators' reactions and lead to conflicts over the use of public space.

The conflict triggers summarised in Figure 9 induce reactions from freight operators which amplify tensions over kerbside space. The observed reactions included queueing in the waits for parking space, parking in banned zones, portering (walking with goods from distant locations to the receiver point), operational changes (e.g., delivery cancellation or postponement), double parking, cruising, and parking on the pavement.

Finally, the research identified space-sharing conflicts as a result of the loose couplings in the freight delivery interface. Paper I defined these conflicts as follows:

- Collision risks: situations characterised by the potential for collisions involving freight vehicles, operators, or goods and other street users or infrastructure elements (such as street furniture.) This risk can occur on the pavement, in car/bike lanes, or city squares.
- Traffic obstruction: situations where the flow of pedestrians, cyclists, scooters, public transport, or cars is impeded by the presence of obstacles, such as parked freight vehicles, queues, or temporary goods occupying street space.
- Space overuse: situations characterised by prolonged dwell times or operational rework during deliveries due to restricted access to the designated delivery location. This contributes to increased street traffic, due to repeated attempts to execute the same activity. Moreover, this conflict results in prolonged occupation of space, particularly when freight operators are parked far away from the intended delivery point, as this leads to extended portering activities.
- Damage to the pavement: infrastructure effects due to parking on the pavement or (un)loading of goods. This conflict significantly impacts the safety aspects of other street users as well as subsequent freight operators who utilise the same space for their delivery operations. The degradation of pavement integrity not only poses potential hazards to individuals navigating the area but also creates challenges for the efficient and secure execution of freight deliveries.

Defining these conflicts extends the understanding of the problems which kerbside access management addresses when considering freight needs. In doing so, the research builds on and complements prior work exploring freight-related conflicts in addition to traditional traffic approaches (Conway et al., 2013; Pokorny et al., 2018). The results aid in addressing gaps highlighted by Conway et al. (2013), specifically those related to analysing conflicts which are often not explicitly recognised (such as pavement damage and overuse of space), as well as in drawing attention to the root causes of unsustainable impacts of freight in urban areas (i.e., conflict triggers). This broader categorisation and analysis provide an understanding of the ways misalignments between system goals and everyday practices manifest in urban freight, and why these issues are critical to the effective management of kerbside space.

Implications of misalignments on sustainability from the freight perspective

Space-sharing conflicts –which arise from the misalignment between the urban freight system goal and the conditions at the freight delivery interface– hamper the achievement of urban liveability, as elaborated in Paper I and illustrated in the framework shown in Figure 10. These conflicts result in unequal accessibility to transport infrastructure by street users, unsafe public spaces as a result of traffic violations, damages to the infrastructure,

collisions, illegal occupation of space, and poor air quality due to cruising or reworks after failed deliveries. While these consequences concern all street users, this research uncovered conflict implications on freight operators related to health, social, economic, and environmental aspects. Data collected during the workshop in Study 1 provided the insights for this analysis.

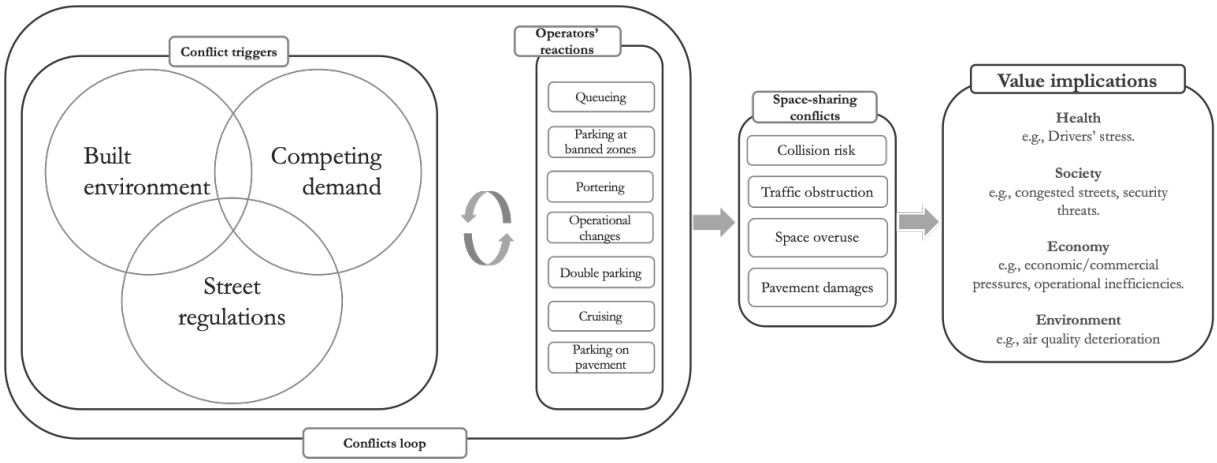

Figure 10. Framework for assessing freight-related space-sharing conflicts
Source: Paper I

The results revealed that health is affected by both physical and psychological risks. Collision risks inherent to contestations of kerbside space can result in injuries or fatalities for pedestrians, freight operators, and other users. Frequent traffic obstructions, prolonged dwell times, and repeated delivery attempts due to access restrictions or infrastructure failures lead to increased stress, anxiety, and exhaustion among delivery crews. Occupational risks are heightened by distant deliveries, which force operators to carry heavy loads without adequate equipment or support, and damaged pavements create additional safety hazards for all.

Socially, conflicts over kerbside access increase traffic congestion and undermine compliance with regulations, which produce spillover effects for all street users. Congestion and traffic violations often arise when freight transport operators attempt to work around obstacles or delivery restrictions, which can cause unsafe manoeuvres and traffic jams. Repeated delivery attempts (due to failed or delayed access) exacerbate congestion, while long working hours and elevated stress diminish the job satisfaction and stability of freight operators. Job quality is further compromised when performance metrics are impacted by circumstances outside operators' control, such as rerouting or delivery delays. Moreover, exclusion of freight from accessible kerbside space raises concerns about equity in the use of public streets.

Economically, space-sharing conflicts impose both direct and indirect costs on freight operators. Collisions and traffic obstructions lead to vehicle damage, repair costs, insurance claims, and potential legal liabilities, as well as penalties for delayed deliveries. Inefficient delivery operations caused by congestion or regulatory barriers increase labour and fuel expenses, and financial losses can be generated from the fines incurred for illegal or prolonged parking. Over time, these inefficiencies cause losses in competitiveness and jeopardise the continuation of business contracts. Damaged pavements and infrastructure from overuse or improper access further diminish the quality of the built environment and can generate reputational harm for freight operators and their companies.

From an environmental perspective, space-sharing conflicts contribute to urban air pollution and noise through increased cruising, traffic congestion, and repeated delivery trips. Operational inefficiencies, such as rerouting and re-scheduling of deliveries, raise fuel consumption and thus greenhouse gas emissions. Practices such as sudden braking, honking, and manoeuvring around obstacles add to local environmental degradation, and repeated access failures further intensify the environmental footprint of last-mile deliveries. Pavement damage also affects urban aesthetics and the overall quality of the urban environment.

In conclusion, freight operators play a dual role as both users and actors impacting the significance, worth, and utility of streets –i.e., the value of streets– in health, economic, social, and environmental terms (Carmona, 2018). As users, they require access to transport infrastructure to distribute goods, as well as designated areas for (un)loading activities and portering. Additionally, they are directly affected by the environmental and traffic conditions of streets, to which they are continually exposed. As value contributors, the service provided by freight operators enable the functioning of daily businesses and people's lives by supplying the goods necessary for these activities. For instance, previous research has suggested that freight deliveries contribute to the place-making function of streets by enabling economic activities (e.g., those of businesses such as restaurants, retailers, and shopping malls, among others) which enhance street vitality by attracting residents and visitors and which promote social interaction (Creutzig et al., 2020). Paper I addressed the implications of space-sharing conflicts on the four dimensions of the value of streets from the freight operators' perspective. The analysis of loose couplings served as a diagnosis tool which can inform approaches for space allocation, discussed below.

Approaches for making decisions on space allocation

Urban and transport planners have adopted different strategies to de-conflict the kerb, based on the type of demands and the priorities defined in urban and transport policies. For instance, Rodriguez-Valencia (2014) formulated the right-of-way allocation problem (ROWAP), which entails the optimisation of the distribution of the available space to fulfil streets' movement, place-making, and environmental functions. Although this definition relates to the utilitarian concept of value optimisation, Lefebvre-Ropars, Morency, & Negron-Poblete (2021) affirmed that the ROWAP can be approached using the lenses of three distributive justice principles: sufficientarian, utilitarian, and egalitarian. Focusing on the type of kerbside demand related to freight deliveries, this thesis built on these distributive justice principles and reflected on the extent to which they manage the identified space-sharing conflicts, their implications in policies, and implementation challenges.

The sufficientarian principle gives priority to ensuring that each kerbside user receives enough space to meet their access demand. Policymakers following a sufficientarian principle consider the demand for freight deliveries, then provide the corresponding space to fulfil this demand. This space can take the form of loading zones or dynamic-access regulations, which enable delivery operations at certain times of the day or week (further addressed in Section 5.2). The challenge of this approach emerges in situations where there is not enough space for the demand levels from all the users and providing space to all users is not possible. In such cases, ROW allocation decisions should rely on either utilitarian or egalitarian principles and prioritise users accordingly.

Under the utilitarian principle, ROW allocation decisions are based on the utility provided by freight and other users to the city's goals. Here, the space allocation for freight depends on the assessment of its contribution to the street's economic vibrancy and to the realisation of social interactions given the access to services/products on the street. This place-making role of freight would differentiate this demand type from movement functions or private vehicles' demand for space, as pointed out by Creutzig et al. (2020). The challenge of this approach is access to data which can inform allocation frameworks that consider built environment limitations, demand constraints, and the value generated by providing public space for freight deliveries. Although this research identified some categories and ways in which conflicts affect the value gained by freight users from street space, there is still a need to formalise and quantify users' impact on each dimension (health, social, economic, and environmental) and conflict intensity, so that the utilitarian problem can be formulated.

For its part, the egalitarian principle aims to provide equal access to space to all users and strives for participatory approaches to street design, assessing the impacts of public space enhancement on people's physical, social, and psychological well-being, as well as on economic development and the environment. Open innovation and city labs are strategies which have been implemented in different contexts to reach solutions which balance space needs and supply for all users. To this end, the freight-oriented framework for conflict assessments (Figure 10) can inspire discussions in co-creation activities, in which actors are called on to discuss conflict triggers, reactions from freight operators, generated conflicts, and the corresponding implications on value of streets. The solutions emerging from these discussions could follow this loop to assess the potential impacts.

While these justice principles offer distinct rationales for allocating kerbside space, in practice the application of all three is by means of kerbside interventions. LZs provide a tangible means of realising space allocation decisions, and their effective deployment depends on the tools and frameworks addressed in the following sections. Thus, this thesis focuses on LZs as a crucial intervention for managing kerbside access and balancing supply and demand for freight deliveries.

5.2. Kerbside interventions leading to sustainable cities

RQ2 corresponds to the identification and development of rules and practices which tighten the identified loose coupling, directing access management towards sustainable cities and communities. To this end, first, this thesis explored factors determining kerbside supply and demand for freight deliveries, with LZs as the cornerstone for solutions to balance supply and demand; second, it developed data-driven tools for LZs' implementation; third, it estimates the impacts of LZ-related interventions on the SDG11's targets.

Factors informing kerbside supply and demand

Focusing on the supply side –i.e., the provision of kerbside infrastructure for freight deliveries– Study 2 of this thesis builds on the concept of LZs, expanding its definition to incorporate technologies which facilitate their management. Accordingly, Paper II introduces smart loading zones (SLZs) as follows:

> Stop delimitated areas, where freight loading and unloading operations take place, equipped with technologies that provide real-time information for vehicle

detection, parking space monitoring, and parking assignment, where data coming from connected infrastructure and mobile devices are used by public authorities, space owners/managers, and private companies to make informed decisions that enhance operational efficiency and urban liveability.

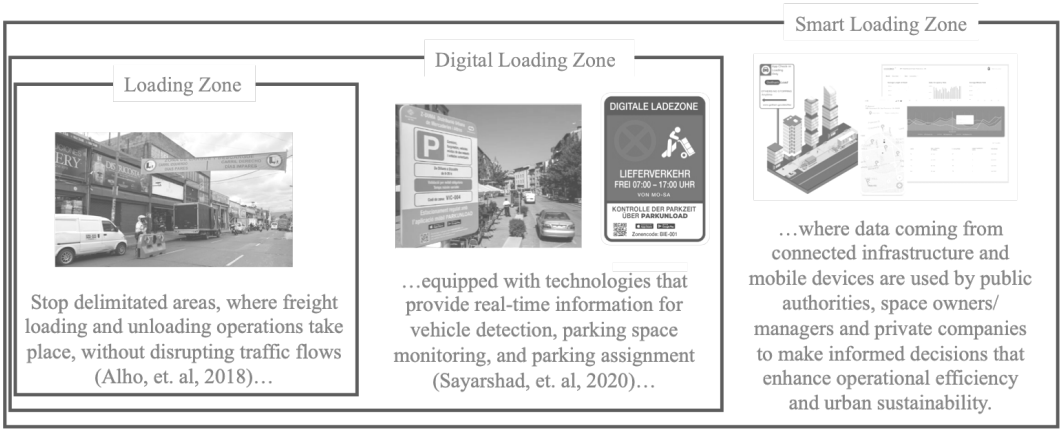

Figure 11. Definition of SLZs
Source: Adapted from Paper II

Paper II also introduced three decision levels in the management of SLZs: strategic, tactical, and operational. At the strategic level, decisions are focused on determining the number, location, and capacity of LZs, as well as establishing the authorisation process and implementing stationary technologies (e.g., cameras or ground sensors) which support infrastructure management. At the tactical level, attention shifts to the dimensions of the LZs, regulations concerning parking durations and pricing conditions, and the deployment of mobile technologies to facilitate dynamic adjustments. Finally, the operational level addresses day-to-day space management, enforcement mechanisms to ensure compliance, and the ways in which users interact with the ICTs associated with the use of kerbside space. This multi-layered approach unlocks a flexible, data-driven management system which can adapt to the needs of freight operations and other kerbside uses.

The results from the interviews in Study 2 revealed that flexible kerbside management is instrumental to balancing scarce infrastructure with variable kerbside demand. Interviewed actors confirmed what was found in the literature regarding how the allocation of fixed space may lead to an oversupply of infrastructure when, e.g., freight demand for kerbside space is low; consequently, the excess infrastructure and the fixed regulations on the use of such space prevent other users from using kerbside space even if it is empty. Conversely, overlooking freight operations in the allocation of space or providing insufficient space for such operations in relation to demand leads to cruising for parking or illegal parking, which are detrimental to the environment, mobility, and nearby establishments, as discussed in Section 5.1.

The content analysis of the data from the interviews and the literature review in Study 2 revealed four major factors of successful leveraging of flexible kerbside management: an understanding of the uses of public space, knowledge about and management of parking durations, enforcement-related capabilities, and data-sharing strategies. Urban and transport planners could consider those four factors when designing and implementing SLZs to ensure that supply-side conditions satisfy users' demands dynamically over time. For instance, in Study 2, city authorities may revisit the allocation and size of LZs given the findings from data analytics. Relatedly, Figure 12 shows the gap between LZs' occupancy

and capacity, revealing conditions of kerbside oversupply and undersupply at specific times during an average week; those profiles were built with data on parking durations and demand across time. In addition, the factor of enforcement-related capabilities appeared to be fundamental to making users comply with rules for using the kerbside. More broadly, estimations of the use of capacity were valid because they were based on actual kerbside operations.

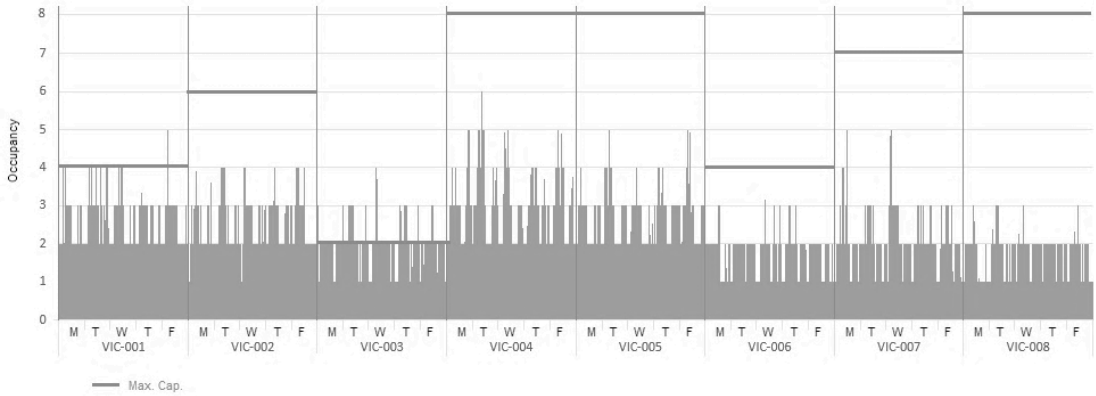

Figure 12. Freight parking occupation profile
Source: Paper III

Information about kerbside operations can also be used to induce user behaviours in relation to patterns of demand. For instance, regulations about parking durations may encourage higher turnover at peak hours and promote the occurrence of longer operations during less congested times. Demand-driven regulations can also take advantage of flexible kerbside management to free up space for diverse uses when freight parking demand is low and other specific modes seek support (e.g., biking and walking).

Data about walking distances and a receiver's location and economic activity are needed to conduct greenfield analyses and to optimise the design of LZs, as showcased in Paper II. The critical input for these models is parking demand.

Factors determining parking demand were identified using quantitative models (Paper III). After parking operations from the case study were probed, explanatory models using machine learning (CatBoost) were used to identify the importance of certain variables to estimating parking durations. Economic activity, vehicle size, and the hour of the day were the most relevant factors for estimating parking durations (Figure 13); of these, hour of the day strengthened the convenience of flexible kerbside management establishing rules based on temporal variabilities. Surprisingly, weather conditions did not significantly explain variability in parking durations, which could be explained by the low variability of this factor in the studied context, and it may become significant in cities where weather conditions are extreme.

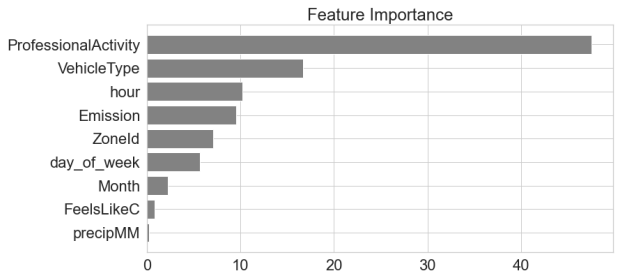

Figure 13. Ranked features explaining durations of freight users at the kerbside
Source: Paper III

Once kerbside supply and demand factors were understood, the thesis generated tools for implementing SLZs which enable data-driven decisions in kerbside access management.

Data-driven kerbside interventions

Investments in technology for kerbside access management enable the making of data-driven decisions informed by analytics on supply and demand patterns, as discussed in the previous section. The utilisation of technology to monitor freight delivery operations forms the foundation of the SLZ concept, where digitised monitoring and data exchange support strategic, tactical, and operational decisions (see Figure 14). This approach enhances the ability to optimise kerbside allocation and to respond dynamically to changing urban freight needs.

At the strategic level, digitalisation facilitates the collection of freight data on arrival rates, parking durations, types of economic activity, and parking locations. These data, combined with information from freight generators/receivers and urban-form characteristics, serve as inputs for clustering algorithms and optimisation models which inform decisions on infrastructure provision –specifically the number, location, and capacity of LZs– as discussed in Paper II. This approach directly addresses challenges identified by the City of Vic, where decision-makers emphasised the need for robust methodologies or "ratios" based on zone characteristics to determine the appropriate number and placement of LZs, akin to established practices for private transport.

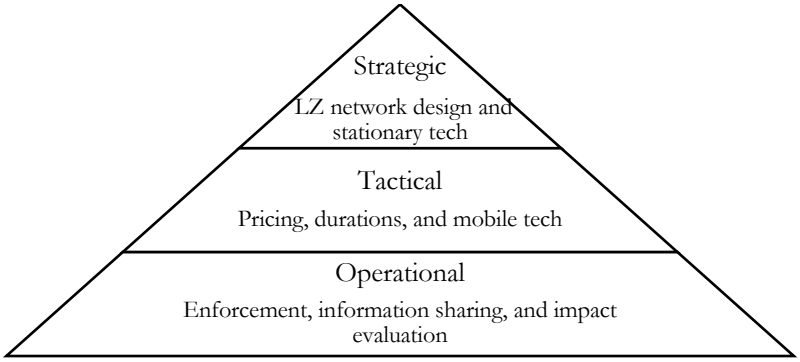

Figure 14. Decision levels in LZs' management
Source: Adapted from Paper II

Despite the benefits of digitalisation, transport and urban planners should keep in mind the extent to which different forms of technology provide the necessary data for making strategic decisions. For instance, sensors can provide data about occupancy, but not details about vehicle types or economic activity.

With regard to tactical decisions, probed parking data support the design and implementation of adaptive rules concerning the use and management of LZs. Identifying patterns across time supports the designation of dynamic parking regulations and variable ROW allocation according to fluctuations in freight demand for kerbside space. At this level, probed data on parking durations and the operational features of parking operations provided the input needed by models of demand and durations (e.g., ML algorithms or queueing models), as shown in Paper III. Duration models led to accurate forecasts of LZs' occupancy, which benefits routing plans by reducing cruising for parking and defining time windows when LZs can be freed up for other types of users.

Although the research focused on data analytics tools for strategical and tactical decisions, the papers' discussions also acknowledged the impact of SLZs on the enforcement of LZ regulations and monitoring, which are enhanced by the digitalisation of the kerbside. Technology (such as cameras) helps with identifying misuses of LZs and with the fines for violations. Data analytics about traffic violations are also input for improving regulations based on users' behaviour.

The benefits of digitalising kerbside management become tangible when data-driven decisions address the identified loose couplings –i.e., aligning practices with sustainability goals. For instance, SLZs represent a means to spur cleaner vehicle technologies by allowing only certain vehicle types to use them, thereby motivating modal shifts. SLZs can also encourage operations at off-peak hours with the use of pricing incentives and/or access regulations, which bring operational and sustainability benefits while freeing up space for other users when needed. SLZs also contribute to influencing freight transport operators' behaviours by not only making them comply with kerbside regulations but also facilitating their search for available parking stalls. Given this, the research assessed and quantified the impacts of kerbside interventions on the sustainability objectives for cities.

Impacts of kerbside interventions on SDG11

RQ2 prompted the exploration of how kerbside interventions affect sustainability metrics for public spaces, focusing on key factors –urban space allocation, data sharing, parking limits, and enforcement– in the provision of kerbside space for freight operations. For each factor, the analysis linked the evaluated KPIs to the relevant SDG11 metric. Figure 15 summarises the findings from the systematic literature review, displaying the quantified KPIs (on the left) and their connection to SDG11 metrics (on the right).

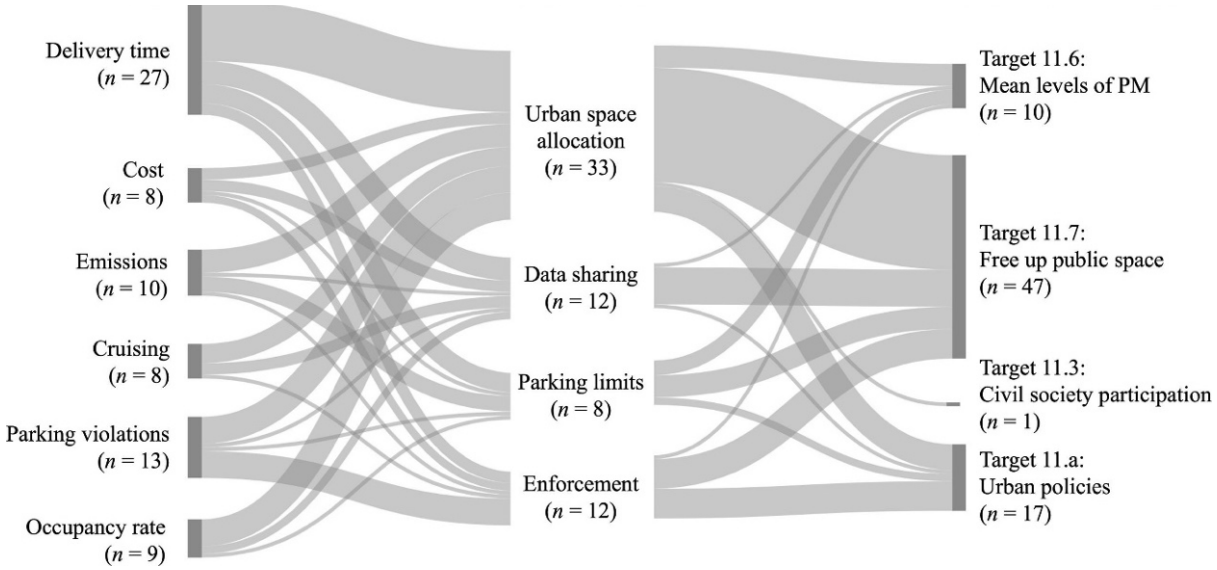

Figure 15. Kerbside interventions' impacts on sustainability
Source: Paper IV

Most of the reviewed papers are related to allocating public space for freight operations. According to these findings, such provision of space for freight operations benefits cities' sustainability and operational efficiency, as it reduces cruising by an average of 25%, last-mile emissions by 41%, and delivery times by 28%. The KPIs of effective space management for freight are aligned with SDG11 because they reduce mean levels of PM and free up space for other users, with the latter occurring due to reductions in congestion

when fewer parking violations and less cruising occur. Nonetheless, those impacts can be overshadowed if a static allocation of space exacerbates supply–demand imbalances for kerbside uses other than freight.

Data-sharing, the factor with the second-highest number of reported impacts, refers to technological implementations which enable the exchange of data between kerbside infrastructure, users, and space managers. Most benefits mentioned in the papers are quantified in terms of decreased delivery times (by 32% on average) because data-sharing made the availability of LZs visible as well as supported pre-booking systems which, on average, reduce cruising by 32%, emissions by 46%, and costs by 37%. Although data-sharing schemes are becoming popular in kerbside management's contribution to SDG11 metrics regarding urban policies for the use of public space, they remain underdeveloped—partly because in the case of booking systems, freight transport operators find it challenging to comply with booking times due to traffic delays in congested areas. During the interviews conducted in Study 2, one freight transport operator stated, "It is impossible for us to know when a freight transport operator will be at a certain LZ when there are 70–80 delivery points an operator must make."

Regulating and enforcing parking limits are common actions by policymakers in kerbside management. Most of the collected reports on parking limits regulations have contributed to SDG11 metrics in relation to urban policies and freeing up public space, because these encourage higher turnover, modal shifts, and compliance with regulations. The relevant performance measures are primarily parking violations, cost, and delivery time, although the ranges of increase and decrease vary from one case to another.

Only one report was found to contribute to the SDG11 metric on civil society's participation, namely Trott, Baur, Auf der Landwehr, Rieck, & von Viebahn (2021). Stakeholders' engagement has been overlooked in the definition of freight kerbside access policies and interventions, which has impeded the potential effects thereof on urban sustainability. It has also led to users having insufficient knowledge about ROW rules, which only adds pressure on enforcement means, which may in turn cause confrontations between users and parking wardens over costs due to fines issued or over illegal uses of the kerb.

In conclusion, data sharing, enforcement, parking limits, and the allocation of public space can contribute to the goals of reducing emissions, managing congestion, making delivery times efficient, and ensuring equitable access. However, some trade-offs need to be assessed, and new approaches are needed which focus on citizens' engagement in freight kerbside access management.

While the analysis demonstrated how kerbside interventions can advance urban sustainability, the actual impact of these measures depends on their successful implementation and institutionalisation. Achieving lasting change requires more than designing effective interventions: it also entails understanding the conditions and processes which facilitate the embedding of these solutions in practice. To this end, the following section covers RQ3, regarding the institutionalisation process of kerbside interventions.

5.3. Factors influencing the institutionalisation of kerbside interventions

RQ3 guided the exploration of factors influencing the institutionalisation process of practices in kerbside access management for freight deliveries. In the analysis of the

conducted interviews, patterns were identified concerning the most frequently coded themes, which were consistently present across the pilot phases: legal mandate of public agencies (legal competence), public benefit, scope definition, stakeholders' involvement, business model, data management, and user experience. As the practices tested in the pilots were institutionalised, the research of Study 3 identified the factors which supported and hindered the institutionalisation process of kerbside interventions. Figure 16 illustrates the patterns and the identified interactions which influenced this process.

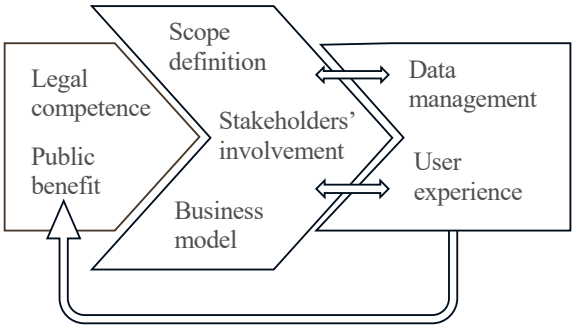

Figure 16. Patterns in the institutionalisation process of kerbside interventions

As reported in Paper V, pilot originators (e.g., public agencies) initially involve those stakeholders whose ability to implement freight kerbside pilots is given in regulations. Originators motivate the pilot based on the hypothesised public benefit of an initiative. Once this foundation is established, the pilot is designed with respect its scope, business model, and the involvement of relevant stakeholders. While data management and user experience are considered during the planning phase, these are often subject to adjustments during the implementation phase in a back-and-forth loop which aligns the plan, scope, and business model with the actual conditions. The analysis of data collected during the pilot together with users' feedback then serve as the inputs for reassessing the public benefit; this assessment ultimately determines whether to maintain or discontinue the tested practices.

The institutionalisation process, which is influenced by the seven patterns shown in Figure 16, leads to the adoption of tested practices as established institutions if certain factors –i.e., success factors– are present. However, failure factors can impede this process and hinder the institutionalisation of pilot practices, as elaborated in Paper V. Forces driving the transition across pilot phases are explained in terms of the coercive, normative, and mimetic isomorphisms of INT (as mentioned in Section 2.4).

Coercive forces

As regards coercive forces, local authorities' mandate to regulate the kerbside space coupled with national government bylaws for parking management were found to be a coercive driver of change supporting the institutionalisation of practices learnt in pilots. This force is featured in legal instruments for allocating ROW and providing LZs with the appropriate traffic signs and, eventually, kerbside technology. Enforcement is key in the institutionalisation of practices, with technological deployed to increase the effectiveness of kerbside control (e.g., automated fines using cameras). According to the data collected in the interviews of Study 3, this force hinders the institutionalisation process only when local authorities lack the autonomy to define rules, when there is no interest in regulating the use of space, or when there is a misalignment between enforcement practices/regulations and freight kerbside pilot practices.

The allocation of LZs drive change in kerbside practices, in line with the results from Rose et al. (2016) about the coercive pressure imposed by the built environment on freight kerbside practices. Trucks navigating through narrow streets and not finding parking spots influence driving behaviour, as this often leads to illegal parking or driving on the pavement, generating rejection from the general community. Moreover, the implementation of smart signs and enforcement technologies is unfeasible when the availability of energy services (e.g., electric utilities, suitable outlets to plug in kerbside technologies) is limited.

Additionally, the interest of funding agencies in developing kerbside practices influences change related to the institutionalisation of practices learnt in projects funded by these agencies. Thus, the scope of grant applications and the requirements of the funding agencies funding cities' projects represent coercive forces also identified in Akgün & Monios (2018). If the funding comes directly from the government and a tender process was required for the pilot's continuation, then the legal framework for contracting technology firms also becomes a manifestation of coercive forces.

Normative forces

In terms of normative forces, successful pilot scaling-up occurred when the analysed data was properly communicated vis-à-vis the demonstrated efficiency gains for companies and the benefits for the city in terms of congestion reduction and a cleaner environment. Pricing schemes to encourage parking turnover and prevent other users from occupying freight zones act as a normative driver in contexts where paying for kerbside access is an institutionalised practice. Thus, legitimating practices tested in pilots and adopting them later in the organisational field depended heavily on how various users of the kerbside and other stakeholders perceived the benefits of certain practices from their own perspectives. Furthermore, compliance with on-street parking regulations legitimates access to the kerbside space by freight vehicles, especially if these regulations result from the participation of stakeholders and are effectively communicated to all kerbside users. Additionally, the business models organising the implementation of pilots influence the institutionalisation process by prioritising the fair balance of interests among the involved actors.

These benefits were tangible when interventions took place in areas with urgent needs to balance supply–demand, as confirmed by the interviewees. An identification of LZs also gained legitimacy when robust methods informed the allocation of LZs based on demand estimations, traffic modelling, and impact assessment (as addressed in Section 5.2). These aspects of pilot project design are crucial because they influence the institutional process of kerbside interventions and their scaling-up, as Sista & De Giovanni (2021) also found.

Legitimating the practice of data sharing between enforcement agencies, urban and transport planners, and freight transport operators in order to improve decision-making is possible only under secure conditions of GDPR compliance and responsible use of data to avoid privacy violations. Academia can contribute to these efforts by providing expert knowledge and an unbiased position in public–private interactions.

Training programmes are normative forces of change which are needed to illustrate the benefits of using technologies in kerbside operations. However, freight transport operators' reluctance around new practices and technology in parking can hamper the institutionalisation process of these practices.

Mimetic forces

With regard to the final force, multi-city projects encouraging knowledge-sharing is a mimetic force of change. However, mimetic forces related to the replication of pilots from city to city require an a priori assessment about the suitability of the transferability (Janjevic & Ndiaye, 2014). City aspects such as demography, innovation willingness, and experience in the pilot's implementation can determine whether mimetic forces result in an effective vehicle enabling the institutionalisation process of freight kerbside interventions. Additionally, transferability challenges (for instance, between the US and Europe) persist due to differences in regulations and conceptions about public space management.

In conclusion, the implementation of data-driven interventions necessitates several requirements to become permanently adopted practices in access management. According to the results of this research, the successful institutionalisation of practices relies on the strategic selection of LZs in high-demand areas, which address freight kerbside challenges effectively. Enforcement and demonstration of the public benefits can leverage the institutionalisation of practices which are tested in pilots. In addition, starting with a few zones and expanding based on feedback ensures a smoother scaling process. Finally, user experience –enhanced by tools like apps showing available LZs– are also relevant to the legitimation of kerbside practices.

5.4. Summary of research results

A summary of the results from this thesis is shown in Figure 17. The results of this research have demonstrated that supply–demand imbalances in kerbside access for freight arise from loose couplings between the urban freight system goal and current practices, and they are driven by built environment constraints, competing user demands, and fragmented regulations.

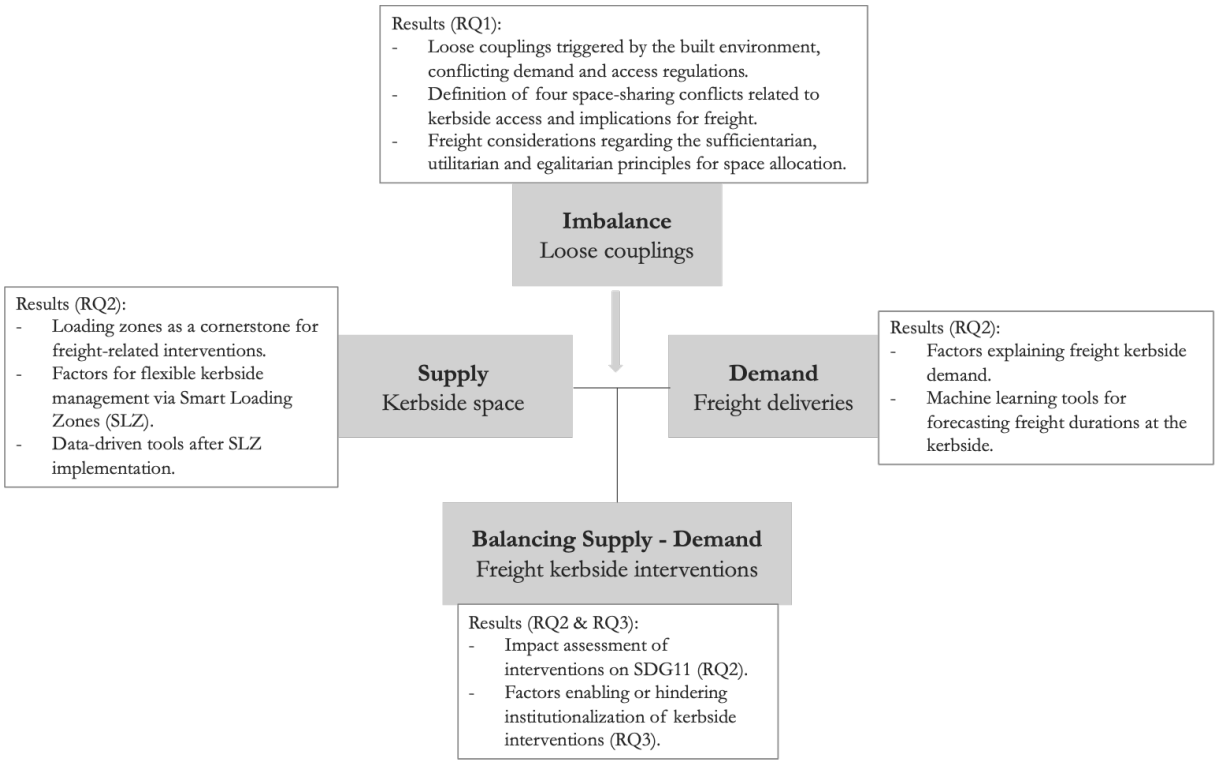

Figure 17. Summary of the research results

The thesis elaborates on SLZs as a core intervention, showing how digital tools support flexible management of kerbside supply and demand forecasts. Data-driven interventions contribute to balancing supply and demand, thereby supporting progress towards SDG11. However, the successful institutionalisation of these interventions depends on legal mandates, stakeholder collaboration, data governance, and user experience. Together, these findings highlight the need for integrated, adaptive strategies to address kerbside conflicts and to improve urban freight operations.

6. Discussion

This chapter discusses the results in relation to the thesis aim and research questions. It elaborates on the theoretical and practical contributions, which inform concrete areas of action for addressing freight kerbside access management using a data-driven approach. The chapter ends by outlining limitations and suggesting directions for future research.

6.1. Discussion of results in relation to the thesis aim and RQs

The purpose of this thesis was to advance knowledge on kerbside access management for freight deliveries by examining space-sharing conflicts, developing data-driven tools for interventions balancing supply and demand, and identifying factors which influence the institutionalisation of such interventions. To achieve this, the research combined qualitative and quantitative methods as complements: qualitative approaches were used to uncover underlying interactions, actor perspectives, and context-specific challenges, while quantitative methods provided analytical tools with which to model demand patterns, evaluate impacts, and support decision-making. The analysis was structured around three RQs addressing conflicts, interventions, and institutionalisation, respectively, with the broader aim of improving urban freight sustainability.

Conflicts

With the first RQ, this thesis addressed the supply–demand imbalance in freight kerbside access management by analysing the loose couplings between the goal of the urban freight system and the existing conditions at the freight delivery interface. Building on the work of Browne et al. (2022), who identified fragmentation and minimal coordination in the road freight system, this research extends the discussion by applying the concept of loose coupling specifically to the freight delivery interface (Paper I).

The analysis revealed that built environment constraints, competing demands from other street users, and fragmented regulatory frameworks trigger conflicts over kerbside access. These triggers help explain reactions of freight transport operators such as cruising and double parking, previously analysed in studies by Dalla Chiara & Goodchild (2020) and Lopez et al. (2016). The identified conflict triggers align with recent findings on misalignments between freight and land use planning (Conway, 2024) while also expanding the analysis beyond traffic-related concerns to include effects on place-making and environmental outcomes –domains in which freight both affects and is affected by street conditions.

This dual role of urban freight is central to understanding its impact on the value of streets, a notion defined by Carmona (2018) as encompassing social, economic, environmental, and health dimensions. While negative externalities of freight operations have previously been revealed (e.g., Dablanc, 2007), the thesis advances views about how freight enables liveability by ensuring the functioning of local businesses and providing access to goods and services. These views bring freight into the core of kerbside access debates and provide a structured way to assess its needs and interactions. They also challenge prevailing policies –which often treat freight delivery similarly to private vehicle traffic– by advocating instead for differentiated interventions which recognise freight's distinct functions, needs, and contributions.

To this end, the thesis discusses ROW allocation approaches, in acknowledgement of the dual role of freight, and provides insights for reassessing access priorities in line with distributive justice principles for space allocation (i.e., sufficientarian, utilitarian and egalitarian). This contributes to bridging the gap concerning freight's marginal presence in urban planning discourse, which is traditionally centred on passenger mobility (Haarstad et al., 2023). Additionally, the thesis addresses the implications of space-sharing conflicts which go beyond operational inefficiencies to cover aspects related to the well-being of freight transport operators (e.g., stress, exhaustion, safety) and the quality of the street infrastructure and environment, as suggested in Sheikh-Mohammad-Zadeh, Saunier, & Waygood (2022).

Findings led to the analysis of loose couplings and their resulting implications –namely space-sharing conflicts, which not only disrupt freight operations but also hold broader implications for street liveability. The framework developed in this thesis captures how misalignments in space configuration, rules, and multiple users' demands translate into direct operational inefficiencies and sustainability challenges. The considerations of value for freight transport operators complement the analysis of the value of streets for other users reported in Gössling, Schröder, Späth, & Freytag (2016), Creutzig et al. (2020), and Lefebvre-Ropars et al. (2021). Additionally, this contribution fills the gap identified in Rose, Bell, Autry, & Cherry (2017) regarding the absence of identifiable models, theories, or frameworks to explain how urban characteristics impact freight operations.

The concept of loose couplings proved valuable not only for identifying the misalignments between kerbside access conditions and the overarching goal of the urban freight system, but also for understanding the functional dynamics within these imperfect arrangements. While loose couplings highlight areas of disconnect –such as fragmented regulations, inconsistent infrastructure provision, and conflicting user priorities– they also enable reflection on how freight deliveries continue to operate despite these challenges; this indicates that the system, while not ideal, remains functional. This reality leads to the reflection that not all loose couplings necessitate immediate correction: some offer adaptive capacity and institutional flexibility, enabling the system to absorb variation and remain resilient when facing uncertainty. The latter features are indeed the reason for developing interventions which capture variability and enable dynamic kerbside access management.

Interventions

At the intersection of the three conflict triggers –the built environment, street regulations, and competing demand –LZs were identified as a potential intervention to provide kerbside access for freight deliveries. RQ2 focused on the development of data-driven tools to inform strategic, tactical, and operational decisions in the implementation of LZs. To this end, the thesis explored factors explaining the supply and demand of kerbside space for freight deliveries and assessed the impact of interventions addressing the supply–demand imbalance.

For supply, a data analytics approach is proposed to support flexible kerbside management based on variability in the supply of kerbside space for freight (Paper II). The time-variant method enables the identification of opportunities to free up kerbside space for other users when freight parking demand drops. The proposed tool, involving greenfield analysis and optimisation, expands on past research (e.g., Comi et al., 2022) by considering the stochastic behaviour of parking demand and using big data on parking

operations and the flexible sizes of LZs across time. Beyond the data analytics approach, the research conducted for the thesis also revealed critical factors for implementing dynamic kerbside regulations –which, aside from the technological aspects mentioned in Mor et al. (2020), require the flexible allocation of kerbside space for freight operations, an understanding of parking durations, and enforcement-related capabilities.

The thesis proposes an approach to defining SLZs built on previous conceptualisations (Alho et al., 2018; Sayarshad, Sattar, & Gao, 2020); the definition includes elaborations on the scope of different decision-making levels which incorporate the implementation of technology, data-driven regulations, and the dynamic management of the available infrastructure.

For demand, explanatory assessments of the variability in parking durations were conducted using probed parking operations from the case study (Paper III). Findings from the studied context confirmed and expanded the results obtained by Low et al. (2020) with respect to the significance of such variables as type of commodity and location when estimating freight parking durations. In the research for this thesis, temporal variables were added –specifically, the hour of the day and weather conditions– which are fundamental to flexible kerbside management. That latter finding was possible due to the availability of technologies to track all of the operations occurring across time (i.e., a time window of 18 months in the context of the study), thereby outperforming analyses which consider limited observations within specific windows of time, as suggested by Jaller et al. (2021).

The thesis also involved comparing queueing models and ML algorithms to forecast the occupancy of LZs. Those models overcome the challenge of stochasticity in parking demand, highlighted in the literature as a research gap (Gardrat & Serouge, 2016; Jaller et al., 2021). Tailor-made regulations can be designed by applying these approaches to specific contexts and urban areas. The tools may also enable transport companies to plan routing for urban distribution while knowing the availability of LZs in advance, thereby improving delivery times by reducing cruising and/or illegal parking.

As for balancing kerbside supply and demand, the thesis examined the impacts of SLZ-enabling factors on KPIs (Paper IV), linking kerbside management and urban sustainability using the UN's SDG11 metrics. Results from the research suggest that data sharing, enforcement, parking limits, and the allocation of public space may contribute to accomplishing the goals of reducing emissions, managing congestion, and implementing urban policies for public space and equitable access. The thesis also points to some trade-offs when implementing these interventions which need to be assessed.

The research found that with the implementation of SLZs, effective space management supported by technologies can free up space for other users while increasing LZ occupancy rates by 15% on average, as well as avoiding illegal parking. This is a concrete outcome showcasing the benefits of including freight in kerbside allocation decisions beyond improvements in last-mile delivery efficiency (Butrina et al., 2017).

Implementation

Technological innovation and analytical tools, while necessary, are not sufficient to drive change in kerbside access management. One of the contributions of this thesis lies in its investigation of the institutionalisation process of kerbside interventions, specifically the factors which support the evolution of freight pilots into established practices (Paper V).

Despite growing experimentation with digital solutions for freight kerbside access management, such as booking platforms or sensor-equipped loading zones (Yang, Ma, Pi, & Qian, 2019), a gap remains in the understanding of the organisational, political, and social conditions under which these interventions become embedded in policy and practice.

The thesis identified seven key factors which shape the institutionalisation process: legal mandate, public benefit framing, scope definition, stakeholder engagement, viable business models, data governance, and user experience. These factors are not only present across the pilot phases but often interact in facilitative or constraining ways. For example, the perceived legitimacy of public agencies (legal mandate) often determined the ability to mobilise stakeholders and sustain a pilot beyond its experimental stage, a point also highlighted by Akgün & Monios (2018) in their study on urban freight policy inertia.

Furthermore, the findings resonate with institutional theory, particularly the influence of coercive, normative, and mimetic pressures (DiMaggio & Powell, 1983). Coercive forces emerged through regulations or interagency mandates, normative forces through professional norms and stakeholder values around liveability and street use, and mimetic forces through the emulation of perceived successful interventions in other cities. This research situates institutionalisation within the context of decision-making on kerbside space as viewed from the public sector perspective, complementing prior studies focusing on technology adoption in private freight companies (Rose et al., 2016).

6.2. Practical contribution

The results of this thesis help to inform transport and urban planners addressing freight needs for space in street activation plans. This contribution helps bridge the gap identified in Butrina et al. (2020) regarding kerbside management guided by ad hoc resolutions, lobbying, or political influence instead of the actual needs of freight and other kerbside users. The frameworks, tools, and impact evaluations developed in this thesis provide the groundwork for public authorities to work together to develop consistent, evidence-driven regulations for kerbside access with explicit consideration of freight operations, to avoid conditions of the liveability–freight paradox (Williams & Carroll, 2015).

The contribution to practice also centres on the development of data-driven tools for the allocation and management of kerbside space for freight deliveries. This research builds on the notion that the adoption of technologies benefitting public and private organisations improves decision-making processes under the conceptualisation of SLZs. Operational benefits result from improving freight delivery performance by using forecasts of LZs' occupancy or timely information on access regulations. From the public sector perspective, introducing a data-driven approach to manage kerbside space opens the possibility of introducing flexible kerbside management, thereby freeing up space for other users and offering opportunities for new business models and innovations (e.g., on-street lockers, charging stations for e-vehicles, and new dynamic commercial or recreational space).

Beyond investment in technologies, this thesis has demonstrated that ML is a convenient way to handle data, analyse them, and use the results as inputs for policymaking. Descriptive, predictive, and prescriptive models can be integrated into parking systems so that urban and transport planners and the private sector can base their decisions on forecasted and actual conditions. ML in kerbside access management expands the use of data by linking them to actions which de-conflict the kerb and make freight operations more sustainable.

Tailor-made regulations can be designed by applying these approaches to specific contexts and urban areas. Those tools may also enable transport companies to plan routing for urban distribution while knowing the availability of LZs in advance, thereby improving delivery times by reducing cruising and/or illegal parking.

Finally, the thesis offers an understanding of what enables the transition of freight kerbside pilots into established practices, equipping policymakers with insights not only for designing effective interventions but also for ensuring their continuity, legitimacy, and alignment with long-term urban goals.

6.3. Theoretical contribution

The theoretical contribution of this thesis lies in its advancement of the conceptual and analytical foundations of kerbside access management by operationalising existing constructs –such as space distribution principles and loose couplings– in the context of freight deliveries. The research provides empirical evidence of loose couplings at the level of the kerbside, thereby extending the work of Browne et al. (2022), who discussed fragmentation in the broader freight transport system. Adapting Ingersoll's (1993) approach for analysing loose couplings, this thesis demonstrates how misalignments between freight system goals and the freight delivery interface –driven by built environment conditions, conflicting demands, and street regulations– translate into observable conflicts at the kerbside.

The thesis positions freight transport operators as not merely sources of congestion or emissions but also contributors to urban liveability. Drawing from Carmona (2018), the research integrates freight into the multi-dimensional value of streets, including the social, economic, environmental, and health dimensions. By framing freight transport operators as kerbside users with distinct roles and spatial needs, the thesis supports a theoretical shift towards a recognition of freight's place-making function. This redefinition enables applications of distributive justice principles –namely sufficientarian, utilitarian, and egalitarian (Lefebvre-Ropars et al., 2021)– in kerbside allocation debates and supports the argument that street space should be allocated not only according to movement efficiency but also based on the broader value freight provides.

This theoretical contribution is concretised in the conflict assessment framework introduced in Study 1, which identifies conflict triggers, escalation loops, and distinct categories of space-sharing conflicts. In this way, the thesis contributes new theoretical vocabulary and structures for understanding the dynamics of kerbside competition, thus filling a gap in frameworks which include freight in street space management.

Although the concept of loosely coupled systems did not originally guide the development of Study 1, its retrospective application provided a valuable lens for interpreting the findings in this thesis. By framing the misalignments in freight kerbside access management through the theoretical construct of loose coupling (Browne et al., 2022; Weick, 1976), the thesis strengthened the analytical depth of the observed space-sharing conflicts and their implications. This post hoc theoretical alignment fortifies the robustness of the contribution by linking empirical results to established organisational theory and opening further theory-grounded research paths through the interventions addressed in Study 2.

By using institutional theory, the thesis also contributes to addressing gaps identified by Stough & Rietveld (1997) which remain relevant in the transport field today. It offers public sector-focused approaches for kerbside decisions, estimates benefits linked to improved freight access, and proposes guidelines for flexible, adaptive infrastructure management. Other relevant advancements lie in the integration of data-driven tools into planning processes and in the analysis of institutional conditions supporting the permanent adoption of kerbside interventions, as addressed in Study 3. By identifying factors underpinning institutionalisation –i.e., legal competence, public benefit, scope, stakeholders, business models, data sharing, and user experience– the research provides a structured basis for understanding how temporary interventions can evolve into long-term policy and practice.

6.4. Generalisability and transferability of the results

While some of the studies in this thesis build on context-specific applications (particularly within the European urban context), the frameworks and tools developed – such as those for assessing space-sharing conflicts and managing SLZs– are suitable for other contexts. Although their applications require adjustments to account for local regulatory, spatial, and institutional conditions, the core concepts and data analytics are transferable to contexts where space access is managed to accommodate freight deliveries among other uses. For example, ongoing collaborations involving the author of this thesis are adapting the space-sharing conflict framework to cities like Nairobi, Kenya, demonstrating the utility of these tools in other urban freight environments. Furthermore, the thesis identified factors influencing the institutionalisation of kerbside interventions through experiences from several contexts. This provides guidance for tailoring pilot kerbside interventions to local contexts, increasing their potential for long-term adoption.

To support transferability, this thesis proposes a structured guide for freight kerbside access management which synthesises the thesis' main findings into a practical sequence. This guide offers researchers and practitioners a replicable pathway to identify conflicts, assess supply and demand, and implement interventions which align freight access needs with broader urban policy objectives. This three-phased approach is based on the empirical and analytical work conducted in this thesis and follows the structure in which the results are presented. Specifically, it begins with the identification of conflicts, proceeds to the application of tools to assess supply and demand of kerbside space for freight deliveries, and concludes by outlining pathways for intervention implementation. These three components offer a replicable and adaptable structure for cities seeking to manage freight access in a way which balances operational efficiency with broader sustainable development goals. These three stages constitute an iterative cycle which informs and strengthens freight kerbside access policies and offers cities a structured approach to developing freight kerbside access management agendas. Figure 18 summarises the content of the areas of action, operationalising the definition of freight kerbside access management provided in section 2.2.

The first stage involves identifying conflicts. The framework presented in Figure 10 (further elaborated in Paper I) begins with analysing the conditions in the built environment, the intensity of competing demands at the kerbside, and the regulatory frames governing access. At this point, efforts should prioritise collecting data to capture conflict triggers and the behaviours of freight transport operators in their use of street space. This understanding helps avoid actions which instigate the liveability–freight paradox as well as improve the detection of root causes of space-sharing conflicts. Once conflicts are mapped,

preliminary sustainability assessments can be anticipated, ensuring that potential interventions are justified and their implications clearly communicated to stakeholders. This phase also encourages a revision of the assumptions underlying distributive justice principles by incorporating the value that streets provide to, and gain from, freight activity (as addressed in Section 5.1).

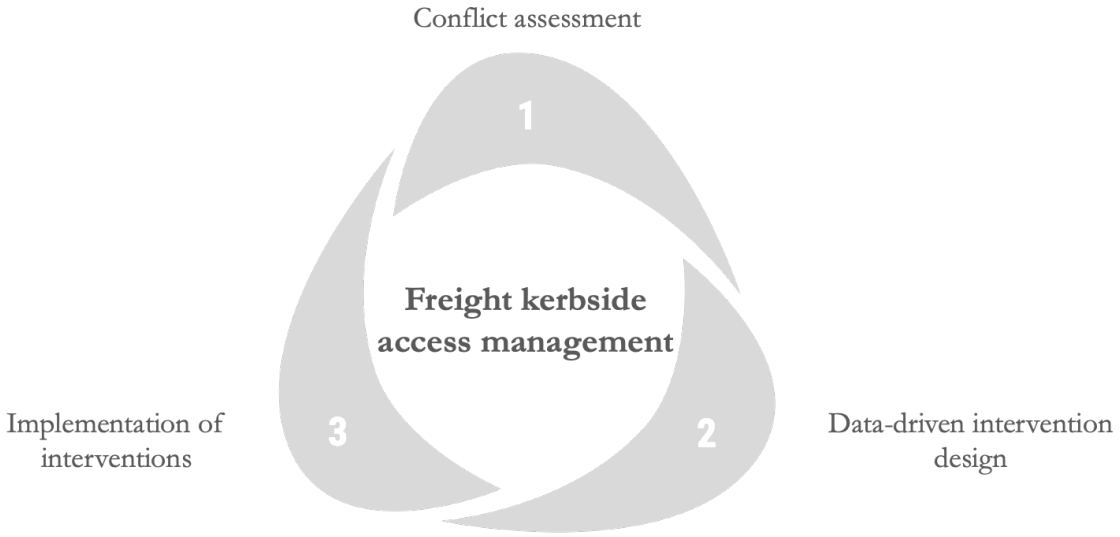

Figure 18. Areas of action for addressing freight kerbside access management

The second stage concerns apply tools to analyse the supply and demand of kerbside space for freight deliveries (Section 5.2). On the supply side, decisions about LZs can be guided by strategic, tactical, and operational considerations, each supported by data and their analysis (as presented in Paper II and III). To this end, the concept of SLZs proposed in this thesis provides a blueprint for implementing scalable, evidence-based management strategies with explicit connections to sustainability goals such as SDG11. Strategic, tactical, and operational decisions should be aimed at enabling the realisation of the four factors identified in this thesis which are needed for the implementation of SLZs, namely dynamic allocation of space, differentiated parking durations based on the type of economic activity, data-sharing schemes, and enforcement capabilities. The impacts identified in Paper IV can support communication and engagement efforts, which in turn help to build the momentum necessary for pilots and the institutionalisation of interventions.

The third stage focuses on implementation: it involves setting up interventions, testing effects, and adopting practices for improved freight kerbside access. The thesis identified conditions –namely legal mandate, public benefit, scope definition, stakeholder engagement, viable business models, data sharing, and user experience– as necessary for the institutionalisation of freight kerbside interventions (Section 5.3). These conditions should guide pilot design and evaluation in order to ensure long-term adoption and integration into public policy (as reported in Paper V). The data-driven tools provided in this research –particularly regarding public benefits, scope definition, and data sharing– can assist actors in addressing these conditions to institutionalise practices.

6.5. Research limitations and future research

The research conducted for this thesis had several limitations which should motivate further attempts to study kerbside access management for freight deliveries. This section

describes the limitations of the research regarding its theoretical contributions, methods, and practice.

From a theoretical perspective, the constructs (i.e., space-sharing conflicts framework and SLZs) require further validation and operationalisation efforts to verify their explanatory power; more efforts in data collection and replication studies could contribute to this. Additionally, this thesis studied how the design of data-driven tools deal with kerbside supply–demand imbalances for freight deliveries, but an open research opportunity involves understanding how these tools should be adjusted during the implementation and evaluation phases, for instance through longitudinal studies.

Other research opportunities deal with the analysis of the differences across countries in the ways they solve access management problems for freight and understanding the influence of cultural institutions in the allocation and distribution of public space. Moreover, there are further efforts to be conducted in the operationalisation of justice principles for space allocation, and the data analytics associated with them.

With regard to methods, the quantitative study of parking operations (Study 2) was limited to a specific context; further research should consider data from multiple cases and identify nuances among them. Transferability analysis would also enrich the research conducted in the field by illustrating how urban conditions affect the suitability of the methods and their results. As regards the qualitative studies (mainly Studies 1 and 3), the convenience sampling of interviewees could be expanded to include actors from more cities and users of different forms of technology. Moreover, because the impact assessments of the proposed solutions were conducted only at the level of literature review, future contributions should consider empirical data to evaluate the impacts of kerbside management interventions on urban sustainability.

The modelling approaches and results are subject to change under a broader scope of analysis, including conditions of multiple kerbside users with their own demands, dynamics, and variabilities. Therefore, urban and transport planners should be aware that the results presented in this thesis could be a solution to the problem, but only a partial one. Further analyses need to address the needs of all actors using the kerbside, their behavioural aspects, and variabilities regarding land use.

In terms of practice, freight kerbside interventions contribute to improving cities' sustainability when institutionalised. Pilots induced reductions in delivery times and eliminated cruising and double-parking behaviour. However, there is still room to develop more knowledge on the long-term effects of institutionalised freight kerbside interventions.

People-centred initiatives grounded on collaborative mechanisms for the design of kerbside access regulations are also a future research avenue to be explored. This will contribute not only to bridging the gap to meet one of the SDG11 metrics (specifically, 11.7.) but also to elaborating on other ways of designing interventions by focusing on the norms/beliefs and cognitive patterns. Tactical urbanism can serve as a reference for how to involve communities in decisions related to the public space. Additionally, further studies on behavioural aspects in freight deliveries which assess the impacts of interventions on the driving behaviours and well-being of freight transport operators can provide more elements for decision-making in freight kerbside access management.

7. Conclusion

This thesis aimed to advance knowledge on kerbside access management for freight deliveries through the study of space-sharing conflicts and the interventions to address them. In doing so, the thesis explored conflicts related to kerbside access faced by freight transport operators during last-mile deliveries in urban areas, or space-sharing conflicts. It also explored data sources and analytics to inform rules for access management to kerbside space and considered potential interventions, their impacts on cities' SDGs, and the institutionalisation process of these interventions in different contexts.

The thesis was driven by the supply–demand imbalance of kerbside space for freight deliveries and its negative effects on urban sustainability, and particularly the lack of visibility of freight transport operators in ROW allocation frameworks, which exacerbates conflicts over kerbside access.

Including freight considerations in urban planning required the development of a framework and methodological tools which inform policymakers' decisions in the face of space demands from several actors. By defining a conceptual framework for assessing space-sharing conflicts, this research expanded the understanding of loose couplings between the goal of the urban freight system and the freight deliveries interface. The proposed framework connects space-sharing conflicts with the implications for cities' sustainable development. Furthermore, the research provided insights for right-of-way decisions which include the freight perspective.

Given the identified loose couplings, the research developed tools for needed interventions in access management to kerbside space which satisfy freight demand while achieving SDG11 targets. The findings showed that optimised freight parking space, monitored occupancy, efficient parking duration management, and enforcement generated, on average, a 32% decrease in greenhouse gas emissions. The research also found that effective space management supported by technologies can free up space for other users while increasing LZ occupancy rates by 15% on average, thereby avoiding illegal parking. Additionally, improved kerbside policies on average reduced last-mile delivery times by 29%, parking violations by 44%, and last-mile costs for freight companies by 25%.

This thesis explored significant factors in managing kerbside supply and demand for freight parking operations. The research conducted for the thesis elaborated on the development of flexible kerbside management to avoid the unsustainable effects of using static space found in past research. The dynamic allocation of public space, regulations on parking durations, enforcement-related capabilities, and data sharing were the most relevant factors to implementing flexible kerbside management. Based on these factors, a definition of SLZs was proposed, and decision-making at the strategic, tactical, and operational levels was described.

In the implementation of SLZs, this thesis analysed data needs and proposed the implementation of data analytics to facilitate kerbside management decisions. Using probed data about parking operations, the research showed the benefits of data analytics (namely ML, queueing models, and optimisation programmes) in estimating parking durations, forecasting LZ occupancy, and designing LZ networks. Results from the implementation of the models in the context of study showed optimal solutions for space allocation, which

freed up kerbside space when parking demand dropped, as well as acceptable accuracy in predicting parking occupancy compared with other published models.

The research aligned with SDG11 "Sustainable Cities and Communities", which promotes policies and actions that leverage universal access to safe, inclusive, and green public spaces. The research showed that managing kerbside access for freight deliveries emerges as one action to this end and highlighted its demonstrated impacts.

Finally, the research identified factors which influence the successful adoption of kerbside interventions. These insights responded to a critical gap in the literature on urban freight, which has often focused on the development of innovations and trial implementations but provided limited elaboration on the conditions for long-term institutionalisation. The findings provided a coherent guide for cities seeking to integrate freight into kerbside access management and balance operational needs with broader goals of sustainability.

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Appendix A

Interview guide – Study 1

Value provided by streets

1. "Local authorities need to develop, assert and clearly communicate a sense of their true ownership of street and kerb space and of the common value associated with that property." What is the value of the kerbside?
2. Which metrics do you find relevant to assessing kerbside management?

Space-sharing conflicts

3. What type of user tends to be more active in the claims for space?
4. How would you define "conflicts" in the context of kerbside management?
    1. How to measure them? What is the most critical?
    2. PCN – pros and cons of using them to support kerbside decisions.

ROW allocation decisions

5. What do you know about the overall right-of-way strategy of the city?
6. How is freight considered under the strategy?
7. Is there any way to measure the success of right-of-way decisions?
8. How do you handle priorities among kerbside users?
9. Users' priorities: How helpful are these schemes in defining space allocation strategies?
10. Participatory approach: What are the risks? How are they being mitigated?
11. Have you seen any progress in the way that decisions are made? If you had to prioritise one solution, what would it be? Do you foresee any pros and cons?

Interview guide – Study 2

1. Can you please introduce yourself and your role?

Freight Companies

2. How many trucks does your company operate in the city?
3. How many deliveries are there per route?
4. How are these routes set and planned for each truck?
5. Are different trucks used when delivering in urban areas?
    a. Are different trucks used for urban areas? Capacity/size etc.
6. Are the loading and unloading activities standardized in urban areas for all goods or are fragile and/or bulky goods handled differently with different tools?
7. What is the average time spent on a LZ in urban areas?
    a. How have you measured this?
    b. Do different goods have different time duration when loading/unloading?
8. What are the biggest challenges with regards to urban freight for last mile deliveries?
    a. Have there been any initiatives to deal with such problems? If so, which problems are prioritized and how?
    b. Are there any challenges with loading and unloading for the truck operators? - received any complaints from truck drivers?
9. Are LZs' parking durations in urban areas given or can you park for as long as you need to?
10. Do you get any fines and, if so, what are the most common reasons?
11. Where do you get most of the fines? Are there any commonalities between fines and type of vehicle or type of goods transported?
12. Are there any current technologies that you think would help the challenges you have with regards to your urban freight?
    a. Are any technologies currently used in your operations? (GPS, smartphone apps etc.)
    b. What decisions do you make based on these technologies?
13. Have you heard of smart loading zones?

    a. What features would you like to see in such a system that could potentially mitigate frequently occurring problems of urban freight?
    b. Would you be able to adopt this technology if it were to become mandatory and how long would it take? What would it require from your side?
14. What would a dream scenario look like from an operational perspective regarding urban freight?
15. What would you do if you were a policy maker to improve last-mile operations?

Kerbside Technology Provider

2. Can you give a brief explanation of your business model?
3. In how many cities or countries have this system been applied? Is it solely for urban areas for freight vehicles?
    a. Have the results been the same?
4. How would you define a smart loading zone compared to a "regular" loading zone?
5. What has been different when implementing this system in different areas?
6. What has been the biggest challenge in the implementation but also operations - when the system has been used?
7. Have you received any complaints from municipalities or logistics companies?
    a. Have these complaints been dealt with by some form of new feature or technology or new business model?
8. Have risks been taken into consideration for such a system that is heavily dependent on digitalization and electronic devices?
    a. Can you mention potential risks?
    b. Are there standard procedures to fix such problems quickly?
    c. Do you have regular maintenance for the smart sign?
9. Have you observed other smart LZ solutions and or features that could also be implemented in your platform?
10. What differentiates you from other kerbside technology companies in this industry/area?
11. What would a dream scenario look like from an operational perspective regarding urban freight?
12. What would you do if you were a policy maker to improve last-mile operations?

Transport planners / Experts (from academia or consultancy firms)

2. What are the main challenges in urban freight transport at your city, especially in last-mile deliveries? How has the city prioritized and faced them?
3. How could new technologies (e.g. app-based parking system) ease monitoring and control activities of public space?
4. How are technology adoption processes going on at your city in this regard?
5. Have you ever worked with SLZs? If so, how do SLZs work? What challenges / improvements / suggestions have you considered?
6. How is the planning process for defining LZs?
7. Are parking durations in LZ defined by your organisation?
8. How many LZs are in your city? Where are they located?
9. Does the public authority consider any regulation/exception policy for specific products e.g. food? If so, how did the city define them?
10. What are the designed strategies for LZ enforcement (wardens, technology, regulation)? What are the main challenges?
11. How have you evaluated the abovementioned strategies impact on LZ use and related KPIs (traffic, violations such as double parking, efficiency)?
12. How are warden allocated to the LZ? How many zones each warden handles? How do they manage various zones in capturing violations. How far apart the zones are?
13. Have you quantified the impact of LZ misuse on mobility? How do you penalize LZ misuse?
14. How are pricing policies defined? How much money does the city collect from LZ fines?
15. What are the most common violations? Time related? Vehicle type? Type of products?
16. From your experience, what are the main recommendations for public authorities and researchers about succeeding in LZ management?

Interview guide – Study 3

1. ORGANIZATION INFORMATION
    a. Description of the organization: Role in curb management.
    b. Description of the experience with pilots.
2. PRE-PILOT

    Governance / regulatory

    a. What was the pilot governance (leader organization, actors involved)?
    b. What was the process of involving participants in the pilot? What motivated them to be part of it?
    c. What motivated the pilot implementation in those cities? What was the most critical problem to be solved with the pilots?
    d. What was the legal framework supporting the pilot's implementation?

    Technical

    e. What were the city requirements for curb management?
    f. What was the planning process for the pilot before its start, in terms of time (establishing the horizon of time for the pilot), budget, LZ selected, and communication of the pilot?
    g. During the pilot design phase, did the cities consider a way of scaling up the pilot?
        i. What was necessary to be tested during the pilot study to assure future roll-out, expansion, or replication of the solution?

    Organizational

    h. Who was responsible for leading the pilot in your organization?
    i. What strategies did your organization adopt to communicate the pilot plan internally?
3. PILOT

    Governance / regulatory

    a. How were the actors involved in the pilot concerned?
    b. What mechanisms were used to keep all the actors informed about the pilot's progress?
    c. Did you encounter any contradicting regulations with respect to the pilot logic that hampered the pilot implementation?
    d. Who ensured that the pilot implementation went according to the plan?

    Technical

    e. Description of the pilot (# of LZ, actors involved, communication with the citizens, business, transporters, time, data collection). How did these elements differ from the initial plan?
    f. During the pilot, was it mandatory for all logistics companies to use the app? What were the pros and cons?
    g. What were the challenges faced?

    Economic/Social/Environmental

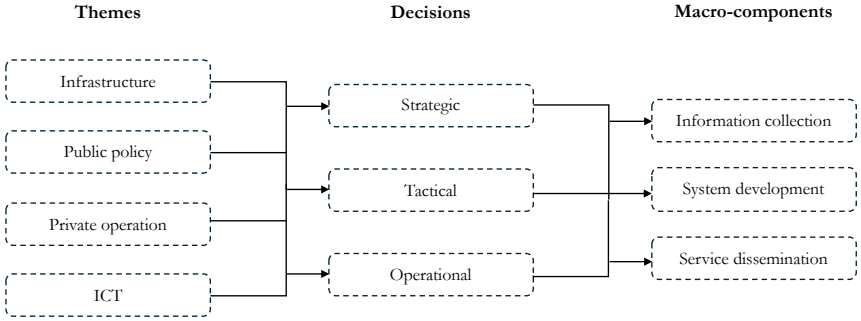
    h. Was there any over-cost experienced during the pilot? Why?
    i. What do you conclude about the economic benefits of the initiative?
    j. What do you conclude about the social benefits of the initiative?
    k. What do you conclude about the environmental benefits of the initiative?

    Organizational

    l. What were the main challenges your organization faced during the pilot?
4. POST-PILOT: SCALING UP FREIGHT CURBSIDE PILOTS
    a. Main insights from the design, execution of the pilot
        i. How was the communication between the stakeholders of the project?
        ii. How was the data sharing managed during and after the pilot development?
            1. Did you use any kind of incentives for data sharing?
    b. Scaling up process: Roll-out, expansion, or replication?
    c. What do you think were the barriers for scaling up the pilots?
    d. What organizational / regulatory / infrastructure changes were needed to pilot scaling-up?
    e. Which do you think are the factors for scaling up the pilot you performed?

Appendix B

Codification of the interviews – Study 2



Codification of the interviews – Study 3