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Characterising and Modelling Urban Freight in Developing Economies

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Abstract

Urban freight systems in developing countries present significant challenges due to their complexity. Authorities often have inadequate institutional structures, making it difficult to identify and implement relevant initiatives. This thesis aims to characterise the systems in developing economies and model freight demand using innovative approaches by considering new attributes, dimensions and alternatives.

As a first modelling step, freight (trip) generation was improved by considering spatial and locational determinants, as freight activities are strongly related to spatial and locational characteristics of establishments. Spatial models were developed using a combined spatial autoregressive model (SAR) and geographically weighted regression (GWR) or multiscale GWR (MGWR) (GWR/MGWR-SAR model). This model accounted for non-linearity, spatial heterogeneity and spatial dependency and demonstrated significant improvements (R^2 0.29-0.71, RMSE reduced by 71% and AIC value by 56%).

Shipment size decisions related to the choice of truck type were strongly time-dependent, with commodity type, activities at the trip end, truck body type and industry sector affecting the preferences. Freight demand, including shipment size choices, was influenced by economic fluctuations, with shipment size declining after an economic slowdown. In freight demand modelling, it is imperative to consider economic conditions, especially those in developing countries, which are often susceptible to strong economic fluctuations.

The models were applied in *ex ante* testing of a policy restricting large trucks from entering a city centre, as commonly considered in many developing countries. In tests, the truck restriction was accompanied by single-tier and two-tier distribution systems. The results showed that the two-tier system had a slight advantage over the single-tier system regarding operational expenditure and emission levels. Truck restriction was generally counterproductive, even when accompanied by distribution systems with greater speed and efficiency.

We conclude that the models enhance the accurate prediction of freight demand patterns. The *ex ante* evaluation of policy alternatives supports the decision-making process for urban freight systems of large cities in developing economies. The models allow considering relevant practical, local contextual conditions.

Keywords: Urban freight, city logistics, developing country, *ex ante*, trip generation, shipment size, vehicle choice model, impact analysis

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This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I. **Reda, A.K.**, Gebresenbet, G., Tavasszy, L. & Ljungberg, D. (2020). Identification of the regional and economic contexts of sustainable urban logistics policies. *Sustainability* 12, 8322.

II. **Reda, A.K.**, Tavasszy, L., Gebresenbet, G. & Ljungberg, D. (2022). Modelling the effect of spatial determinants on freight (trip) generation: A spatially autoregressive geographically weighted regression approach. *Research in Transportation Economics* (Submitted & under review).

III. **Reda, A.K.**, Holguin-Veras, J., Tavasszy, L., Gebresenbet, G. & Ljungberg, D. (2022). Temporal stability of shipment size decisions related to choice of truck type. *Transportmetrica A: Transport Science* (Submitted & under review).

IV. **Reda, A.K.**, Tavasszy, L., Gebresenbet, G. & Ljungberg, D. (2022). Integration of logistics facilities and service zones in various distribution systems under truck movement restrictions (Manuscript).

Paper I is reproduced with the permission of the publisher.

The contribution of Abel Kebede Reda to the papers included in this thesis was as follows:

I. Planned the paper, performed literature retrieval and the review work. Wrote the paper with input from the co-authors.

II. Planned the paper, performed data collection, model building, calculations and result analysis. Wrote the paper with input from the co-authors.

III. Planned the paper, performed data collection, model building, calculations and result analysis. Wrote the paper with input from the co-authors.

IV. Planned the paper, performed the model building and analysis. Wrote the paper with input from the co-authors.

Abbrevations

FG/FTG	Freight generation/Freight trip generation
FA/FTA	Freight attraction/Freight trip attraction
EBFS	Establishment-based freight survey
SIC	Standard Industrial Classification
LISA	Local indicators of spatial autocorrelation
SEM	Spatial error models
SAR	Spatial autoregressive model
GWR/MGWR	Geographically weighted regression/multiscale GWR
GWR-SAR	Spatially autoregressive-geographically weighted regression
MGWR-SAR	Spatial autoregressive-multiscale GWR
EOQ	Economic order quantity
ICLV	Integrated choice and latent variable model
LG	Latent growth model
UCCs	Urban consolidation centres
TPs	Trans-shipment facilities
SZs	Service zones
VKT	Vehicle kilometres travel
VHT	Vehicle hours travel

1. Introduction

More than half of the global population lives in urban areas (UN-Habitat, 2016). This rapid urbanisation and sustained economic growth necessitate an efficient urban freight system, *i.e*. a network of infrastructure, processes and policies that enables the movement of goods within the urban area or a city (Browne *et al*., 2012). These systems are important in maintaining and preserving urban life but also contribute to negative externalities in terms of congestion, air pollution, accidents and noise (Quak, 2008). The terms urban freight transport system and urban freight system are often used interchangeably, but there is a subtle difference between the two. Urban freight transport systems refer to the physical infrastructure, vehicles and technology used to transport goods within urban areas (Elbert *et al*., 2020). Urban freight systems, on the other hand, refer to the entire system of actors, activities and processes involved in moving goods within urban areas, including transportation, warehousing, distribution centres and last-mile delivery (Kervall & Pålsson, 2022). Urban freight systems and urban (city) logistics are similar concepts used synonymously in this thesis.

Several trends create a need for urban freight measures, including the rise of e-commerce and the sharing economy, the desire for speed in supply chains, and a growing focus on sustainability (Savelsbergh & Van Woensel, 2016). Urban freight is inherently complex due to the presence of multiple stakeholders with conflicting stakes (Behrends, 2016), intricate routing patterns and diverse commodity types (Stathopoulos *et al*., 2012). In addition, because of the structure of the economy and the dynamics of doing business (Dablanc, 2011), cities worldwide face unique challenges with distinct aims or priorities and varying levels of adoption of remedial measures (Herzog, 2010). For instance, cities in developed countries exhibit fast-paced changes with lower store inventories, just-in-time (JIT) supplies to businesses and more frequent and customised deliveries of a wide variety of products on the market with the rise in the service economy (Dablanc, 2007). On the other hand, cities in developing countries focus on small-scale manufacturing in homes or small high-tech parks, creating more transport service needs (Dablanc, 2011).

Apart from this difference in focus, cities at different economic levels also differ in adopting urban freight measures. Cities in emerging economies, such as China, India, Mexico and Brazil, are at an earlier stage of adoption than developed countries, such as France, the Netherlands and Japan (TURBLOG, 2011). Moreover, the Middle East and Africa show lower uptake of these measures than cities in developed countries (Kin *et al*., 2017). Cities in developing countries face a range of challenges and constraints with different barriers.

The challenges in developing countries generally relate to the urban environment and specifically to urban freight operations, as summarised in Table 1. These challenges and constraints range from the broader set-up of relevant institutions to specific urban freight operations. The general challenges in urban areas include the categories of urban development and land use, institutional set-up and their role, policy and planning, and city traffic conditions. The urban freight problems are grouped into freight infrastructures, urban logistics operations and environmental impacts. These challenges play a crucial role in the success of adapting new or improving existing urban freight systems. In addition to the challenges and constraints, various barriers exist, *i.e*. factors that potentially undermine the adoption or transferability of urban freight measures between different contexts. Transfer of measures from cities in developed countries to cities in developing countries faces institutional, financial, physical, technological and cultural barriers.

The constraints on urban freight in cities in developing countries are multifaceted but have not been well-studied or considered to date. Apart from lack of institutional capacity, other standout causes are lack of freight and related data, fragmented industry structure, lack of urban freight initiatives, and poorly defined strategic policies and limited implementation of these. Overall, a lack of understanding of the urban freight system in developing countries is the key problem. This is because of a lack of scientific data, models and essential information that can be used to characterise (build knowledge and create understanding) the system and support decision-making. The focus in this study was to fill these knowledge gaps through different steps involving data collection and preparation, analysis and modelling of various system components using urban freight models.

Table 1. *Problems related to urban freight systems in developing countries (Paper I)*

Category	Summary of main problems
Institutional setup and role	Poorly developed municipal and regulatory institutions (Gwilliam, 2003); limited institutional capacity (Okyere *et al*., 2018); institutional and legal framework ignored in applications (Evren, 2001); lack of freight and related data (Herzog, 2010)
Urban development and land use	Low level of infrastructure development, fragmented industry structure and extensive informal sector (Herzog, 2010); mixed land use (Castro *et al*., 1999); urban sprawl (Robertson, 2015)
Freight infrastructure	Infrastructure for walking and cycling often lacking (Pojani & Stead, 2017); lack of logistics infrastructure like loading/unloading areas (Castro *et al*., 1999; Okyere *et al*., 2018, Córdova *et al*., 2014); parking and road design problems and insufficient road network (Castro *et al*., 1999); congested intersections, obstructed sidewalks and roadways, and uncontrolled access by heavy delivery trucks (UN-OHRLLS, 2017)
City traffic conditions	Lower availability and quality of transport system (Robertson, 2015); weak traffic management (Gwilliam, 2003); extreme variety in transport modes and vehicle sizes; frequent breakdowns and accidents (Herzog, 2010); walking and cycling often unpleasant or unsafe (Pojani & Stead, 2017)
Environmental impacts	Emissions from old vehicles (Castro *et al*., 1999); high pollution from trucks using leaded fuel (Gwilliam, 2003)
Policy and planning for urban logistics	Lack of initiatives for urban freight (Córdova *et al*., 2014); poorly defined strategic policies and limited implementation (Okyere *et al*., 2018)
Urban freight operations	Presence of many small traditional retail stores (nano-stores) complicates distribution of goods (Córdova *et al*., 2014); high truck movement with lack of coordination and overloading (Herzog, 2010); higher empty returns increase the cost of trucking even for short distances (World-Bank, 2020).

Urban freight models incorporate different dimensions, including data aggregation level, objectives, perspective, analysis scale and the modelling process (Anand *et al*., 2012). There are four modelling units: trucks/vehicles, commodities, deliveries and mixed (Comi *et al*., 2012). Since there is a substantial disparity between freight demand and freight traffic (Holguin-Veras *et al*., 2000), the intricate process of urban freight is difficult to describe using trucks or commodity units. Instead, trips can be used as a unit to quantify the effect of goods movement on traffic (Toilier *et al*., 2018). Integrating trip generation in the first stage can improve the estimation process (Holguín-Veras *et al*., 2011). However, a lack of freight/commodity flow surveys in developing countries hinders the development of freight generation (FG)/trip generation (FTG) models (Pani *et al*., 2018). Another important factor in FG/FTG modelling is the industry classification system (Holguín-Veras *et al*., 2014; Gonzalez-Feliu & Sánchez-Díaz, 2019), as the industries in developing countries are highly fragmented (Herzog, 2010). Moreover, accounting for inherent spatial issues could improve FG/FTG models, which usually have low explanatory power (Novak *et al*., 2011; Sánchez-Díaz *et al*., 2016; Pani *et al*., 2018).

Establishments are agents in the freight system that interact by sending and receiving goods. This involves several decisions, such as the type, amount and frequency of shipments and the associated choice of mode or vehicle type. However, these decisions are unobservable to outsiders, and it is difficult to find data of sufficient detail to explain the underlying logistics processes. In addition, the operational conditions have a dynamic nature due to the market or economic fluctuations that tend to characterise many cities in developing countries. The other important dimension is reducing the impact of goods movements that pose disproportionate negative externalities. Urban freight measures are less widely adopted in developing countries, and city authorities usually tend to restrict or ban truck movement without providing alternative mechanisms (Oliveira *et al*., 2018). This can be expected to be sub-optimal, and alternative measures may be proposed. However, before any implementation of such alternative policies can be recommended, there is a need for in-depth analysis and evaluation in an *ex ante* framework.

Considering the above, there is a need to address the gaps in characterising urban freight systems in cities in developing countries, to model the different steps of the process using innovative approaches, and to analyse potential alternative measures.

2. Aims and Scope

2.1 Aim and objectives

The main aim of this thesis was to characterise and model urban freight systems using innovative approaches in order to support *ex ante* assessment of measures in the context of large cities in developing economies.

The following research questions were formulated:

- How can the most appropriate urban freight interventions be selected, considering the context of large cities in developing economies? (Papers I and IV)
- What factors influence freight demand levels, and how do these factors impact freight activity within and across industry sectors in terms of type, quantity, frequency and vehicle type selection? (Papers II, III and IV)
- How can spatial characteristics and logistics decisions of establishments, and operational conditions of vehicles, be incorporated into freight demand models and impact analyses? (Papers II, III and IV)
- How do economic fluctuations over time affect the patterns of freight demand? (Paper III)
- What alternative measures can be implemented to enhance the overall traffic performance of the city when large trucks are subject to movement restrictions? (Paper IV)

Specific objectives of the work were to:

1) Evaluate the contexts of urban freight systems and select interventions appropriate for large cities in developing economies (Papers I and IV).

2) Incorporate the effect of locational and logistical decisions of establishments into freight demand models and examine the overall operational conditions for the urban freight system at city level (Papers II-IV).
3) Enhance the accuracy of freight demand model predictions using spatial and locational determinants (Paper II).
4) Evaluate the temporal stability of shipment size decisions in the choice of truck types (Paper III).
5) Assess the potential of alternative distribution systems to reduce travel expenditure and pollutant emissions (Papers III-IV).

2.2 Scope and study limitations

The work in this thesis covered characterisation of the system, modelling demand and assessing impact of distribution systems. The scope was limited to the urban freight system and to the case of cities in developing countries. Contexts specific to this focus were identified and established using over 300 published research articles and grey literature. However, e-commerce and home delivery systems were not scrutinised, because of a lack of data characterising business-to-consumer (B2C) freight flows in these systems.

Another limitation was the publication culture of developing countries, which made it necessary to use grey literature such as unpublished reports. This could have limited the comparative analyses and discussion of the results.

2.3 Thesis structure

The thesis is based on the work described in Papers I-IV and follows the research structure illustrated in Figure 1. Work began by identifying challenges and gaps, followed by methods and evaluation analysis, and consideration of expected outcomes and potential impacts. Paper I describes the characteristics of urban freight systems in developing countries, including the contexts of the problems and measures related to urban freight. It also outlines the barriers and drivers in transferring urban freight policy experience to developing economies. Papers II and III present behavioural freight demand models that use innovative methodological approaches to model different steps of urban freight systems. In Paper II, freight (trip) generation was modelled using spatial econometric techniques and datasets from establishment-based freight surveys and city structural data. In Paper III, the overall truck type and shipment size choices were modelled using a combined choice and latent variable method that revealed the choice conditions of trucks and corresponding shipment sizes at system level. The shipment size at the individual truck level and the temporal changes in shipment size were analysed using the latent growth method. Papers II-IV also considered locational aspects, logistical decisions, economic conditions and freight operations on a large city scale in a developing country. The results were used to analyse the urban freight system in an *ex ante* framework. The distribution system formulated by integrating logistics facilities and operational conditions was evaluated as an alternative solution (Paper IV).

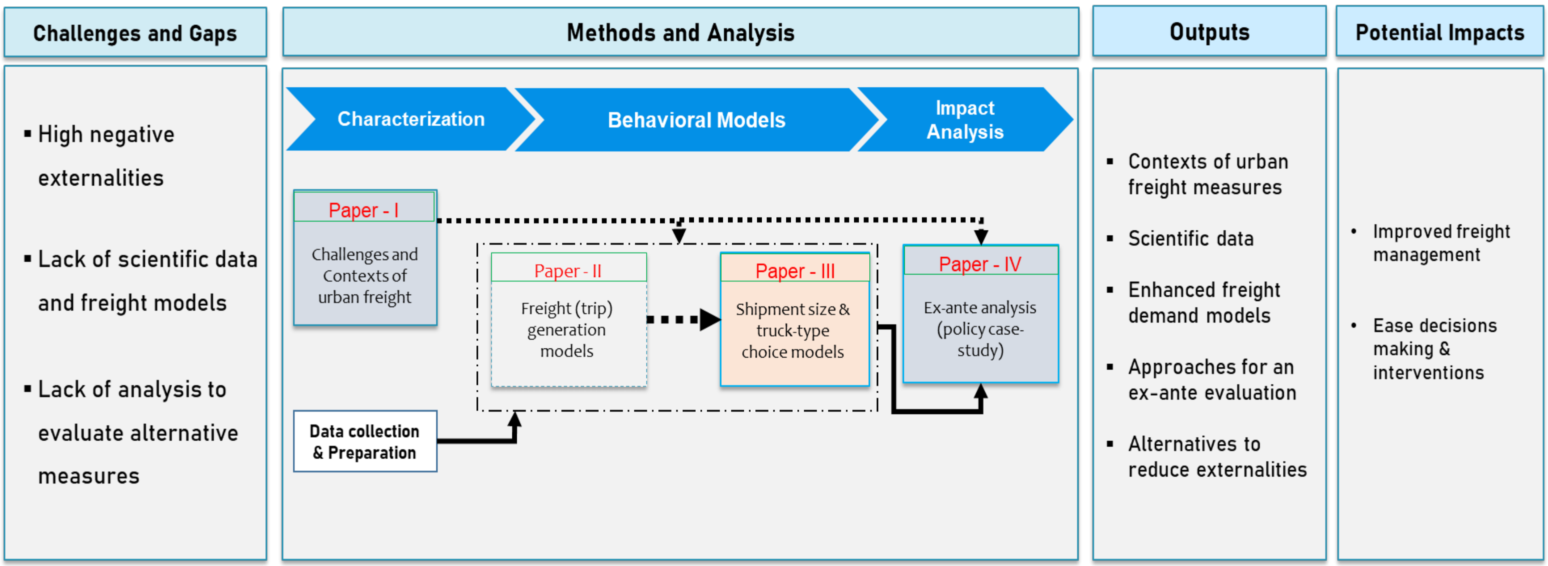


Figure 1. Research framework applied in this thesis.

3. Literature review

3.1 Contexts of urban freight in developing economies

The objective in urban freight systems is diverse when comparing cities worldwide (Dablanc, 2011). The priority in many European cities is to protect urban residents from noise and preserve historic town centres, whereas cities in developing economies focus on enhancing the economic efficiency of urban centres while mitigating congestion and air pollution (Herzog, 2010). Moreover, the level of adoption of urban logistics measures varies between cities at different levels of economic development. Developed countries (*e.g.* France, the Netherlands and Japan) are more advanced in urban logistics development than emerging economies (*e.g.* China, India, Mexico, Chile and Brazil) (TURBLOG, 2011). Countries in the Middle East and Africa also show lower uptake of these measures (Kin *et al*., 2017). This variability in adoption of urban logistics measures enables transfer of measures as best practices, even though the challenges and the objectives differ between cities in different parts of the world.

Identification, analysis and uptake of urban transport policy ideas, concepts or instruments from elsewhere are subject to various influences, including political, professional, institutional, economic and social influences (Pojani & Stead, 2018). A study on contextual factors can provide a first response to the key challenges and opportunities for transferring sustainable urban freight policies, especially to cities in developing countries. The context of urban freight in developing countries is better studied by considering the overall measures considered and their transfer from more experienced cities in developed countries. Understanding the context of dependencies associated with measures, standardised barriers and drivers is reported to be the main precondition for transferring urban logistics policies (Macário & Marques, 2008).

Matching of context is the core activity for reliability and success in transferring measures between a source and recipient cities. The variability of contexts for measures in different regions makes it necessary to identify the barriers (potential undermining factors) and drivers (potentially motivating factors) of success in transferability. In this thesis, the barriers and drivers examined were mainly the problems in developing economies and implemented measures in developed economies.

Five general types of barriers were considered: institutional, financial, physical, technological and cultural. These barriers were rated for relevance when applied to the transferability considerations. The context of the measures in the source city (developed economy) and existing challenges in the recipient city (developing economy) were used to rate the relevance of the barriers. The drivers (enablers) in transfer of measures to developing countries were identified from the particular problems and respective topics in developed economies. A barrier to one measure can sometimes be a driver for other measures. Therefore, identifying the specific enablers of measures in the recipient city is essential.

3.2 Modelling urban freight demand

Freight transport demand refers to the required volume of goods movement between different locations. This demand can be measured in terms of shipments, tonnes, tonne-kilometres, vehicle trips or tours, vehicle kilometres or transport costs (De Jong, 2015). The main modelling methodologies for freight originate from passenger four-step models. The emergence of the first freight models in the 1970s mainly focused on international, national or regional transport (Tavasszy, 2008) and did not consider supply chains and logistic behaviours (Tavasszy *et al*., 2012). Many national freight transport models have recently shown significant changes and are moving away from the four-stage design by considering more aspects of transport logistics and even inventory logistics (De Jong *et al*., 2016). However, the specific case of urban freight modelling differs considerably from the national or international approaches. The interurban exchange is channelled by scarce road, rail or waterway infrastructure and it is useful to conceptualise it at the macroscopic scale. These approaches are limited when the focus is on the urban conditions, requiring evaluation of the impact of freight vehicles at a smaller scale. Thus it is necessary to consider the interactions between the urban environment and freight transport differently (Toilier *et al*., 2018).

Urban freight models comprise different dimensions depending on the level of data aggregation, the objectives and perspectives of modelling, the analysis scale and the modelling approach used (Anand *et al*., 2012; Holguín-Veras *et al*., 2013). Modelling approaches are classified into four categories based on the modelling units: trucks, commodities, deliveries and mixed (Comi *et al*., 2012). However, use of vehicle and commodity units cannot represent the complex processes in urban areas, and the notion of trips has therefore been introduced to explain the intricate structure of urban freight flows. Trips can be used as a unit to quantify the impact of goods movement on urban traffic (Toilier *et al*., 2018).

An alternative to the classical four-step model for urban freight is to convert the commodity demand into delivery generation and then build the trip sequences (Nuzzolo & Comi, 2014; Holguín-Veras *et al*., 2013). These introduce additional steps in the estimation process, so trip generation improves estimates of traffic flows and various approaches include it as a primary step (Holguín-Veras *et al*., 2011). Trip generation is a reflection of the economic structure of the urban environment, and freight flows can be described precisely considering the characteristics of firms (Holguín-Veras *et al*., 2014), but these data types are usually not available in developing countries (Sahu & Pani, 2019).

The economic development of cities in developing economies is highly dynamic and requires appropriate infrastructure and logistics services to support growth. Decisions should be supported by proper analysis of freight transportation systems and development of analytical models. However, this is challenging for multiple reasons, *e.g.* limited data availability, lack of proper analysis of the freight system and lack of analytical models (Errampalli *et al*., 2021).

To evaluate and draw appropriate distinctions in modelling urban freight in developing economies, it is better to first consider the general issues in freight modelling within four clusters (De Jong *et al*., 2016): (i) *institutional*: model development and confidence in their outputs; (ii) *requirements*: defining the right question, appropriate scope and level of detail; (iii) *specifications*: developing the right approach and methodology; and (iv) *data*: using existing data, handling limited data availability or collecting new data. Developing countries have more significant constraints with all these issues.

The institutional capacity in developing countries is limited and often identified as the main barrier to making informed decisions regarding urban freight (Paper I). It also hampers the processes of defining applicable requirements and specifying suitable approaches to model the freight system. Moreover, the fragmented industry structure and the presence of an extensive informal sector complicate the task of defining the requirements and outlining the specifications. The lack of data on freight and other related entities in developing economies also hinders model development and evaluation of impacts after measures have been implemented (Herzog, 2010). A critical aspect of freight planning is understanding and forecasting freight movement. Therefore, greater availability of data and better models would enable planners to predict freight movements accurately and make well-informed policy decisions (Errampalli *et al*., 2021). The following sections discuss the approaches, aspects and constraints within different steps of urban freight modelling in the context of developing economies.

3.3 Freight generation and freight trip generation models

Freight generation is the direct output of the economic process of commodity production and attraction, whereas freight trip generation results from logistical decisions influenced by shipment size and other transport considerations (Holguín-Veras *et al*., 2011). The models are subdivided into three spatial levels (Gonzalez-Feliu & Sánchez-Díaz, 2019): macroscopic (regional or city-level), mesoscopic (neighbourhood or street level) and microscopic level (establishment level). The techniques used to model FG/FTG include ordinary least squares regression, generalised linear regression, ordered logit, negative binomial, multiple classification analysis (MCA), and artificial neural networks. These models typically employ explanatory variables such as employment, industry category, gross floor area, commodity type and years in business (Balla *et al*., 2022). However, a lack of establishment-level data on firm characteristics and actual flows has hindered the development of such models for urban freight systems, especially in developing countries (Sahu & Pani, 2019).

The most important factors in FG/FTG modelling are (i) the choice of aggregation level, (ii) the type of aggregation procedure or technique used and (iii) the selected classification system for the economic sector (Holguín-Veras *et al*., 2014; Pani *et al*., 2018; Gonzalez-Feliu & Sánchez-Díaz, 2019). However, most empirical models still exhibit low explanatory power (Holguín-Veras *et al*., 2013), which can be due to using a small set of variables in freight models (Sánchez-Díaz *et al*., 2016). Therefore, addressing the spatial issues inherent in freight patterns is essential to advance model development (Novak *et al*., 2011; Sánchez-Díaz *et al*., 2016; Pani *et al*., 2018).

The location interdependencies in spatial analysis are revealed in three different ways: as spatial dependence (spatial autocorrelation), spatial heterogeneity (spatial non-stationarity) and the "modifiable area unit problem" (MAUP) (Miller, 1999). The spatial autocorrelation effect systematically clusters *e.g.* variables with high values near other high values. This correlation of variables may violate the linearity assumptions in the model (Novak *et al*., 2011) and bias the parameter estimates (Sánchez-Díaz *et al*., 2016). Spatial non-stationarity refers to the parameters or their relationship behaving differently over space due to locational uniqueness within the spatial system. This might result in inability of the spatial model to describe the overall process (Anselin *et al*., 1993), manifesting in biased parameter estimates or predictions (Griffith *et al*., 1999). The MAUP effect arises due to inconsistency in data availability between the pre-defined areal units (such as administrative, census tracts and districts) and the choice of zoning system for spatial analysis, which leads to biased estimates and erroneous statistical inferences (Openshaw *et al*., 1979). Only a handful of previous studies on freight demand modelling have explicitly considered the spatial indicators of modelling FG and FTG patterns (Garrido & Mahmassani, 2000; Kawamura & Miodonski, 2012; Novak *et al*., 2011; Sánchez-Díaz *et al*., 2016; Pani *et al*., 2018; Sahu & Pani, 2019).

The main implication of findings in previous studies is that spatial effects and locational determinants influence FG/FTG models. Although the analyses in the studies cited considered spatial variables in the entire area, their effects differed locally. This indicates a need to include the effect of spatial heterogeneity in order to allow the relationship between the model parameters to vary over space and essentially capture the local impacts.

The geographically weighted regression (GWR) technique has an advantage over other methods by explicitly incorporating local relationships in the regression. However, as it assumes that the scale of spatial relationships is constant over space, it can be inadequate to analyse the relationships at different scales. Multiscale GWR (MGWR) relaxes the assumptions in GWR and allows the analysis scale to vary. Thus, MGWR can minimise overfitting, reduce bias in parameter estimates and mitigate collinearity (Fotheringham *et al*., 2003; Oshan *et al*., 2019). Spatial autocorrelation, spatial heterogeneity and non-linearity are inseparable in model calibration, and misspecification of one can bias the others (Geniaux & Martinetti, 2018; Basile *et al*., 2014). Spatial autoregressive (SAR) models can explain the spatial autocorrelation effects. A combined GWR-SAR or MGWR-SAR framework considers spatial effects where the autoregressive parameter varies locally or with other parameters over different spatial scales. However, the GWR/MGWR and GWR/MGWR-SAR approaches have not been applied previously for spatial analysis of FG/FTG patterns.

3.4 Choice of freight vehicles and shipment size

Freight activity follows the logic of economic rationality and involves a range of complex decisions, including choice of transport mode (Ortúzar & Willumsen, 2011). Shipment size embodies an essential decision in freight transport demand, and its characteristics can represent the logistics activity of a firm. However, it is difficult to integrate shipment size decisions into models due to: (i) lack of data of sufficient detail on the underlying processes and limited information concerning the drivers of logistical decisions made by firms (Combes, 2009) and (ii) interactions between agents (shippers, carriers, receivers) and the behavioural aspect of those interactions determining operational conditions, which are often regarded as complex because of their unobservable and dynamic nature under the influences of market fluctuations (Holguín-Veras *et al*., 2021a).

Previous studies on freight mode choices have considered different modes (truck, rail, waterways, air, intermodal, parcel), scopes (theoretical or empirical) and geographical ranges (national or regional) (Holguín-Veras *et al*., 2021a). Recently, the choice of truck type has become particularly relevant with the geographical range becoming urban/metropolitan/intercity (De Jong, 2014). In the case analysed in this thesis, the choice between truck types, ranging from pick-ups to semi-trailers, was critical due to their significant differences in operational characteristics and related consequences (Holguin-Veras, 2002).

The choice of mode and shipment size are interrelated and are part of the same logistics decisions made by firms, with the literature strongly suggesting that the two choices should be modelled jointly (McFadden *et al*., 1985; Abdelwahab & Sargious, 1992). In econometric modelling, discrete-continuous model forms are often considered suitable for joint modelling of choice of mode and shipment size. In the case analysed in this thesise, truck types or modes were used as discrete variables, while shipment size was continuous. The correlation between discrete and continuous choices leads to an endogeneity problem, which results in estimation bias.

The methods to correct the endogeneity problem differ based on the assumptions considered and usually take two forms: (i) indirect methods, such as control functions or instrumental variables, and (ii) direct methods, such as bias correction term, expected values and full information maximisation (Mannering & Hensher, 1987). The indirect method involving instrumental variables has been used in previous studies (Holguin-Veras, 2002; Abate & De Jong, 2014). The direct methods consider explicit econometric interactions between the two choice models. The latent variable construct for shipment size has the advantage of explicitly treating the interaction between the factors affecting the choice process. The discrete-continuous model formulation treats the shipment size as a latent variable integrated into the vehicle type choice model, also referred to as the integrated choice and latent variable model (ICLV). The method was first introduced in the mid-1990s (Ben-Akiva & Boccara, 1995) and has since been applied in different contexts (Walker *et al*., 2010; Márquez *et al*., 2014; Cantillo *et al*., 2015; Cantillo *et al*., 2018). The ICLV method simultaneously models the specific econometric interactions between the two choices and uses the full information maximisation likelihood approach in the latent variable models to address endogeneity.

Economic fluctuations directly affect freight demand, which can be explained in freight models in three ways: (i) by assuming that all mechanisms are linear, where economic growth directly induces more freight; (ii) as a trade-off between transport and inventories, where larger logistics flows between firms and larger shipment size are only due to the economic order quantity (EOQ) at work and there are no changes in other parameters (De Jong & Ben-Akiva, 2007; Abate & De Jong, 2014); and (iii) by assuming changes in the supply chains and technology. The focus in this thesis was on the third case, *i.e.* how economic changes affect freight demand.

The link between economic sectors that determine the level of freight activity is constantly changing with shifts in economic conditions or inter-sector set-ups (Holguín-Veras *et al*., 2011). Thus changes in economic conditions over time can directly result in changes in the parameters in freight demand models. Capability of models to produce an accurate estimate at different points in time indicates temporal stability.

The stability of the mode choice has been extensively tested in the literature related to passenger transport, with the results indicating that models are stable over short periods, even with changes in transportation infrastructure, but not over more extended periods. In contrast, the temporal stability of freight demand models is understudied in the freight literature. Relevant studies have only assessed the stability of freight demand using FG and FTG models (Holguín-Veras *et al*., 2011; Oliveira-Neto *et al*., 2012; Holguín-Veras *et al*., 2013; Sahu & Pani, 2019; Sahu & Pani, 2020; Pani *et al*., 2021; Holguín-Veras *et al*., 2021b), and not the choice of shipment size.

3.5 Impact analysis with an *ex ante* framework

Municipalities usually find it difficult to deal with problems in the urban freight system and mostly tend to introduce restrictive measures, such as banning or restricting the movement of large trucks. Such vehicle restrictions are common in developing countries with limited institutional capacity (Okyere *et al*., 2018). However, placing restrictions on trucks in an urban area have a tremendous impact on the economy, since freight movement is an expression of the economy. In this case, the realistic option for carriers is to continue to serve the market by sending the cargo with smaller trucks, but these induce even more congestion and pollution (Ocampo-Giraldo *et al*., 2019). The negative impacts of these problems require implementing urban logistics measures as an alternative. These policies include urban consolidation centres (UCCs), delivery time, truck size or access restriction, off-hour delivery and pick-up points.

Cities worldwide have been showing interest in implementing measures to improve logistics activity with different measures, such as UCCs. Modern

UCCs are a type of urban logistics space consolidating deliveries entering a dense urban area and are typically installed to increase the payload of freight vehicles entering congested urban areas (McKinnon, 2004). The main impetus for implementing UCCs is the tendency of cities to restrict (or plan to restrict) vehicle circulation in urban cores, allowing only fully-loaded environmentally-friendly vehicles to enter (Amodeo *et al*., 2015). For instance, UCCs have been shown to be more effective in reducing environmental externalities than fleet renewal for Rome, Italy (Filippi *et al*., 2010). The main disadvantage of UCCs is their low financial viability, necessitating substantial initial investments and government subsidies, resulting in numerous failures of UCC trials (Allen *et al*., 2012). The presence of minimal infrastructure facilities and domination of the retail sector by small family-owned stores (nano-stores) can be an additional limitation in transferring UCCs to developing economies (Merchan *et al*., 2016). These necessitate alternative and adaptable solutions such as trans-shipment terminals or platforms (TPs) to enable urban freight distribution.

The use of TPs provides greater operational flexibility for logistics operators and eases cargo transfer between large trucks and small freight vehicles before accessing congested urban areas. Consequently, TPs reduce the number of trips and the distance travelled by heavy trucks, and can easily be integrated into networks by changing business requirements and operating conditions (Taniguchi & Thompson, 2018). The current literature on urban logistics focuses on the two-echelon system, whereby goods are consolidated outside the city and then transported to redistribution points before making the final delivery to the receivers using smaller vehicles (Bektas *et al*., 2015). These models focus solely on the inbound logistics flows and pay little attention to the outbound logistics flow, which produces more empty truck movements. Empty truck trips are significant, particularly in developing economies, contributing to high logistics costs. Therefore, the efficiency of the system needs to be improved (Gonzalez-Calderon *et al*., 2021). However, the literature on a two-tier city logistics system capable of solving these problems and improving the efficiency of the distribution system is scant (Fontaine *et al*., 2017).

The two-tier city logistics system consists of two layers. First, the goods are shipped to consolidation centres at the city borders. Second, the goods are transported by urban vehicles to so-called “satellites” for sorting and consolidation before the final distribution to the receivers by greener vehicles

(Crainic *et al*., 2012). This two-tier city logistics system establishes service zones for the satellites and interconnects with TPs and the movement of freight vehicles linking these operational nodes. These integrated systems of satellites and TPs can be a useful alternative for cities in developing countries. However, changes in the configurations of satellites and service zones with integration to TPs have not yet been explored with the objective of reducing operational, economic and emissions levels. These mainly direct how several logistics facilities, TPs and satellites with their service zones can be operationally configured to reduce the negative consequences of freight movement under truck restrictions.

ex ante evaluation of measures is important in indicating their potential implications prior to their implementation. Despite the importance of *ex ante* evaluations to test the efficacy of selected measures, few studies have utilised an integrated and coordinated methodology to examine all relevant components and their interaction (Gonzalez-Feliu & Routhier, 2012).

4. Methods and materials

4.1 Study location and data description

All analyses in this thesis were conducted using the case of Addis Ababa, which is the capital city of Ethiopia and the diplomatic centre of Africa. It is also one of the fastest-growing cities on the African continent, with an estimated population of 4.8 million (World-Bank, 2020). The city consists of 99 municipal wards aggregated into 10 administrative zones or sub-cities (Figure 2).

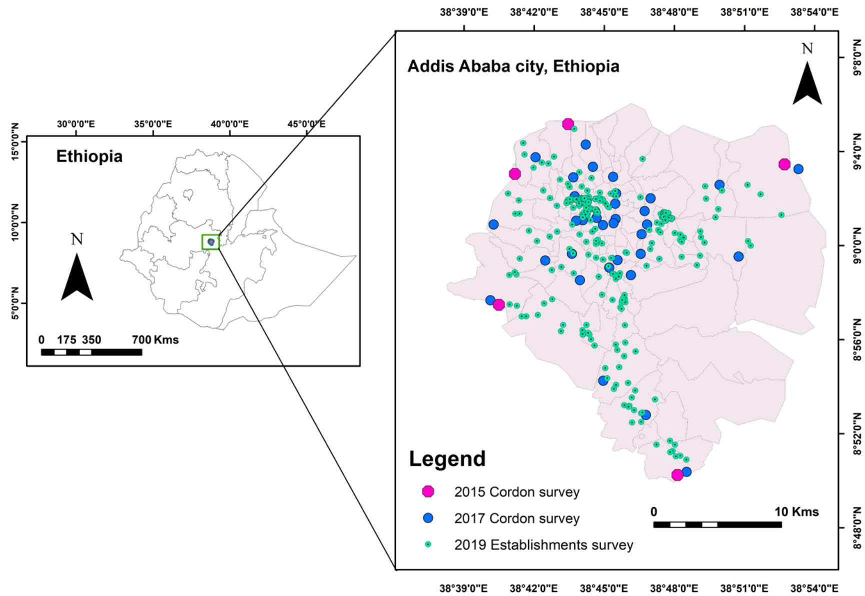


Figure 2. Location of Addis Ababa city, Ethiopia, which was used as a study case in this thesis, and of the data collection points in the city in surveys in 2015, 2017 and 2019.

The datasets analysed in this thesis originated from three cross-sectional surveys conducted in 2015, 2017 and 2019 (specific locations of all three surveys are shown in Figure 2). The 2015 data were collected in roadside interviews with truck drivers at the city entry/exit points and major market locations in the city centre of Addis Ababa and consisted of 601 observations. The 2017 data were also collected through roadside interviews with truck drivers and classification of traffic at 27 internal and seven external cordon points of the city, and comprised 2349 observations. The 2019 data comprised an establishment-based freight survey (EBSF) of 446 businesses in freight-intensive industrial sectors in Addis Ababa, including manufacturing and raw material production, construction, wholesale and retail trades. The EBSF dataset comprised information about the amount of freight (freight attraction (FA)/freight trip attraction (FTA)) employment, land use and industry sector and was used for spatial analysis of freight (trip) generation of establishments.

The analysis conducted in Papers II-IV, the corresponding dataset from the survey(s) and a description of the attributes are given in Table 2.

Table 2. *Summary of the dataset and attributes used in Papers II, III and IV*

Study	Dataset used	Attributes used
Paper II	2019 EBFS survey for the main analysis and 2017 survey for validation analysis	Type of commodities, employment, land use and industry sector description
Paper III	All three surveys (2015, 2017 and 2019) combined and cross-validation	Vehicle attributes, shipment and haulage characteristics
Paper IV	2017 classified traffic count and cordon-based surveys	Classified traffic count, vehicle age, fuel type and emission standards

In Paper III, the datasets from the three surveys were combined to analyse the freight demand pattern over time in terms of the choice of shipment size and truck type. The combined dataset captured various attributes characterising the trip, the truck type and the freighted commodity, including payload. It encompassed 3396 observations on commercial vehicle hauls taken at different time points over the five-year data collection period (2015-2019), with two-year intervals between surveys. The unit of observation for all datasets was truck trips. The variables of interest included trip share, mean payload and gross weight limits of each truck type. The truck trips split into inter-urban and intra-urban trip types are presented in Table 3.

Table 3. *Truck types and trip share based on origin and destination (OD) location as inter-city/intra-city (Paper III). Note: na - indicates non applicability of the standard. Truck type: LT-1 (pickups), LT-2 (light commercial vehicles, LCV), T-2, T-3 and T-4 (two, three and four-axle rigid trucks, respectively), ST-23 (five-axle semi-trailer) and ST-33 (six-axle semi-trailer).*

Vehicle type	Intra-city			Inter-city			Gross weight Limits (tons)*
	Trip share	Mean payload	Std. dev.	Trip share	Mean payload	Std. dev.	
LT-1	468	1.40	0.83	77	1.37	0.81	na
LT-2	404	3.46	1.26	258	3.50	1.55	na
T-2	271	5.69	1.85	238	5.63	2.19	18
T-3	186	13.38	3.96	243	12.80	4.59	24
T-4	84	19.05	4.45	443	20.18	5.46	32
ST-23	13	27.58	4.19	308	29.98	7.10	44
ST-33	8	33.69	5.59	395	37.42	6.33	52
Total	1434			1962			

Truck characterisation was based on the Ethiopian vehicle classification standards and legal axle load limits (Negarit-Gazeta, 1990). The light truck categories LT-1 and LT-2 refer to two-axle light-duty vehicles with loads below 12 metric tons, while T-2 to T-4 are rigid trucks of up to 32 metric tons gross weight and ST-23 and ST-33 are multi-axle tractor-trailer combinations of up to 52 metric tons (Table 3). The combined dataset was split based on trip OD into trips with both ends within the city (intra-city trips) and connecting the city with other cities or regions (inter-city trips). Intra-city trips tended to be dominated by haulage using light truck types (LT-1 and LT-2) over shorter distances. In contrast, inter-city trips generally had a more balanced utilisation of truck types. Mixing intra-and inter-city trips could thus bias the freight analysis and undermine model estimates. Therefore, the ICLV model used in this thesis considered only inter-city trips in the combined dataset.

4.2 Spatial analysis of freight (trip) generation

The methodology used for analysing spatial freight generation consisted of several steps, as illustrated in Figure 3. The first step involved filtering and sorting data from the 2019 EBFS. This was followed by a verification procedure that included tasks such as checking for spatial autocorrelation and identifying explanatory variables. The final step involved modelling the relationship between freight patterns and explanatory variables using techniques such as OLS, SEM, SAR, GWR/MGWR and GWR-SAR/MGAR-SAR. This included checking model specifications and assessing the correlation and multicollinearity of variables. Further details on these methodological steps are provided in the following subsections.

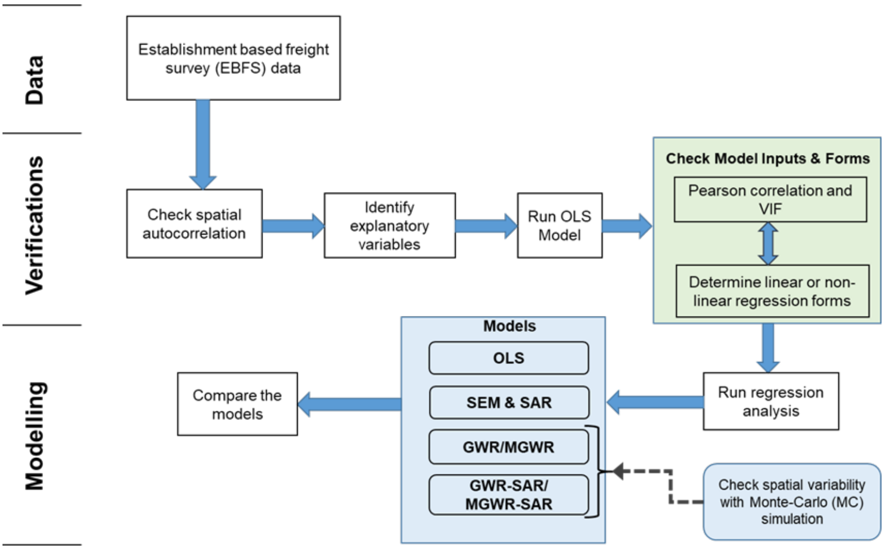


Figure 3. Methodological steps in spatial analysis of freight attraction/freight trip attraction (FA/FTA) (Paper II).

4.2.1 Explanatory variables and spatial indicators

The explanatory variables used for modelling FA and FTA were categorised into three groups:

- *Economic* attributes, including the establishment's industry sector (SIC) and employment (E). These variables were used to measure the size of the establishment and distinguish the type of business activity.

- *Land* use characteristics, represented by the variable land value (LV), were extracted based on land lease information obtained from the city's land management directory. This was used a proxy indicator for the revenues and associated inventory costs at establishment, potentially affecting freight patterns.
- *Network* characteristics connecting the freight patterns of establishments with the locational attributes mainly related to the transport infrastructure, including distance to primary network (DPN), distance to major market (DMM), distance to nearest city gate (DCG) and street width in front of an establishment (SW). DPN was measured as the location of an establishment relative to a main street. DMM was measured as the closeness of the establishment to a major market/commercial hub at the city centre. DCG was measured as the establishment's location relative to the closest city gate (among the five city gates). SW accounted for the vitality of the location and was used as a proxy variable to enhance the locational value of businesses.

The locations of freight needs are correlated to the underlying spatial processes, so spatial indicators can be used to quantify the dependency of establishments on locational geography. The most widely used technique to express the underlying spatial relationship is spatial autocorrelation (Anselin & Bera, 1998), with *Moran's I* used to measure its magnitude. The specification of *Moran's I* is:

$$I = \left(\frac{n}{\sum_i \sum_j w_{ij}}\right)\left(\frac{\sum_i \sum_j w_{ij}(x_i-\bar{x})(x_j-\bar{x})}{\sum_i (x_i-\bar{x})^2}\right) \qquad (1)$$

where n is the number of observations, x_i is the value at location i, $\bar{x}$ is the mean of x, and w_{ij} is the spatial weight defined with the inverse of the distance between establishments with locations i and j.

The expected Moran's *I value* (*E(I)*) when no spatial autocorrelation is defined as:

$$E(I) = \frac{-1}{n-1} \qquad (2)$$

The overall tendency of spatial autocorrelation is given by the difference between the value of *Moran's I* and the expected value. When *Moran's I* value is greater than *E(I)*, this indicates an overall tendency toward clustering, while when it is less than *E(I)*, this indicates dispersion (Moran, 1950). *Moran's I* is sensitive only to large spatial autocorrelation, but autocorrelation may exist in some zones within the analysis area. In these cases, the analysis area is divided using Thiessen polygons, and the interaction between the neighbouring polygons can be calculated with the local indicators of spatial association (LISA) approach. The location of significant interactions with LISA can be mapped using statistical tests (Anselin & Bera, 1998). Presence of spatial autocorrelation indicates a need to incorporate spatial interactions in freight (trip) generation modelling. Systematic handling of spatial autocorrelation and its relationship with the geographical location enhances FA models (Novak *et al.*, 2011) and also FTA models (Sánchez-Díaz *et al.*, 2016).

4.2.2 Global and local models

Conventional OLS regression was used as the starting point for modelling FA/FTA in this thesis. The general form of the model is (Ward & Gleditsch, 2018):

$$y_i = \beta_0 + \beta x_i + \varepsilon_i \qquad (3)$$

where y_i is the amount of freight (in FA in tons/week or in FTA in trips or deliveries per week), β_0 is the intercept, x_i is the characteristics of the i^{th} business establishment in the respective industry sector, β is the vector of the regression coefficients and $\boldsymbol{\varepsilon}_i$ is a random error term.

The regression coefficients were optimised by minimising the sum of squared prediction errors. The main assumptions in the regression are independence between observations and uncorrelated error terms (Anselin & Arribas-Bel, 2013). The OLS assumed that the observations (establishments in this case) were independent and did not consider the spatial interaction between establishments. However, spatial interactions between establishments play an important role in the amount of FA/FTA, as demonstrated in previous studies (Sánchez-Díaz *et al.*, 2016; Novak *et al.*, 2011). Variants of OLS that take into account the spatial dependence between observations include the spatial lag model (SLM) and the spatial error model (SEM) (Anselin, 2003; Ward & Gleditsch, 2018).

Spatial dependence can be introduced into the model specification in two ways: as spatial lag dependence or spatial error dependence (Anselin, 1988).

The SLM or spatial autoregressive (SAR) model assumes spatial dependency between the dependent and the explanatory variables and includes an additional spatially-lagged dependent variable to account for spatial dependence (Anselin, 2003). The spatial autoregressive (SAR) model is given with mixed regressive form and denoted as:

$$y_i = \beta_0 + \beta x_i + \rho W_i y_i + \varepsilon_i \qquad (4)$$

where ρ is the spatial lag (spatial autoregressive) parameter and W_i is the spatial weights matrix. In this thesis, the spatial lag for variable $\boldsymbol{y}$ (FA/FTA) at i was expressed as $W_i y_i$. The spatial weight matrix W was built with the distances between every pair of observations and then row-standardising W to interpret $W_. y$ as the average FA/FTA of the neighbours.

The spatial dependence in the SEM assumes that the error term of the OLS model decomposes into two terms ($\lambda W_i \xi_i$ and ε_i). The SEM model becomes (Ward & Gleditsch, 2018):

$$y_i = \beta_0 + \beta x_i + \lambda W_i \xi_i + \varepsilon_i \qquad (5)$$

where ξ_i is the spatial component of the error at i, λ indicates the level of correlation between these components and ε_i is a spatially uncorrelated term.

The correlation and multicollinearity between explanatory variables was evaluated with Pearson correlation coefficient and variance inflation factor (VIF), respectively. Global models such as OLS, SAR and SEM assume spatial stationarity when modelling the relationship between the dependent and explanatory variables. The GWR model extends the general regression model and relaxes the spatial stationarity assumption to allow the variables to vary over space (Brunsdon *et al.*, 2002). The mathematical notation of the GWR model in this thesis was extended from Eq. (3) as (Fotheringham *et al.*, 2003):

$$y_i = \sum_{j=0}^{m} \beta_j \,(u_i, v_i).\, x_{ij} + \varepsilon_i \qquad (6)$$

where y_i denotes the amount of freight (FA/FTA) at point i, $\beta_j\,(u_i, v_i)$ is a varying jth coefficient in the estimation of continuous explanatory variables, x_{ij}, at any point i within the given spatial analysis area, and ε_i is a random error term.

Multiscale GWR (MGWR) extends GWR and allows the relationship between the dependent and explanatory variables to vary locally at different scales. The MGWR model has the form (Fotheringham *et al.*, 2017):

$$y_i = \sum_{j=0}^{m} \beta_{bwj} (u_i, v_i) x_{ij} + \varepsilon_i \qquad (8)$$

where (u_i, v_i) denotes the x-y coordinates of the i^{th} point, y_i is the amount of freight (FA/FTA), and bwj in β_{bwj} indicates the calibration bandwidth for the jth conditional relationship.

The spatial variability of all parameters studied in this thesis was determined with the Monte Carlo (MC) test for spatial variability. When all the parameters are local or have spatial variability, then the type of model will be GWR and GWR-SAR, or otherwise MGWR and MGWR-SAR. The GWR/MGWR-SAR model takes the possibility of having both global and local variables with the general form (Geniaux & Martinetti, 2018):

$$y_i = \rho(u_i, v_i)Wy + \beta_c X_c + \beta_v(u_i, v_i)X_v + \varepsilon_i \qquad (9)$$

where (u_i, v_i) denotes the x-y coordinates of the i^{th} point, y_i is the amount of freight (FA/FTA), X_c are K_c independent variables with constant coefficients (β_c), and X_v are K_v independent variables with spatially varying coefficients (β_v), Wy is the spatial lag variable with varying coefficient $\rho(u_i, v_i)$.

The GWR and MGWR models were calibrated with a Gaussian kernel function and fixed bandwidth and implemented in *MGWR 2.2* tool (Oshan *et al.*, 2019). The optimal bandwidth for the kernels was selected based on minimising corrected Akaike Information Criterion (AICc). Moreover, since an artificial increase in the t-value arises when estimating the GWR, because the local GWR estimates often overlap, the estimate's significance level was adjusted to solve this problem (da Silva & Fotheringham, 2016):

$$\alpha = \frac{\xi_m}{p_e / p} \qquad (10)$$

where ξ_m is the usual significance level α, p_e is the effective number of parameters that are actually contributing to the model's predictive power, and p is the total number of parameters.

The performance of the global and local models was compared using adjusted coefficient of determination (R^2), AIC and root mean square error (RMSE):

$$\text{AIC} = 2k - 2\ln(\hat{L})$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y_i})^2}{n}} \qquad (11)$$

where $\hat{y_i}$ and y_i is the estimated and observed value of the dependent variable, respectively, n is the number of observations, k is the number of estimated parameters, and $\hat{L}$ is the maximum likelihood function value of the model.

4.3 Choice of shipment size and truck type

A two-step approach was employed to analyse the temporal stability in shipment size decision related to the choice of truck type. The first step was a joint choice model of shipment size-truck type at the overall system level using the integrated choice and latent variable (ICLV) model framework. The second step was temporal analysis of shipment size decisions at the level of each truck type using the latent growth (LG) model.

4.3.1 Integrated choice and latent variable (ICLV) model

In the ICLV model, shipment size was treated as a latent variable that became an explanatory variable in choice models. These formulations integrated latent variable models simultaneously into the choice settings with structural and measurement equations. The ICLV approach developed in this thesis (Figure 4) solves the joint choice model of truck type and shipment size.

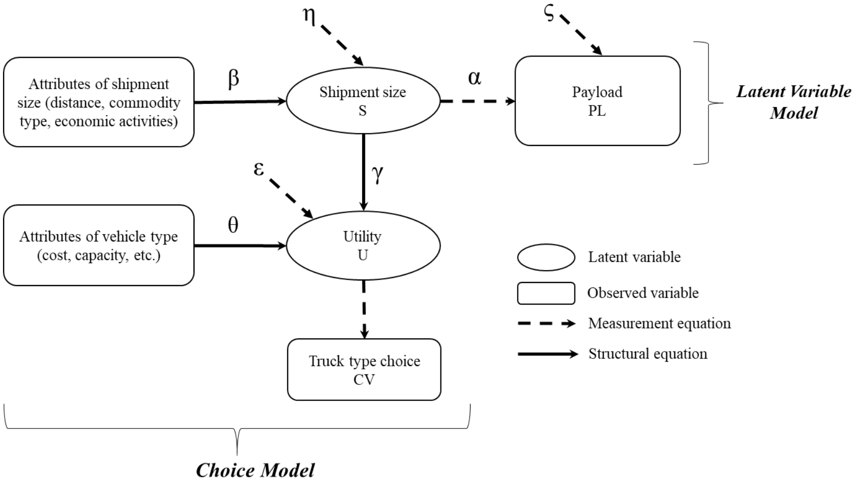


Figure 4. Discrete-continuous model framework with integrated choice and latent variable model (adapted from Ben-Akiva & Boccara (1995) and updated in Paper III).

The ICLV model results revealed the latent variable that best fitted both the choice model and the indicator variables. The analysis used the full information maximum likelihood approach to correct the endogeneity problem in the ICLV model. The specification of shipment size *S* and the utility functions of the model were (Holguin-Veras, 2002):

$$S = \ln(d)\,\{\beta_0 + \sum_{i=1}^{n} \beta_i \delta_i\} + \eta \qquad (12)$$

where d is the transport distance (km), $\delta = (\delta_1, \delta_2, \ldots, \delta_n)$ is a vector of binary variables representing commodity classes, type of activities at the trip ends, trip characteristics (whether it starts/ends at a port location), the specialist truck body trucks required to transport the shipments and data collection year. The binary variable representing the data collection year has an essential implication for whether time-dependent patterns exist in shipment size decisions. η is an error term, assumed to be normally distributed with $\eta \sim N(0, \sigma_\eta)$.

The observed payload of trucks was considered the indicator variable of actual shipment size in the measurement equation:

$$PL_n = \alpha\, S_n + \varsigma \qquad (13)$$

where PL is the observed payload for vehicle class n and α is the parameter of the latent variable to be estimated with the measurement model. The error term ς was assumed to be normally distributed, with $\varsigma \sim N(0, \sigma_\varsigma)$.

The choice of truck type considered random utility maximisation theory and the corresponding utility of the truck type U_n, given as:

$$U_n = \theta_n Cw_n + \gamma V_n + \varepsilon_n \quad (14)$$

where Cw_n is the average operating cost per ton and V_n is a function of shipment size, specified as an index for the unused loading capacity of trucks given as $V_n = |M_n - S_n|$, where M_n is the maximum capacity of the truck class n. ε_n is a vector of independent and identically distributed (i.i.d) Type 1 extreme value error terms. The index V_n shows how appropriate a particular truck type n is for handling a given shipment, where a larger value of V_n for truck class n indicates the lower probability of being selected.

In the case of the observed latent variable S, the choice probability would be represented by $P(CV_n|\theta, \gamma, S, Cw_n)$, where θ and γ are unknown parameters in the choice model. The latent variable was not observed, and the choice probability was obtained by integrating the conditional probability over S (Train, 2009):

$$P(CV_n|\theta, \gamma, \beta, \delta, Cw_n) = \int_s P(CV_n|S, \theta, \gamma, Cw_n).\, g(S|\beta, \delta)\, dS \quad (15)$$

which is an integral of dimension equal to the latent variable S and g(.) is the density function of the latent variable.

The measured payload PL_n was introduced as an indicator variable to characterise the unobserved latent variable S_n and permit identification of the choice model with the latent variables. The joint probability of observing CV_n and PL_n was calculated as:

$$P(CV_n, PL_n|\theta,\gamma,\beta,\delta,d,\alpha,\sigma_\eta,\sigma_\varsigma,Cw_n) = \int_s P(CV_n|S, \theta, \gamma, Cw_n)\ h(PL_n).\, g(S|\beta, \delta)\, dS \quad (16)$$

where CV_n and PL_n were assumed to be correlated only due to the presence of the latent variable S_n. The unknown parameters ($\theta, \beta, \gamma, \alpha$) can be estimated using simulated maximum likelihood from the observed type of truck choices. The variance of the structural model was fixed to 1 to make the structural equation identifiable.

The choice probability of truck types estimated with the ICLV model was cross-validated with the actual choice of trucks in the data. The cross-validation procedure repeated the holdout sampling process multiple times to produce a set of randomly split estimation-validation data pairs. The notation of the cross-validation estimator (CV) was (Parady *et al.*, 2021):

$$CV = \frac{1}{B}\sum_{b=1}^{B} H_b \qquad (17)$$

where B is the number of data pairs generated (estimation-validation) and H_b is the holdout estimator for set b.

The type of cross-validation used here was repeated cross-validation, where the data are partitioned into K subsets that are mutually exclusive, B = K, and the process is repeated R times.

4.3.2 Latent growth (LG) model

The latent growth (LG) model was used to extend the structural equation model (SEM) framework to analyse the trajectories over time for the shipment size of each truck type. The complete path diagram of the latent growth is presented in Figure 5. The matrix notation of the LG model had a data model, a covariance structure and a mean structure (Preacher *et al.*, 2008). The shipment size observations at three-time points were considered with the LG model.

The data model represented the relationship between the factors and the repeated measures of shipment size (S) as:

$$S = \tau + \Lambda\varphi + \mu \qquad (18)$$

where τ is the intercept (3×1) (typically fixed to zero for identification reasons), Λ is the factor loadings of the intercept and slope (3×2), μ is the residual term (3×1), and φ is the latent intercept and slope, with latent means λ_1 and λ_2 (2×1). The latent intercept and slope φ can be expressed as:

$$\varphi = \lambda + \rho \qquad (19)$$

where the residual ρ is the individual deviation from the mean (also referred to as random effects).

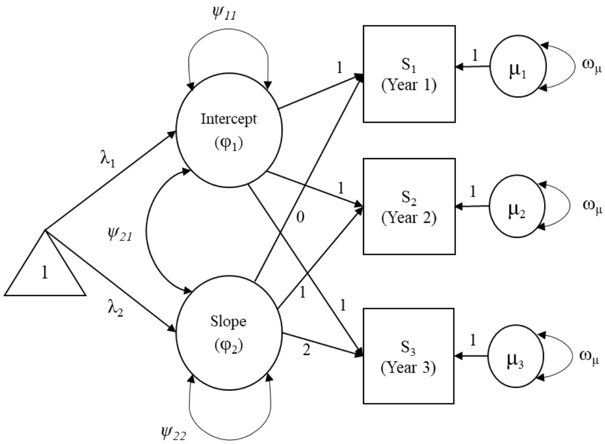


Figure 5. Complete path diagram of growth curve model for the shipment size at each truck type (adapted from Preacher *et al.* (2008) and updated in Paper III).

The covariance structure comprised the variances and covariances of the repeated measures of shipment size as functions of the model parameters:

$$\Sigma = \Lambda\psi\Lambda' + \omega_\mu \qquad (20)$$

where Σ is the variance and covariance of the shipment size variables (3×3), ψ is factor variance and covariance (2×2), Λ is the fixed loadings of the intercept and slope (3×2), and ω_μ is the matrix of disturbance variances and covariances (3×3).

The mean structure was obtained by taking the expectations of the data model, given as:

$$\bar{s} = \tau + \Lambda\lambda \qquad (21)$$

where $\bar{s}$ is the mean of the shipment size variable (3×1) with intercept τ (3×1), factor loadings Λ (3×2) and latent variable mean λ (2×1).

The necessary constraints in the shipment size linear growth analysis model with homoscedastic and uncorrelated residual variance were:

$$\Lambda = \begin{bmatrix} 1 & 0 \\ 1 & 1 \\ 1 & 2 \end{bmatrix} \quad \psi = \begin{bmatrix} \psi_{11} & \\ \psi_{21} & \psi_{22} \end{bmatrix} \quad \lambda = \begin{bmatrix} \lambda_1 \\ \lambda_2 \end{bmatrix} \quad \omega_\mu = \begin{bmatrix} \omega_\mu & & \\ 0 & \omega_\mu & \\ 0 & 0 & \omega_\mu \end{bmatrix} \qquad (22)$$

Therefore, LG model estimation involved a total of six parameters, comprising three parameters of intercept and slope variance and covariance ($\psi_{11}, \psi_{21}, \psi_{22}$), two mean intercepts and slope (λ_1, λ_2), and a disturbance variance (ω_{μ}).

4.4 Impacts of truck restrictions and other alternatives

In the analysis of truck restrictions and alternatives, TPs and satellites were integrated with their respective service zones. Given the location of origin-destination (OD) points and the city's boundaries, four distinct types of freight trips were identified (Figure 6): Internal-internal (IN-IN) trips, which originate and terminate within the city; internal-external (IN-EX) trips, which begin within the city and end outside its boundaries; external-internal (EX-IN) trips, which start outside the city and terminate within its limits; and external-external (EX-EX) trips, which bypass the city entirely, with both origin and destination outside its periphery.

Due to the presence of TPs, IN-EX and EX-IN freight trips were assumed to take the form of freight tours, where transfer trips to TPs were separated from delivery trips originating from TPs. Shipments passing through TPs had to undergo (de)consolidation to comply with restrictions on large trucks entering city centres, resulting in changes to shipment size.

EX-IN freight trips originating outside the city were deconsolidated at TPs and transferred to light commercial vehicles (LCVs) or T-2 vehicles for delivery within the city. Conversely, IN-EX freight trips starting within the city were consolidated at TPs and loaded onto larger trucks (T-2 or above) for transport to destinations outside the city. Conversion factors, derived from the average payload and shipment size values obtained from the ICLV model results (Paper III), were used to convert between truck types. The passenger car unit (PCU) was applied to each vehicle type to assess traffic flow on roadways relative to a standard passenger car.

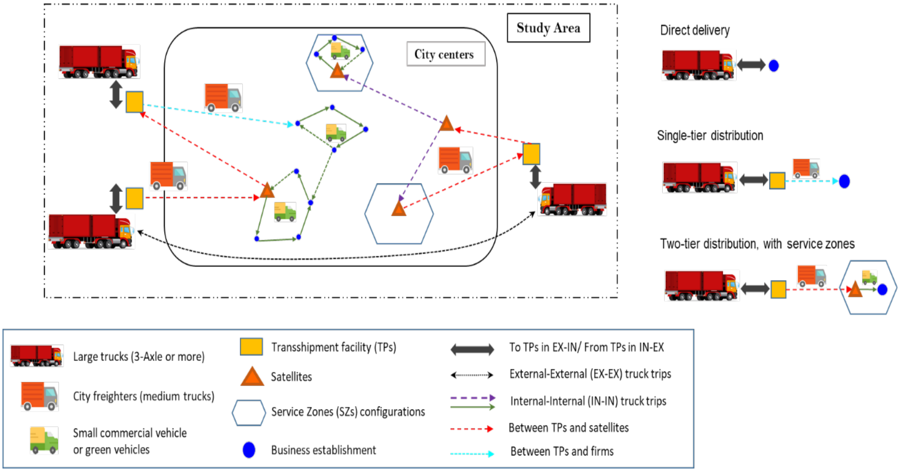


Figure 6. Distribution systems with truck trips, trans-shipment facilities (TPs) and service zones (Paper IV). Different combinations of trips were used as the basis for formulating alternative policies.

Cities typically have two or three layers of administrative systems in which distinctions can be made. Any zoning system, such as census or traffic analysis zones (TAZs), can be created by combining administrative areas or areal units that can be aggregated. In this thesis, the aggregated zones are referred to as service zones (SZs). The aggregation level of SZs was examined in two ways: without and with aggregation. For the aggregated service zones, an applicable approach was to aggregate along the lines of administrative boundaries at different scales.

Four different policies were formulated, comprising the baseline situation and three alternatives. Policy I referred to the baseline situation and reflected the operational condition of the city without truck restrictions, TPs and SZs. Policy II prohibited the entry of trucks larger than 2-axles and introduced TPs, but not SZs. This case was thus a single-tier distribution system with TPs that served zones based on the origin of the inbound flows and the destination of the outbound flows from the city. Policy III and Policy IV were two-tier distribution cases with TPs and SZs with large truck restrictions. The only difference between the two was how the SZs were formulated, where detailed area-based assignment was used for Policy III and the existing administrative zoning for the aggregated zone-based assignment was used for Policy IV. For Policy III, TPs serving a particular ward depended on the one nearest to the recipient location (in this thesis the ward centre) with the lowest impedance (travel time or distance) that created SZ-1. On the other hand, Policy IV allocated TPs to a pre-aggregated administrative zone that created SZ-2.

The two additional cases were considered based on the use of LCV and T-2 for the freight trips within the city in the three alternative policies: Case-1 involved deploying only LCV truck type for all internal movements (EX-IN, IN-EX and IN-IN), while Case-2 used the T-2 truck type for transfer trips between TPs and satellites or establishments (EX-IN and IN-EX) and the LCV type for the internal segment (IN-IN).

The analysis was implemented in PTV Visum and involved three steps to simulate the baseline and other policies. The first step was to establish the road networks with the roadway types as links and junctions as nodes. The second step was to establish the freight demand from OD surveys and represent these demands as OD matrices. The third step involved assigning the demand on the network with the multi-path equilibrium method of an all-or-nothing approach, based on the generalised cost to compute the trip time impedance and iteratively update with the volume-capacity ratio on each link in the network.

5. Results and Discussion

5.1 Selection of urban freight measures for developing economies

Choice of relevant urban freight measures in the case of developing countries can be a challenging task due to the presence of various problems. These problems include limited resources and knowledge about the system, inadequate infrastructure, weak institutional setups to initiate and implement measures *etc*. Therefore, selection of measures should consider dimensions such as: (i) infrastructure, (ii) city traffic conditions, (iii) institutional and legal framework, (iv) economic viability, (v) environmental impact and (vi) stakeholder participation in the decision-making process.

Cities in developing countries have limited infrastructure for urban freight transport. Some of the problems are lack of loading/unloading space, lack of storage/warehousing (Okyere *et al*., 2018) and an insufficient road network (Castro *et al*., 2003). When implementing any urban freight measure, it is important to consider the level of existing infrastructure and the required additional investment to potentially suit the proposed measure(s). The traffic conditions are characterised by congested intersections and roadways (UN-OHRLLS, 2017), weak traffic management and lack of coordination and overloading with truck movements (Herzog, 2010). These also negatively impact the environment, so it is crucial to prioritise the sustainability of the measures. The existing gaps in the institutional and legal framework have to be assessed, and new measures need be designed in a way that aligns and potentially narrows these gaps before any implementation. Short and long-term economic impacts (costs and benefits) and detailed evaluation of the potential return on investment also require more emphasis, due to the limited availability of resources and many competing priorities. Moreover, urban freight transport has various heterogeneous stakeholders with conflicting interests, and the main target of measures should be finding a solution that benefits all these agents (Marcucci & Gatta, 2017). Engaging stakeholders affected by the proposed measures can ensure their support and help to identify challenges and opportunities.

Cities in developing countries currently employ urban freight measures to a much lesser extent than developed countries, creating an opportunity for transfer of measures and experiences. Another essential dimension is to contextualise the measures to the case of developing countries. The context can be established from a measure's objective(s) and/or method(s) or combinations used to solve the prevailing problems. The main reason behind this consideration is the stronger focus on economic efficiency and the unique local conditions. For instance, urban consolidation centres (UCCs) focus on user perceptions, financial viability, governance mechanism and their combinations with electric vehicles in the case of developed economies, whereas effectively managing UCC operations is the main focus in developing countries. This indicates where problems may lie in the case of developing countries, and the next step in the process is to build from these points to solve the target problems. However, the variability of contexts creates a need to identify the barriers and the drivers in local conditions.

Adopting urban freight measures in a specific city is influenced by factors that either hinder (barriers) or facilitate (drivers) the process. This thesis identified five general barriers and numerous specific drivers for implementing a range of urban freight measures. For example, the most significant barrier to measures related to (un)loading/parking areas was found to be a physical or lack of facilities and financial, institutional and technological barriers. The primary motivation for implementing such measures is to reduce the impact of freight activity in urban areas.

The analysis in this thesis showed that financial and physical barriers are highly relevant, in addition to institutional barriers, for transferring urban freight measures to developing countries. Similar findings have been made in other studies, with transferring urban road pricing from other European cities to Valletta, Malta (Attard & Enoch, 2011), and for clusters of urban mobility measures (Macário & Marques, 2008).

5.2 Freight demand at the establishment level

The spatial location of establishments has vital implications for their freight (trip) generation patterns. Thus, spatial analysis can capture the interaction between establishments and the urban environment for their FA/FTA. In this thesis, Moran's I and LISA were used as indicators of the spatial autocorrelation effect. The values of these indicators obtained are presented in Table 4. In most cases, Moran's I values were close to zero and different from the expected (E(I)) value, indicating some degree of spatial autocorrelation. The overall tendency for spatial autocorrelation was conclusive (at 5% level of confidence) for FA and FTA in the construction and retail sectors. In addition, the LISA indicator revealed the presence of several positive associations in the construction sector and clusters between neighbouring polygons with negative and positive associations in the retail sector. In contrast, the manufacturing and wholesale sectors exhibited dispersion, but LISA values revealed several clusters and outliers with polygons surrounding polygons of high tonnage or number of deliveries with low tonnage deliveries or shipments. Overall, the LISA indicators indicated the presence of spatial autocorrelation in almost all sectors.

5.2.1 Linear regression, SEM and SAR model estimates

The OLS model specification was evaluated using the Ramsey regression equation specification error test (RESET) to determine the significance of non-linear model specifications. The RESET test results were conclusive for the FA and FTA models across nearly all industry sectors, rejecting the null hypothesis (H_0: all non-linear coefficients are zero) at 5% confidence level.

A non-linear (log-transformed explanatory and predicted variables) OLS regression that minimised the residual sum of squares was used to model the relationship between the explanatory and the predicted variables. Prior to model calibration, Pearson correlation and VIF values of the variables were assessed to eliminate variables exceeding threshold values. The land-value (LV) variable had a VIF value above the threshold in the FA and FTA models for the wholesale, retail and construction sectors, resulting in its exclusion from subsequent analyses.

Table 4. *Indicators of spatial effects: Moran's I indicates the general spatial area, while local indicators of spatial autocorrelation (LISA) indicate the local spatial autocorrelation*

Variable	Moran's I		LISA		Remarks
	I	E(I)	Clusters	Outliers	
Manufacturing (Standard Industrial Classification (SIC) 20-39)					
FA	0.02	-0.006	YES/HIGH & LOW	YES	LISA revealed several clusters and outliers
FTA	0.021	-0.006	YES/HIGH & LOW	YES	LISA revealed several clusters and some outliers
Construction (SIC 15-17)					
FA	0.94	-0.059	YES/HIGH	No	Moran I showed a global tendency towards clustering
FTA	0.769	-0.059	YES/HIGH	No	Moran I showed a global tendency towards clustering
Wholesale (SIC 50-51)					
FA	0.147	-0.031	YES/HIGH & LOW	YES	LISA revealed some clusters and one outlier
FTA	0.13	-0.031	YES/HIGH & LOW	YES	LISA revealed some clusters and outliers
Retail (SIC 52-59)					
FA	0.142	-0.004	YES/HIGH & LOW	YES	Moran I showed a global tendency towards clustering
FTA	0.046	-0.004	YES/HIGH & LOW	YES	Moran I showed a global tendency towards clustering

The non-linear regression model was formulated using employment as the primary variable and involved extensive testing of various functional forms in identifying the best forms. In FA and FTA models for the industry sectors, locational variables exhibited positive and negative signs, as expected. Establishments located near the primary road network, the city gate and the major market location tended to attract higher tonnage and more deliveries. Wider streets were usually prime locations in the city, where firms were likely to attract more tonnage or deliveries due to their proximity to customers and limited inventory space. As anticipated, these variables had negative signs in both the FA and FTA models across all industry sectors.

The results of the FA and FTA models are presented in Tables 5 and 6, respectively. The FA models exhibited a non-linear relationship with employment, with ln-coefficient ranging from 0.47 (wholesale) to 1.77 (construction). In the retail sector, an increase in employment resulted in a marginal increase in FA, as indicated by the back-transformed function in Eq. (22). However, ln-coefficients for the manufacturing and construction sectors were greater than 1, indicating a parallel increase in FA with employ-

Table 5. *Results of the global freight attraction (FA) models for different industry sectors. Note: t-statistcs are shown in round brackets. All the variables given are significant at 5% and 10% levels, (*) indicates significance at 10% level.*

Dependent variable: ln(tons delivered/week)	Manufacturing	Construction		Wholesale	Retail		
	OLS	OLS	SEM	OLS	OLS	SEM	SAR
Spatial lag coefficient, ρ							0.37 (3.10)
Spatial error coefficient, λ			-0.55 (-2.13)			0.34 (2.48)	
Constant	-5.53 (-5.9)						
Economic characteristics							
Ln(Employment)	1.19 (11.57)	1.77 (9.39)	1.78 (14.08)	0.43 (2.28)	0.47 (2.3)	0.49 (2.47)	0.49 (2.49)
Land-use variable							
Ln(land market value)							
Network characteristics							
Ln(SW)	0.78 (2.93)			0.98 (2.19)	0.89 (3.85)	0.82 (3.57)	0.78 (3.46)
Ln(DPN)							
Ln(DCG)		-1.39 (-2.65)	-1.61 (-5.16)				
Ln(DMM)					-0.56 (-6.95)	-0.47 (-4.34)	-0.3 (-2.89)
n	151	18	18	34	243	243	243
Adj. R^2	0.56	0.86	0.91	0.26	0.29	0.33	0.34
F-Stat	39.09	28.12	n.a.	4.85	21.42	n.a.	n.a.
AIC	532	36.95	34.89	102.8	957.23	952.3	949.92
Log-likelihood at convergence	-260.04	-13.47	-12.44	-47.4	-472.61	-470.15	-467.96

Table 6. *Results of the global freight trip attraction (FTA) models for different industry sectors. Note: t-statistcs are shown in round brackets. All the variables given are significant at 5% and 10% levels, (*) indicates significance at 10% level.*

Dependent variable: ln(number of deliveries/week)	Manufacturing	Construction		Wholesale		Retail
	OLS	OLS	SEM	OLS	SEM	OLS
Spatial lag coefficient, ρ						
Spatial error coefficient, λ			-0.48 (-1.72)*		-2.95 (-2.86)	
Constant	-2.03 (-3.89)					
Economic characteristics						
Ln(Employment)	0.58 (10.1)	0.91 (7.06)	0.87 (9.48)	0.53 (2.50)	0.53 (3.31)	0.28 (4.46)
Land-use variable						
Ln(land market value)						
Network characteristics						
Ln(SW)	0.37 (2.52)			1.13 (2.21)	1.4 (3.66)	0.12 (1.7)*
Ln(DPN)	-0.12 (-2.33)		0.12 (2.14)			
Ln(DCG)		-0.7 (-1.93)*	-0.77 (-3.35)			
Ln(DMM)						
n	151	18	18	34	34	243
Adj. R^2	0.51	0.80	0.86	0.26	0.45	0.13
F-Stat	31.78	18.29	n.a.	4.96	n.a.	7.99
AIC	349.36	23.25	22.42	111.75	107.96	379.93
Log-likelihood at convergence	-168.68	-6.62	-6.21	-51.87	-49.98	-183.96

employment. For FTA, ln-coefficients of employment were less than 1 for all industry sectors, with FTA values increasing marginally with the number of employees. Similar trends of increasing FTA with employment for retail establishments have been reported by Sánchez-Díaz *et al*. (2016).

$$FA = E^{0.47} \times SW^{0.98} \times DMM^{-0.56} \quad (22)$$

The variable SW significantly predicted FA and FTA of manufacturing, wholesale and retail establishments. The ln-coefficient of SW was less than 1, except for the FTA of wholesale establishments. The nearness to the closest city gate DCG was statistically significant for the FA and FTA models of construction establishments, indicating that materials production sites were likely outside the city. DPN proved to be a significant predictor of the FTA model for construction establishments. In addition, DMM significantly predicted the FA of retail establishments, indicating that retail shops near the major market tend to receive more tonnage.

The spatial dependences explained by the SEM and SAR models enhanced the OLS models. SEM was significant in the FA model for the construction and retail sectors and in the FTA model for the construction and wholesale sectors. Both spatial models (SEM and SAR) were jointly significant for the FA model of the retail sector, with the SAR model in particular exhibiting a better fit to address the spatial autocorrelation.

The coefficient estimates were altered and became less biased in the spatial models than the OLS models, while addressing spatial autocorrelation effects. In addition, the variable DPN was not significant in the OLS model of FTA for the construction sector, but became significant in the corresponding SEM model. The SAR model was only significant for the FA model of the retail sector. The SEM and SAR models showed a slight improvement over the OLS models, with higher adjusted R^2 and lower AIC values.

5.2.2 GWR/MGWR models: A spatial interpretation

Spatial variability (whether to use GWR or MGWR) was checked with the Monte Carlo (MC) test, indicating whether all the variables could be characterised as local (Table 7). The explanatory variables E and SW were spatially stationary and only had an overall effect where the local model variants became MGWR and MGWR-SAR, as shown in Table 7. The average values of the parameters in both MGWR and MGWR-SAR were not similar to the estimates of OLS and SAR models due to the calibration of the MGWR model with multiple distinct spatial scales.

The problem of local multicollinearity arose for some network characteristic variables in both the MGWR and MGWR-SAR models, but its effect was reduced from MGWR to MGWR-SAR. The most important explanatory variable in the FA model was number of employees, with 100% and 82.72% significance over the spatial area for the MGWR and MGWR-SAR models, respectively. The next most significant variable was street width (SW), with more than 63% of the spatial area for MGWR-SAR but not significant in the MGWR model. The MGWR-SAR model had a better model fit in terms of adjusted R^2, AIC, AICc and log-likelihood estimation. Moreover, the MGWR-SAR model had higher significance of individual variables. The variables SW and DMM were not statistically significant in the MGWR model, but improved greatly with MGWR-SAR. Generally, the local models (MGWR and MGWR-SAR) had advantages over the OLS, SEM and SAR models, as they did not require the variable to be significant throughout the spatial analysis area.

The variable DPN significantly predicted the FA model of retail establishments. It had a stronger effect on the FA of retail establishments near the city centre, due to greater density of the primary road network in those locations. The variable DCG affected the FA of retail establishments in the city's southern part. The city gate at this location is the main freight entry/exit gate to Addis Ababa, serving more than half of the freight flow (Kebede & Gebresenbet, 2017). Retail establishments closer to the city gate can interact more with freight generators outside the city to attract more freight due to their locational proximity. Another critical variable in the locational characterisation of FA of retail firms was DMM. The variable DMM was used as a proxy for the relative location of a retail establishment, which can also be linked with other locational variables such as DCG. Retail shops near the major market tended to have more agglomeration with neighbouring establishments, and becoming closer to this major market was of key importance in receiving more freight tonnage.

Table 7. *MGWR and MGWR-SAR model estimates of freight attracted (FA) for the retail sector* (*MGWR - multiscale geographically weighted regression, MGWR-SAR – spatially autoregressive geographically weighted regression). Note: MC denotes the Monte Carlo test for spatial variability; SN denotes spatial non-stationarity, and SS denotes spatial stationarity at a 5% level of significance*

Dependent variable: ln(tons/week)	Mean	SD	Min	Median	Max	Adj. critical t-value (95%)	Percentage of significance at 95% level	Percentage of cases with local VIF > 10	MC
						MGWR estimates			
Intercept	0.029	0.253	-0.386	0.074	0.312	2.531	40.74%	-	
Ln(E)	0.147	0.001	0.145	0.147	0.148	1.981	100.00%	0.00%	
Ln(SW)	0.020	0.109	-0.307	0.024	0.127	2.004	0.00%	0.00%	
Ln(DPN)	0.199	0.003	0.190	0.199	0.204	2.392	100.00%	0.00%	
Ln(DCG)	-0.084	0.117	-0.240	-0.123	0.203	2.295	35.39%	33.33%	
Ln(DMM)	-0.180	0.000	-0.180	-0.180	-0.180	1.971	0.00%	55.14%	
Kernel function	Fixed Gaussian	N	243		AICc	585.61	Log-likelihood	-278.63	
Optimal bandwidth Criteria	AICc	Global Adj. R^2	0.42		AIC	583.94			
						MGWR-SAR estimates			
Intercept	-9.605	13.528	-31.450	-7.171	3.003	2.789	100.00%	-	SN
Ln(E)	0.066	0.001	0.065	0.066	0.066	1.978	82.72%	0.00%	SS
Ln(SW)	0.133	0.016	0.092	0.140	0.156	2.089	63.37%	0.00%	SS
Ln(DPN)	0.007	0.138	-0.382	0.043	0.217	2.577	57.79%	0.00%	SN
Ln(DCG)	0.052	0.920	-2.477	-0.102	2.078	2.688	26.75%	8.00%	SN
Ln(DMM)	3.090	4.415	-0.063	0.903	12.584	2.607	25.10%	51.00%	SN
Wy*ln(FA)	-9.194	12.384	-31.749	-2.456	0.078	2.937	46.91%	9.00%	SN
Kernel function	Fixed Gaussian	N	243		AICc	443.87	Log-likelihood	-170.54	
Optimal bandwidth Criteria	AICc	Global Adj. R^2	0.71		AIC	425.58			

The spatial autoregressive parameter was also included in the MGWR-SAR model, which allowed estimation of this parameter to change significantly over the spatial analysis area, as illustrated in Figure 7. The spatial autoregressive parameter can be better explained in conjunction with the results for DCG and DMM. The spatial autoregressive parameter was significant at mid-way locations between the major market and the city gates in the eastern and southern parts. Moreover, retail establishments at these locations had higher spatial dependence, implying their relative advantage of interacting with other establishments both within the city (mainly at the major market) and outside the city boundary. Conversely, for establishments located in an area with low or insignificant spatial dependence, the business attributes of the establishment were better for freight analysis than their locational orientation.

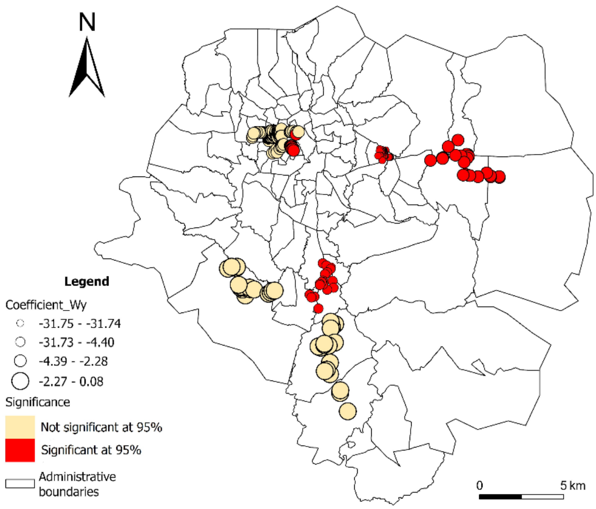


Figure 7. Spatial autoregressive term, Wy*ln(FA), local coefficients and statistical significance of estimates for retail businesses in Addis Ababa (Wy*ln(FA) represents the spatial lag coefficient, which varies over the spatial area).

Model performance was compared using adjusted R^2, AIC and RMSE values (Table 8). The MGWR-SAR model was found to be the best freight generation model, explaining over two-thirds of the variance in FA for retail establishments. MGWR-SAR outperformed all other global models (OLS, SEM, SAR) and represented a significantly improvement over the MGWR model. Unexplained variance in the MGWR-SAR model may be attributable to factors other than business size and establishment location. Additionally, this model simultaneously addressed issues of non-linearity, spatial dependency and spatial heterogeneity.

Table 8. *Comparison of freight attraction (FA) models for the retail sector in Addis Ababa*

Model	Adj. R^2	AIC	RMSE
OLS	0.29	957.2	1.69
SEM	0.33	952.3	1.67
SAR	0.34	949.9	1.65
MGWR	0.42	583.9	0.76
MGWR-SAR	0.71	425.6	0.49

5.3 Logistical decisions related to freight demand

The choice of mode or truck type is a logistical decision made by firms and is closely linked to shipment size, so decisions regarding shipment size may result in changes to the mode of transport. Shipment size is also an inventory management decision at the company level, determined by the size and frequency of supplies (Baumol & Vinod, 1970). Demand at the company level depends on the economy, including domestic and international trade. Economic fluctuations can cause changes in freight demand. The stability of freight demand over time is vital for accurately forecasting future freight transport conditions for planning or decision-making purposes. In this thesis, the temporal stability of shipment size decisions related to truck type choices at both the system level and individual truck type level was emphasised and analysed.

5.3.1 Integrated truck type choice and shipment size model

A joint choice model of truck type-shipment size was estimated using the ICLV model framework and executed using the lavaan package in the R program (Rosseel, 2012). The explanatory variables of shipment size were: (i) trip distance as an intercept and as an interaction with other binary variables, (ii) binary variables representing commodity classes, type of economic activity/sectors at both ends of the trip (inter-sector flow), whether or not origin/destination of the trip was a port location, use of trucks with special body types, and data collection year in the three cross-sectional surveys. The time-specific binary variable characterised the temporal stability of the shipment size construct in the truck type choice model at the system level. The utility of each truck type captured the essence of the truck type selection process with two variables, average unit cost per ton Cw_n and unused loading capacity V_n. The index V_n indicates the appropriateness of a particular truck type to handle a given shipment, which is crucial in the choice of truck type.

The shipment size sub-model results are presented in Table 9. The coefficient of trip distance, ln(D), had a positive sign, indicating that larger shipment sizes were transported over longer distances. Except for textile and wood products, all commodity types showed a positive effect of distance on shipment size, but with varying magnitude of effect. Coal, metals and non-metallic mineral products had a larger positive coefficient, as these items have a higher unit weight and are usually transported in bulk. Commodity groups such as agricultural and chemical products had lower coefficient values, as these items are mostly transported in small units.

Inter-sector flows were found to have a significant impact on shipment size. When retailers were involved, the shipment size function slope was low, except for freight flow from retailers to manufacturers. This suggests that retailers may specialise in providing supplies to the manufacturing process. The flow between manufacturers and wholesalers involved heavier shipments of processed products or inputs for processing and had a large positive coefficient value. The flow between wholesalers was non-significant, indicating competition within the sector. Haul characteristics also influenced the shipment size decision. Hauls involving port locations had a positive coefficient value, as ports typically serve as import/export hubs and attract heavier consignments. Trucks with special body configurations had a negative slope in the shipment size function and transported relatively smaller shipments. The value of α in the measurement equation was slightly less than 1, indicating that the shipment size constructs were slightly larger than the observed payloads.

The time-dependent nature of shipment size was analysed using repeated cross-sectional surveys. Binary variables were used to capture changes over time. The first survey (2015) served as reference when assessing the slope of the shipment size function for the other two survey years (2017 and 2019). The results showed a negative slope over time. Figures 8 and 9 show the overall shipment size and commodity-based trends with travel distance for the three data collection years. As previously mentioned and depicted in the diagrams, larger shipments were transported over longer distances. The trend line represented the average values in the trajectory of shipment size over travel distance.

Table 9. *Integrated choice and latent variable model estimates and shipment size submodel (CC - commodity class, IS - intersectorial flow between origin and destination, YD_2 and YD_3 are the data collection years 2017 and 2019, respectively)*

Shipment size choice model	Estimate	z-stat
Intercept (β_0)	2.72	5.89
Agriculture products	0.45	2.69
Coal, crude oil and natural gas	1.22	4.41
Quarrying products: sand and stone	0.47	2.78
Food and beverage products	0.65	3.94
Textile and leather products	-0.16	-0.67
Wood, pulp and paper products	-0.04	-0.22
Chemicals and chemical products	0.27	1.89
Non-metallic mineral products	1.70	6.97
Metals: basic and fabricated	0.84	4.90
Retailer-Retailer	-0.38	-1.06
Retailer-Manufacturer	0.17	0.58
Wholesale- Retail	-0.21	-1.07
Wholesaler-Wholesaler	-0.15	-0.65
Wholesaler-Manufacturer	0.23	1.01
Manufacturer-Retailer	-0.32	-1.53
Manufacturer-Wholesaler	0.63	3.41
Manufacturer-Manufacturer	0.23	1.43
Port dummy (trip start/end at port location)	0.82	4.92
Specialist body type truck dummy	-0.27	-2.47
YD_2: year 2017 (compared with 2015)	-0.76	-5.75
YD_3: year 2019 (compared with 2015)	-1.88	-6.30
Parameter α in the measurement equation	0.97	9.31
Log-likelihood integrated model	-8409.82	
Chi-square test stat. $\chi 2$ (df = 24) – Robust (p-val<0.00)	1696.12	
Stand. Root Mean Square Residual (RMSR) - Robust	0.015	
Tucker-Lewis Index (TLI) - Robust	0.89	

The trend line for the three data collection years differed, with shipment size gradually declining from 2015 to 2019. This decline was marginally greater with increasing travel distance. In addition, the trajectories of shipment size varied by commodity type and consistently showed a decline over the years.

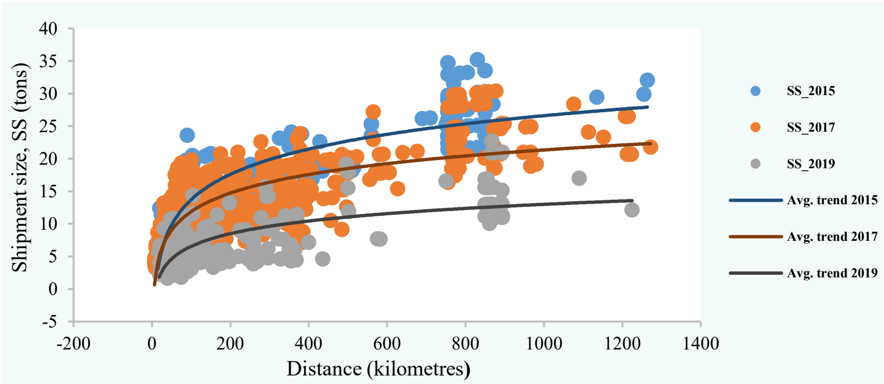


Figure 8. Overall shipment size trends in Addis Ababa in 2015, 2017 and 2019.

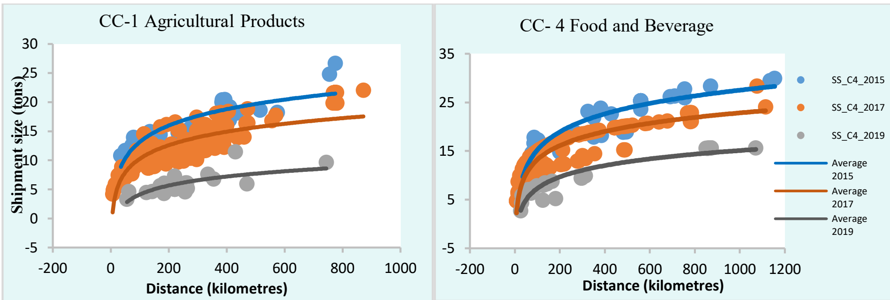


Figure 9. Commodity-specific shipment size trends with travel distance in Addis Ababa based on data from collection years 2015, 2017 and 2019. (Left) Agricultural and related products and (right) food and beverage products (dots indicate individual shipment sizes of observations; lines indicate trends in the overall average).

The truck type choice submodel was conceptually valid and its explanatory variables were mostly significant (Table 10). Compared with the largest truck type (ST-33) used as reference, the specific coefficient of the next larger truck types, ST-23 and T-4, had a positive sign, indicating that these truck types are natural competitors of ST-33 trucks. Both C_w and V_n variables had a negative sign, as expected.

Table 10. *Integrated choice and latent variable model estimates and choice of truck type submodel (ASC - alternative specific constant values; coefficients for each truck type are relative to the reference truck type ST-33)*

Vehicle type choice model (reference truck type ST-33)	Coefficient	z-stat
ASC for LT-1	-3.05	-6.69
ASC for LT-2	-2.14	-6.19
ASC for T-2	-1.28	-4.02
ASC for T-3	-0.84	-3.69
ASC for T-4	0.49	3.02
ASC for ST-23	0.26	2.33
Cw_n cost per metric ton	-0.023	-4.10
Unused capacity index, V_n	-0.34	-32.17
Log-likelihood choice model	- 1727.6	
Likelihood ratio test: chi-sq. = 3834.9 (p.value = < 2.22e-16)		
McFadden R-square	0.52	

The results from the elasticity analysis are shown in Table 11. Important insights were obtained, reflecting the change in the choice probability with a unit change in the value of the variables. The direct elasticities of these choices showed strong elasticity. There was a decrease in the number of truck trips due to a unit increase in both Cw_n and V_n. A unit increment in C_w caused a change in the choice of trucks to types with smaller capacity (LT-1 to T-3).

In contrast, only larger trucks (T-2 up to ST-23) were elastic to a unit change in V_n. This indicates that small trucks are sensitive to cost increments, whereas larger trucks are more sensitive to loading capacity utilisation. The cross-elasticities had larger values for the vehicles considered to be competitive but generally showed small changes relative to the changes in both Cw_n and V_n (Table 11)

Table 11. *Elasticity of truck choice with changes in operating costs (Cw_n) and unused capacity (Vn.). *Values in bold indicate elastic truck-type choices*

Variable in utility function	Truck type						
	LT-1	LT-2	T-2	T-3	T-4	ST-23	ST-33
			Elasticity of Cw_n in the choice				
LT-1	**-2.21**	0.33	0.21	0.075	0.027	0.003	0.23×10^{-3}
LT-2	0.93	**-1.30**	0.68	0.253	0.088	0.010	0.79×10^{-3}
T-2	0.51	0.59	**-1.45**	0.36	0.13	0.016	0.001
T-3	0.14	0.17	0.28	**-1.10**	0.29	0.042	0.004
T-4	0.075	0.090	0.15	0.44	-0.62	0.29	0.039
ST-23	0.004	0.005	0.009	0.030	0.15	-0.50	0.20
ST-33	0.45×10^{-3}	0.55×10^{-3}	0.97×10^{-3}	0.004	0.026	0.26	-0.24
			Elasticity of V_n in the choice				
LT-1	-0.38	0.051	0.040	0.015	0.006	0.001	0.53×10^{-4}
LT-2	0.34	-0.37	0.17	0.072	0.025	0.003	0.25×10^{-3}
T-2	0.57	0.51	**-1.09**	0.20	0.076	0.010	0.92×10^{-3}
T-3	0.37	0.38	0.41	**-1.26**	0.15	0.033	0.48×10^{-2}
T-4	0.35	0.37	0.47	0.67	**-1.18**	0.30	0.084
ST-23	0.035	0.042	0.059	0.13	0.26	**-1.12**	0.44
ST-33	0.47×10^{-2}	0.52×10^{-2}	0.008	0.019	0.068	0.34	-0.36

5.3.2 Shipment sizes with latent growth (LG) models

The time-dependent patterns of shipment decisions at the level of each truck type were analysed with the LG model with a linear functional form within the SEM framework. The model results are presented in Figure 10. For all vehicle types, the slope or average growth ratings were negative, indicating a general decline in shipment size from the reference year. Moreover, truck types from T-4 to ST-33 had larger negative slopes, with ST-23 and ST-33 in particular showing a sharper drop in shipment size over time. Most importantly, these truck types transport various commodity types and can be used across various economic sectors, indicating the state of the economy as a whole. The model's random (variances) and fixed (mean values) elements were statistically significant. The intercept and slope variances were significant and revealed the shipment size heterogeneity carried by each truck type in 2015 and afterwards. The covariance parameter estimate for all truck types showed a significant negative relationship between intercept and slope, suggesting that the shipment size for all truck types followed a declining trend after 2015. Overall, the logistics decisions related to shipment size exhibited a continuous decline after 2015, both at the system level and the level of each truck type. This decline in shipment size over time implies a decrease in freight demand.

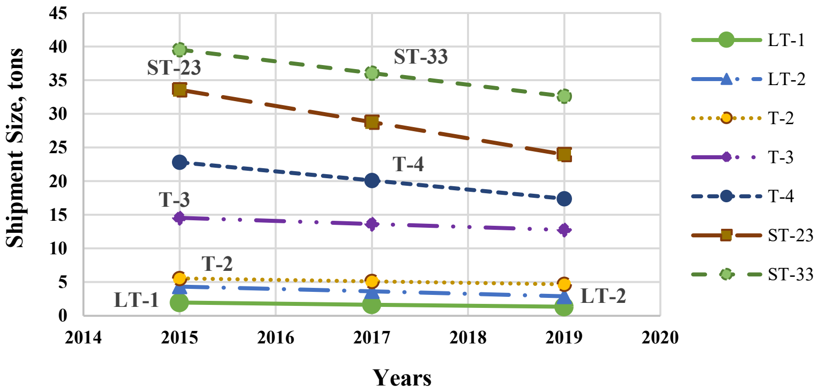


Figure 10. Latent growth curve for different truck types used in Addis Ababa. The shipment sizes at the data points 2015, 2017 and 2019 are the model intercepts, and the change in these values over time indicated with the slope.

Shipment size is an inventory management decision regarding the size and frequency of the supplies at the company level. Demand at the company level will depend on the economy, including domestic and international trade. Generally, shipment size decreases or increases because of changes in the economy or changes in inventory management, due to the total drop in freight demand because of a decline/slowdown in economic activity or recession and also because of changes in inventory management whereby firms reduce shipment size and increase the frequency when transport or fuel costs drop significantly. However, transport cost per ton-kilometre for each truck type increased after 2015. Therefore, our conjecture of shipment size decline was related to the slowdown in economic activity in the same period.

Datasets from Ethiopia were used to estimate the freight demand model, since in the period 2010-2020 the country experienced a series of events that negatively affected political stability and economic growth. The main interest was in the economic growth conditions, particularly in the decade between 2010 and 2020. The metrics used for measuring economic activity were gross domestic product (GDP), inflation, the growth rate of the main economic sectors, import and export real growth, and merchandise imports and exports as percentages of GDP. The trends in these metrics are illustrated in Figure 11. The peak inflation increased from 6.1% in 2015/16 to 20.2% in 2020/21. In addition, real GDP growth declined sharply from 10.1% in 2016/17 to 2.3% in 2020/21. All these metrics showed a declining pattern from the first to the second half of the decade. Overall, the economy vastly underperformed, or there was an economic slowdown in 2015/16-2020/21 compared with 2010/11-2014/15.

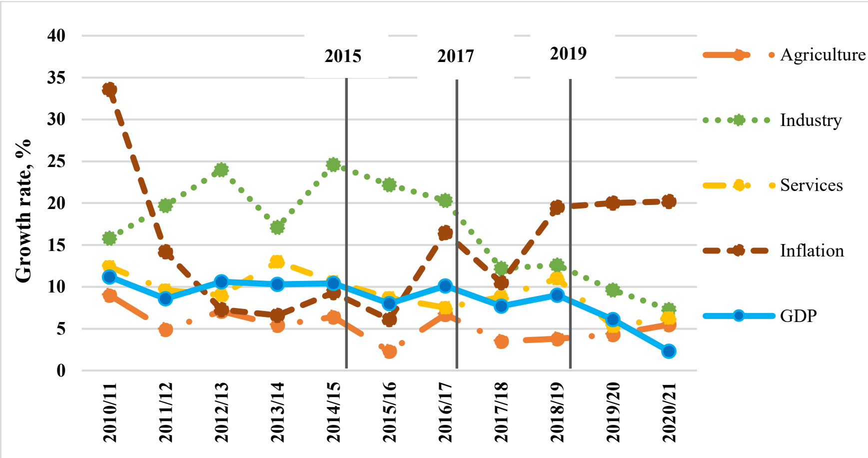


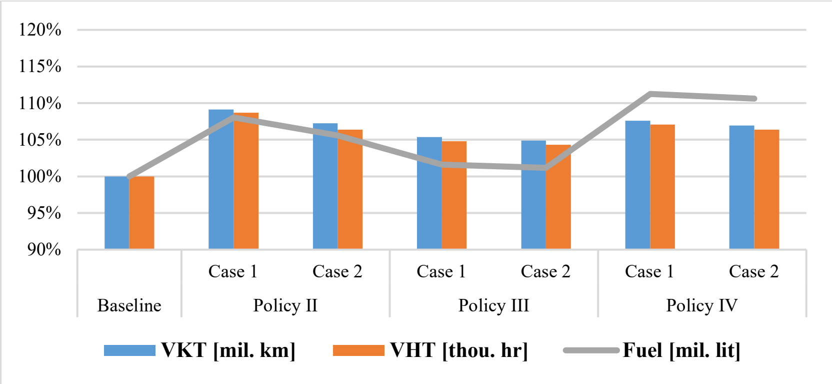
Figure 11. Economic metrics for Ethiopia, 2010/11-2020/21, based on data from World-Bank (2022a) Note: Years on the horizontal axis overlap because the Ethiopian year starts in September). Vertical lines (with years on top) indicate the specific time of data collections.

The data collection years represented two different realities: the 2015 data were collected in the decade's first half, whereas the 2017 and 2019 datasets were collected in the second half. Shipment size decreased after the reference year 2015 at the overall freight transport level (Table 9) and individual truck type level (Figure 10). Shipment size, a crucial decision in freight transport, exhibited a similar pattern to different metrics of economic activity. Consequently, both the economic conditions and freight transport demand changed with time, and the accurate forecast better accounted for the time-dependent patterns of the decisions.

5.4 Alternative distribution systems under truck restrictions

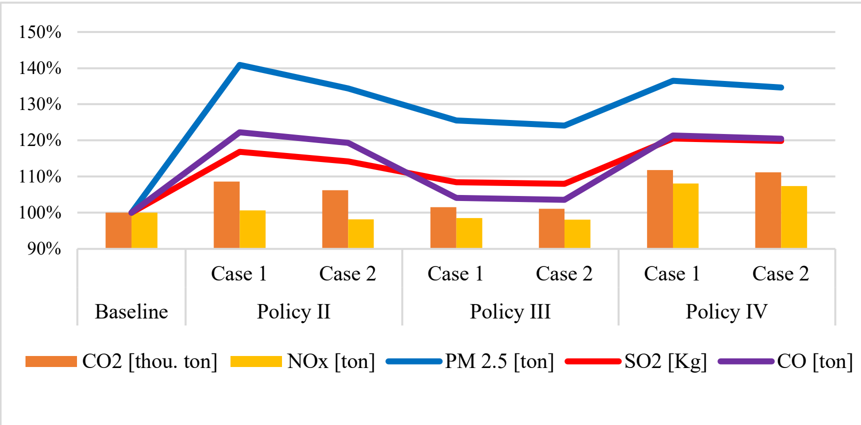
The analysis of alternative distribution systems under truck restrictions focused on formulating an urban freight delivery system for dense urban areas that utilised existing infrastructure and promoted the use of greener light freight vehicles on a large city scale. The impact of freight movement was analysed with four formulated policies (baseline plus three alternative policies) and two cases of operational expenditures, pollutant emissions and logistics costs. The operational expenditures included total vehicle kilometres travelled (VKT), total hours of travel (VHT) and fuel consumption. The pollutant emission types included CO_2, NO_x, CO, SO_2 and particulate matter <2.5μg ($PM_{2.5}$). Logistics costs were estimated based on the average transport cost per ton-kilometre and handling cost per ton at the facilities. These impacts were considered for two cases in the analysis of alternative policies. The policy scenarios were compared using various impacts (Figures 12, 13 and 14).

The baseline case (Policy I) had the lowest operational expenditures and environmental externalities, with 21.53 million kilometres and 395.12 thousand hours of travel. These emitted 4.48 thousand tons of CO_2, 24.94 tons of NO_x, 0.76 tons of PM2.5, 22.21 kg of SO_2 and 28.64 tons of CO. These findings indicate that the truck restrictions caused additional operational and environmental impacts, confirming findings in other studies (Castro *et al*., 2003; Lyons *et al*., 2012; Errampalli *et al*., 2021). Among the alternative policies with large truck restriction, Policy III gave the most advantages, with the lowest travel distance, travel hours and amount of pollutant emissions. Compared with the baseline condition, Policy III increased VKT and VHT by less than 5%, and emissions levels increased by between 1% and 25% of the baseline value (depending on the pollutant type).



Baseline (Policy I)	VKT [mil. km]	VHT [thou. hr]	Fuel [mil. lit]
Values	21.53	395.12	1.96

Figure 12. Comparison of operational expenditure for Policy I-IV, expressed as vehicle kilometres travelled (VKT), vehicle hours travelled (VHT) and fuel consumption.



Baseline (Policy I)	CO_2 [thou. ton]	NOx [ton]	PM 2.5 [ton]	SO_2 [kg]	CO [ton]
Values	4.48	24.94	0.76	22.21	28.64

Figure 13. Comparison of pollutant (CO_2, NO_x, PM2.5, SO_2, CO) emissions levels for Policy I-IV.

Policy IV had lower operational expenditure, but higher emissions, than Policy II, indicating more utilisation of larger trucks for freight delivery in the city. Policy IV gave a 7% increase in VKT and VHT over the baseline, with an increase of 7.5-34.6% in pollutant emissions. Policy II gave an increase of 9% in VKT, 8% in VHT and 6-34.4% in emissions level over the values in the baseline policy.

The logistics cost comprised three categories: transport, handling and inventory (Figure 14). The facilities functioned as cross-docking and no storage service was assumed, so there was no inventory cost. The baseline scenario (Policy I) had the lowest total logistics cost. Among the alternative policies, the least cost was obtained with Policy III (Case-2), and next with an additional 6.4% was Policy III (Case-1). The main difference between the two cases in Policy III was the transport cost, where Case-2 used larger trucks (T-2) with lower cost per kilometre than the smaller trucks (LCV) used in Case-1).

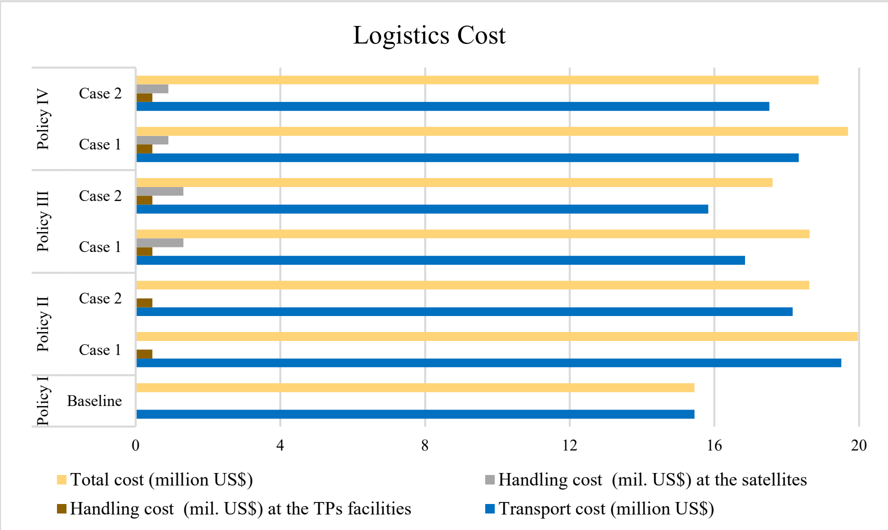


Figure 14. Comparison of the logistics costs for Policy I-IV.

A critical comparison of the policy alternatives was also made by considering the freight trip segments. The main difference between the policies was in the freight trips with the EX-IN and IN-EX movements for trucks larger than LCV, which required passing through the operations of TPs. The expenditure was higher for the movements *to TPs* for EX-IN and *from TPs* for IN-EX freight trips, but these movements were compensated for by lower expenditure movements of the freight trips *from TPs* for EX-IN and *to TPs* for IN-EX. On the other hand, comparison of the two cases within each alternative policy favoured Case-2. Using a two-axle truck (T-2) for the trip segment of EX-IN *from TPs* and IN-EX *to TPs* instead of LCV resulted in a significant reduction in operational expenditure and emissions. This reflected the fact that larger trucks have more operational efficiency in transporting larger loads over longer distances. Overall, the emphasis on the impact of a specific freight trip segment enabled interventions to be strategised to reduce the impact of a particular segment. The freight movements *from TPs* for EX-IN and *to TPs* for IN-EX take place within the city and can still be a focus for further innovation in the distribution system and vehicle technology.

6. Further Discussion

6.1 Factors in selecting measures in developing economies

The selection of appropriate urban freight measures or solutions in developing countries can be challenging due to various constraints, such as limited resources and knowledge, inadequate infrastructure and weak institutional frameworks. To address these challenges, it is important to consider several dimensions when selecting measures, including infrastructure, city traffic conditions, institutional and legal frameworks, economic viability, environmental impact and stakeholder participation in the decision-making process.

In developing countries, urban freight transport infrastructure is often limited. Common issues include lack of loading/unloading bays, lack of storage/warehousing (Okyere *et al*., 2018), and an insufficient road network (Castro *et al*., 2003). Therefore, any proposed urban freight measure must consider the existing infrastructure and the additional investment required to support its implementation. Traffic conditions in developing cities are often characterised by congested intersections and roadways (UN-OHRLLS, 2017), weak traffic management, lack of coordination and overloading with truck movements (Herzog, 2010). These conditions not only negatively impact traffic flow, but also contribute to pollution. Thus it is crucial to prioritise the sustainability of proposed measures. It is also important to assess the constraints in the existing institutional set-up and regulations when selecting urban freight measures. Any new measure should be designed to align with, and potentially narrow, these gaps.

Moreover, it is important to carefully evaluate the short- and long-term economic impacts of any proposed urban freight measures in developing countries. This includes assessing costs and benefits and estimating the potential return on investment. Due to limited resources and competing priorities, it is essential to prioritise measures that offer the greatest economic benefits. Urban freight systems involve a diverse range of stakeholders with conflicting interests and it is essential to engage with these stakeholders when selecting and implementing urban freight measures. This can help to ensure their support and identify potential challenges and opportunities (Marcucci & Gatta, 2017).

Cities in developing countries have currently had less exposure to urban logistics measures than cities in developed countries. This presents an opportunity to transfer measures from developed to developing contexts. However, it is essential to contextualise these measures to ensure their effectiveness in addressing local conditions and challenges. For example, urban consolidation centres (UCCs) in developed economies often focus on user perceptions, financial viability, governance mechanisms and the integration of electric vehicles. In contrast, the focus in developing countries was on effectively managing UCC operations. This highlights the need to identify and address local barriers and drivers when implementing urban freight measures in developing countries.

The adoption of urban freight measures in a specific city is influenced by various factors that can either undermine (barriers) or motivate (drivers) the process. For example, Attard and Enoch (2011) investigated the transfer of urban road pricing from other European cities to Valletta, Malta, and identified the city's unique geography as a general barrier, while international events, local conditions, and a commitment from authorities for change were specific drivers. Other barriers to transferring clusters of urban mobility measures, including political commitment and strategy, legislation and regulatory institutions, information and public relations, and technology, have also been identified (Macário & Marques, 2008). In this thesis, five general barriers and many specific drivers when transferring measures to developing countries were considered in the analysis. The results revealed that financial and physical barriers were highly relevant, in addition to institutional barriers.

The final step in the process of transferring or implementing measures is *ex ante* assessment. This involves evaluating the potential impact and effectiveness of proposed measures in inducing desired changes in the behaviour of intended targets (Le Pira *et al.*, 2017). In this thesis, the impact of different alternative distribution systems was assessed within an *ex ante* framework using operational expenditure and emission levels. The results indicated potential of these systems at full scale in a large city and suggested areas for further optimisation of freight trip segments (Paper IV).

6.2 Freight transport demand and industry sectors

The process of moving goods involves multiple agents, including shippers, carriers and receivers. Classifying these agents by industry sector can enhance understanding of the complex freight transport process and facilitate the development of more effective policies and strategies.

6.2.1 Freight demand at the individual establishment

Assessment of freight generation (FG) and freight trip generation (FTG) as a primary step may improve the process of estimating traffic flow (Toilier *et al.*, 2018). This approach reflects the economic structure and describes freight flow based on the characteristics of firms (Holguín-Veras *et al.*, 2014). By considering the business size and industry categories, FG/FTG can better capture freight activity at the level of the individual establishment.

Economic classification systems such as Standard Industrial Classification (SIC) are more effective for modelling FG/FTG than land use-based classification systems (Holguín-Veras *et al.*, 2012). However, the choice of industry classification system depends on data availability and the classification system used by local authorities. In this thesis, the SIC system was chosen to conduct an establishment-based freight survey in 2019. This aligned with the existing industry classification used by the city authority and allowed the existing datasets from 2015 and 2017 to be utilised. This approach helped to address data availability issues and ensure consistency in the analysis and modelling over time.

The influence of business size on FG/FTG models can be explained by considering employment as an input to the economic process. However, the relationship between employment and FG/FTG output varies across industry sectors. For example, among freight-intensive sectors, the rate per employee corresponds to an attracted tons/week (FA) of 0.43 for wholesale, 0.47 for retail, 1.19 for manufacturing, and 1.77 for construction (Paper II).

In a study of seven cities in Kerala, India, the rate per employee FA value for different establishment types ranged from 11.1 to 24.9 tons/year (0.26 to 0.53 tons/week) (Pani *et al.*, 2018). In contrast, a study of establishments in New York (NY) state, USA found a rate per employee FA value of 0.42 for construction, 2.25 for manufacturing, 8.49 for wholesale, and 0.82 for retail (Holguín-Veras *et al.*, 2016). Thus the NY state, USA case had higher rate per employee FA for all sectors except construction. On the other hand, the rate per employee for FTA (deliveries/week) in the case of establishments in Addis Ababa examined in this thesis was generally less than 1 across industry sectors, with values of 0.28 for retail, 0.53 for wholesale, 0.58 for manufacturing, and 0.91 for construction.

Overall, an increase in the number of employees resulted in a marginal increase in FTA values (Paper II). A similar trend has been observed in the retail sector in NY city, USA (Sánchez-Díaz *et al.*, 2016). These findings have two broader implications: (i) there are variations in the FA rate per employee between countries, due to differences in labour productivity, technological advances and economic policies; and (ii) FA/FTA models have low explanatory power and could be improved by addressing spatial effects.

FG/FTG models are influenced by spatial effects and locational determinants, so accounting for these variables in the models can significantly increase their explanatory power. For instance, the R^2 value for the FTA of wholesale establishments in Addis Ababa increased from 0.26 to 0.45 when using a spatial error model (SEM), representing a 73% improvement in explanatory power compared with an OLS model. Similarly, the R^2 value of the retail FA model increased from 0.29 to 0.34 with a SAR model, to 0.42 with MGWR and 0.71 with MGWR-SAR. This represented a significant increase in the ability of the FA model to explain variability. Incorporating locational variables and addressing spatial effects has yielded comparable results in previous studies (Sánchez-Díaz *et al.*, 2016). However, local models, such as MGWR-SAR used in this thesis, show superior performance.

Accurately predicting freight transport demand by incorporating spatial processes can support better decision-making in infrastructure planning, operational management and land-use development strategies. More accurate FG/FTG models, such as MGWR-SAR, can specifically assist freight planners and policymakers in making informed decisions.

6.2.2 Freight demand and interaction between establishments

Freight transport demand is derived from the product market. Accurate knowledge of how this market functions and the behaviour of the actors/agents is essential for understanding freight transport (De Jong, 2015). Freight operations are determined by the interaction between the actors, such as shippers, carriers and receivers. These interactions involve important decisions about mode/vehicle type and shipment size, including how much, how frequent and how to deliver the supplies.

The economic activity at the origin and destination of freight flows plays a strong role in the choice of shipment size and truck type. This thesis showed that the type of industry sector also affects these choices, particularly by directly indicating the shipment size. For instance, freight flow involving retailers was found to typically have lower tonnage, except for flows from retailers to manufacturers which may involve larger shipments of inputs for the manufacturing process. Similarly, flows between wholesalers and manufacturers may involve larger shipments of processed products or inputs for production.

A study of freight flows in Guatemala City found similar results to those in this thesis in that smaller shipment sizes for flows between retailers, but freight flows between wholesalers had the largest shipment sizes (Holguin-Veras, 2002), whereas in this thesis these flows had smaller and insignificant values. In Toronto, Canada, wholesale and retail trade firms were found to have larger and smaller shipment sizes, respectively (Ahmed & Roorda, 2022). Since shipment size and vehicle type choices are interrelated, wholesale firms tend to use larger truck types, such as semi-trailers, while retail trade firms are more likely to use smaller trucks, such as pickups or LCVs.

Another common factor that affects the decision-making process for shipment size and truck type is the cargo or commodity type. In this thesis, commodity groups such as agricultural, textile, pulp (wood), and chemical products were found to be transported in smaller shipment sizes, while coal, metals and non-metallic mineral products were transported in larger shipment sizes. A study in Colombia also found that cargo types such as coal, lime, gypsum and other building materials were transported in bulk with larger shipment sizes, and were more likely to be carried by heavier truck types (Cantillo *et al*., 2018). Similar results have been found in studies of freight flows in Guatemala City (Holguin-Veras, 2002), Danish cities (Abate & De Jong, 2014), and Toronto, Canada (Ahmed & Roorda, 2022). In this thesis, agricultural products were found to be typically transported in relatively small shipments, as found previously for the case of developing countries (Holguin-Veras, 2002; Cantillo *et al.*, 2018). Generally, high-value goods corresponded to small shipment sizes, while low-value goods were transported in larger shipments.

Overall, analysing the type of interacting firms and the commodity type provided a broad indication of the level of freight flow, and can help inform the design of efficient freight-related policies.

6.2.3 Economic fluctuations and logistical decisions

Developing countries are often vulnerable to economic fluctuations due to factors such as weaker economic structures and institutions, a less diversified economy and weaker financial systems (World-Bank, 2022b). These fluctuations can have a significant impact on the logistical decisions of firms. Freight movement follows the logic of economic rationality (Ortúzar & Willumsen, 2011) and the level of freight activity changes with economic conditions or set-ups between different economic sectors (Holguín-Veras *et al.*, 2011). Freight demand at the company level depends on the economy, including domestic and international trade.

In the economic order quantity (EOQ) model, the optimal shipment size depends on firm-level demand, transport cost, and ordering and inventory costs. Shipment size is an inventory management decision that determines the size and frequency of supplies at the company level. Changes in the economy or inventory management can cause shipment size to decline or increase. For example, a decline in freight demand due to a slowdown in economic activity or recession can cause shipment size to decrease. Alternatively, changes in inventory management, such as reducing shipment size and increasing delivery frequency, can occur when transport or fuel costs drop significantly. In this thesis, an observed decline in shipment size was found to be likely due to a slowdown in the economy, since transport costs increased during the period under study (Paper III).

Shipment size is a decision in freight transport, and changes in shipment size over time can cause variations in demand for freight transport. Due to the important role of freight transport in economic development, these changes can affect economic performance. The structural relationship between freight transport and economic development has been analysed using various metrics, mostly GDP and others, including industrial sector production (McKinnon, 2007), logistics industry added value, total employment, freight volume and traffic turnover volume (Reza, 2013), industrial structure, transport intensity and haulage distance (Zhu *et al.*, 2020).

Previous studies have shown the impact of changes in economic growth on freight transport. For example, US-DoT (2017) reported a decline in freight transport services in the USA during the great recession of 2007-2009 and subsequent recovery that followed a similar pattern to GDP growth. A study in Greece found that the 2009 economic crisis had a significant impact on that country's transport sector (Moschovou, 2017). while a similar study in China using panel data from 30 provinces revealed time-dynamic behaviour in the relationship between economic development and demand for freight transport (Wang *et al.*, 2021).

This thesis demonstrated that the choice of shipment size is strongly time-dependent, which opens up a new direction for analysing the behaviour of freight mode (vehicle) choice. It is therefore vital to consider the linkage between freight activity levels and economic fluctuations when modelling freight demand patterns, especially in developing countries.

6.3 Impact of freight movement on the city traffic

Urban freight transport contributes to traffic congestion, traffic accidents and higher emissions, which can substantially decrease the livability of cities (Browne *et al.*, 2012). In urban areas, freight vehicles have a disproportionate impact on traffic conditions and pollutant emissions. The levels of impact from freight transport vary between cities in developing and developed countries.

This thesis showed that freight vehicles in Addia Ababa contributed between 42% and 65% of pollutant emissions (depending on the pollutant type), despite accounting for only 28% of total VKT and 26% of total VHT (Paper IV). According to a report by the city authority (AA-city-administration, 2020), freight vehicles are responsible for reducing driving speed by around 36% from the free flow traffic conditions during peak hours and are directly involved in 12% of traffic accidents.

In developing countries, the impact of urban freight transport can be significant. For example, in Delhi, India, freight trips account for only about 3% of total trips and 4% of total VKT, but have a large impact on traffic congestion, air pollution and road safety-related issues. Freight movement also produces between 15% and 29% of total transport emissions in that city (Errampalli *et al*., 2021). In general, freight traffic in Indian cities accounts for only 3-15% of total traffic on urban arterial and expressways, but is estimated to be responsible for up to 50% of road transport emissions (Sahu *et al*., 2022; Patil & Pawar, 2014).

In contrast, urban goods movement in European cities represents between 20% and 30% of VKT and between 16% to 50% of pollutant emissions (with different pollutant types) from transport activities (Dablanc, 2007). Freight vehicles are responsible for 20% of total road congestion costs, are twice as dangerous per kilometre driven as passenger cars, and produce about 6% of total CO_2 emissions in the European Union with only 7% of total VKT (T&E, 2018). The traffic impact of freight movement is thus higher for cities in developing countries, despite its smaller contribution to overall travel distance.

The impacts of urban freight transport are generally greater in developing than developed countries due to more challenges and constraints. Therefore, characterising the system, predicting freight demand levels and examining alternative measures using an *ex ante* framework can support critical interventions in the decision-making process and help formulate practical and sound policies.

7. Conclusions

Characterisation and modelling of urban freight systems in the case of a large city in a developing economy, revealed that the system poses various challenges and necessitates new approaches and dimensions. The different steps in the modelling process, including freight (trip) generation, truck type and shipment size choice, and impact analysis of distribution systems, were analysed using innovative approaches that incorporated more attributes and accounted for new dimensions and evaluated different alternatives. These approaches were also used in *ex ante* assessment of new policy alternatives using operational and environmental externalities.

Challenges and constraints in urban freight systems in developing economies were identified with a transferability approach. These problems start within the authorities, whose institutional set-up is usually weak and has limited capacity to identify, initiate and implement measures. Other specific sources of problems included inadequate infrastructure and land use development, poorly defined strategic policies, unmanaged road traffic conditions and limited freight-related data. Thus the constraints are mainly institutional, physical and financial. Detailing those conditions can improve the process of defining requirements and specifying approaches to model the freight system.

Spatial and locational determinants affect freight (trip) generation patterns of establishments in different industry sectors. Freight attraction (FA) and freight trip attraction (FTA) models that address spatial dependency with the spatial error model (SEM) and spatial autoregressive model (SAR) can give better R^2 values and lower AIC values. In particular, a FA model of retail establishments was found to achieve significant model improvement when addressing the connected issues of nonlinearity, spatial dependency and spatial heterogeneity. Specifically, the R^2 value significantly increased, from 0.29 (with the least square model) to 0.71, with a combined SAR model and multiscale geographically weighted regression (MGWR) model (MGWR-SAR model), while root mean square error (RMSE) decreased from 1.69 to 0.49, and Akaike information criteria (AIC) value from 957 to 425. Overall, the freight activities at establishments in Addis Ababa were found to have a strong relationship with their spatial and location characteristics.

The analysis revealed that the preference for shipment size in choice of truck type was strongly time-dependent and exhibited a declining trend in overall freight flows and at individual truck-type level. These choices are affected by commodity characteristics, industry sector, type of truck/s and activities at the trip ends. The elasticities of the choices are influenced in turn by the unit cost of transport and loading capacity utilisation. Choice of smaller truck types is more sensitive to changes in cost structure and choice of large trucks to changes in utilisation of loading capacity. An observed shipment size decline in Addia Ababa in recent years appeared to be related to a slowdown in economic activity.

Urban authorities in developing countries commonly tend to impose restrictive measures, such as truck bans, to reduce negative externalities. In an effort to provide alternatives to these restrictions, in this thesis single-tier and two-tier distribution systems were evaluated with an *ex ante* analysis framework at the scale of a large city. The two-tier system was found to perform better than the single-tier system. Restriction of large truck movements emerged as counter-productive, with increased expenditure and emissions, even when accompanied by a distribution system that improved speed and efficiency. Other innovative strategies focusing on specific freight trip segments and their link with logistics facilities were found to enhance the performance of the alternative measures.

In summary, this thesis characterised urban freight systems in developing countries, performed essential steps in freight modelling and conducted impact analysis of several alternative solutions. The resulting framework can support informed interventions that suit the practical reality of urban freight systems and their local conditions. Application of the framework in future work could improve understanding of the system with its context and could provide the ability to better evaluate different policy options in the decision-making process, which is largely lacking in cities in many developing countries.

8. Future research

The urban freight system is composed of multiple layers of activity and involves a variety of actors. This system poses numerous challenges to the liveability of cities and can result in unintended consequences. These challenges are often understudied, particularly in developing countries where their impact can be magnified. This thesis examined various aspects of urban freight, including problem identification, system modelling and policy analysis. The following points can be of interest to future research:

- In developing countries, industry sectors are often fragmented, and informal sectors have a significant presence (Paper I). This makes data collection and analysis related to freight more challenging. Detailed studies are needed to determine the extra considerations that should be taken into account when analysing freight demand in these contexts. In addition, this thesis focused on freight-intensive sectors when modelling freight (trip) generation, so future research could expand by examining non-freight intensive sectors (service-oriented) to provide a more comprehensive understanding of urban freight demand.
- Freight trips in developing countries are frequently associated with issues such as overloading and high levels of empty returns, accounting for up to 40-42% of trips according to cordon surveys in Paper IV. This indicates two potential areas for future research. First, there is a need to develop methods for analysing and predicting freight demand patterns with the use of empty trip modelling and tour-based flow models. Second, research should focus on improving coordination between various stakeholders to mitigate this issue, such as developing effective business models, stakeholder engagement, and formulating regulatory strategies to promote cooperation.

- The impact analysis in this thesis considered freight tours as distinct freight trips (Paper IV). Future research could focus on an in-depth study of empty trip modelling and tour-based flow models to improve the estimation of freight demand.
- Shipment size decisions are temporally unstable, and it was postulated in this thesis that economic fluctuations may have caused this instability. Future research could focus on directly incorporating economic variables, such as shipment value density, into shipment size models to capture the temporal changes between these two variables.
- The detailed application of policy cases using the analysis conducted with shipment-size and truck-type choice models (Paper III) can be used as primary input for evaluating various vehicle-related policies. Overloading of freight vehicles is a common issue in developing countries (Paper I), making it relevant to study weight and size restrictions for freight vehicles to prevent road and bridge damage and improve safety. Additionally, future research could focus on congestion or toll charging policies for accessing city centres with advancing use of environmentally friendly vehicles.
- Analysis of the impact of alternative policies under heavy vehicle restrictions considered existing diesel vehicles, many of which are older than 10 years (35-72% share) (Paper IV). Further analysis could focus on scenarios that replace older vehicles with newer ones and introducing new vehicle types, such as electric freight vehicles, and related vehicle replacement policies.
- Integrating urban freight into city planning is essential for achieving efficient and sustainable freight transport that benefits all agents. Further research is needed to determine how to accommodate urban freight in city planning while considering the interests of freight agents, initiatives focusing on sustainability, and the interactions of freight flows within/across industry sectors.
- Further research is needed to assess the transferability of the concepts and models presented in this thesis to contexts in other developing countries, *e.g.* in Africa, Asia and Latin America, and other settings. The applicability of the models to other samples should be evaluated for comparison purposes and to strengthen the generalisability of the results under different conditions.

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Popular science summary

Urban freight systems help to move goods within cities and are important for city life. However, they also cause problems such as traffic jams, air pollution and accidents. The thesis analysed urban freight systems in large cities in developing countries, using the specific case of Addis Ababa, Ethiopia. The work involved characterising local contexts, modelling using new attributes and evaluating different alternatives as effective strategies to improve urban freight systems. Implementing these new approaches could enhance the management of urban freight and create a more sustainable, efficient and safer environment for the movement of goods within cities.

This thesis looked at how goods are moved, the types of trucks used and how different ways of moving goods can affect cities. It was found that there are many challenges for urban freight systems in developing countries. Weak institutional systems have resulted in limited ability of authorities to identify and implement solutions, while poor city planning and unclear policies make it difficult to improve existing urban freight systems. Bad traffic conditions and insufficient data about goods movements also make it more challenging to find solutions.

The thesis also looked at how the location of businesses affects goods movement. It was found that using new ways to study this can give better results, *e.g.* modelling approaches that consider the local spatial patterns in the location of businesses can give more accurate results. These models can help city planners understand how to consider the location of businesses when planning and making policies.

Another issue examined was how firms decide on the size of shipments and the truck type for specific trips, and how these choices change over time. The results showed that many factors affect these decisions, such as the type of goods being moved, the industry sectors at both ends of a trip, transport costs, and how much of truck capacity is actually used. These decisions can change over time due to *e.g.* economic slowdown or decline.

Cities in developing countries often try to reduce problems caused by urban freight transport by banning trucks or restricting their movement in the city centre. However, this thesis showed that banning large trucks can actually make things worse, by increasing costs and pollution. Integrating truck types and logistics facilities in the comparison of alternatives revealed that a two-tier distribution system using smaller trucks to move goods within the city and larger trucks to move goods between cities would be better than a single-tier system. Other strategies focusing on specific segments of the freight movement could also improve the performance of freight flows in the city.

Finally, a strategic framework for analysing different policies was developed and tested. This framework takes into account the local conditions and practical reality of urban freight systems and can help city authorities better understand their systems and evaluate policy options. In summary, this thesis provides new ideas for improving urban freight systems in developing countries. By using new approaches to study these systems, city leaders can make better decisions about moving goods within cities more efficiently and with less problems.

Populärvetenskaplig sammanfattning

Urbana godstransportsystem förflyttar varor inom städer och är viktiga för stadens liv. Samtidigt orsakar de också problem som trafikstockningar, luftföroreningar och olyckor. Denna avhandling studerar urbana godstransportsystem i stora städer i utvecklingsländer. Studien fokuserar på urbana fraktsystem i storstäder i utvecklingsländer. Den föreslår att lokala förhållanden karakteriseras , att nya attribut används i modellering och att olika alternativ utvärderas, som effektiva strategier för att förbättra de urbana godstransportsystemen. Genom att implementera dessa nya tillvägagångssätt kan vi förbättra hanteringen av stadens varutransporter och skapa en mer hållbar, effektiv och säker miljö för att förflytta varor inom städerna.

Studien undersöker hur varor transporteras, vilka typer av fordon som används och hur olika sätt att transportera gods kan påverka städer. Det konstateras att det finns många problem med urbana godstransportsystem i utvecklingsländer. Svaga institutionella system har resulterat i begränsad förmåga att identifiera och implementera lösningar. Dålig stadsplanering och otydlig policy gör det svårt att förbättra urbana godstransportsystem. Dåliga trafikförhållanden och brist på data om godstransporter bidrar till att göra det svårt att hitta lösningar. Studien tar även upp hur företags lokalisering påverkar hur varor förflyttas. Det konstateras att nya metoder för att studera detta kan leda till bättre resultat. Exempelvis kan modelleringsmetoder som tar hänsyn till lokala rumsliga mönster i lokaliseringen av företag ge mer exakta resultat. Dessa modeller kan hjälpa städer att förstå hur företags lokalisering påverkar stadens varuflöden vid planering och policyutveckling.

Studiens andra fokus är hur företag fattar beslut om sändningsstorlek och typ av fordon för vissa uppdrag med betoning på hur dessa beslut förändras med tiden. Det kan konstateras att dessa val påverkas av många faktorer, som typen av gods som transporteras, vilken bransch avsändare och mottagare tillhör, transportkostnader och hur stor del av fordonens kapacitet som utnyttjas. Dessa beslut kan förändras över tid och påverkas av många faktorer, såsom ekonomisk avmattning eller nedgång.

Städer i utvecklingsländer försöker ofta minska problem som orsakas av städernas godstransporter genom att förbjuda lastbilar eller begränsa deras rörelser i stadskärnorna. Att förbjuda större lastbilar kan dock snarare göra saken värre, genom att öka kostnader och föroreningar. Jämför man alternativen med avseende på hur fordonstyper och logistikanläggningar integreras, är distributionssystem med två nivåer bättre än enkla distributionssystem. I ett system i två nivåer används mindre fordon för att förflytta varor inom staden och större fordon för att förflytta varor mellan städer. Även andra strategier som fokuserar på specifika segment av varuflödet kan förbättra effektiviteten i stadens godstransporter.

Slutligen föreslår studien ett stategiskt ramverk för att analysera olika riktlinjer. Ramverket tar hänsyn till lokala förhållanden och den praktiska verkligheten för de urbana godstransportsystemen. Detta kan hjälpa städer att bättre förstå sina system och utvärdera alternativa riktlinjer. Sammanfattningsvis utvecklar denna studie nya idéer för att förbättra städers godstransportsystem i utvecklingsländer. Genom att Genom att använda nya sätt att studera dessa system kan städernas beslutsfattare fatta bättre beslut om hur varor effektivt förflyttas inom städerna effektivare och med färre problem.

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I

sustainability

MDPI

Review

Identification of the Regional and Economic Contexts of Sustainable Urban Logistics Policies

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Abstract: Urban logistics policies have become instrumental in achieving sustainable transport systems. Developing and emerging countries still lag far behind in the implementation of such policies when compared with developed countries. This exposure gap provides an opportunity for policy transfer, but this is a complex process requiring knowledge of many contextual factors and involving multiple steps. A good understanding of those contextual factors of measures by cities may be critical for a successful transfer. Our study aimed to identify the different contexts of urban logistics measures or policies worldwide and to assess their significance for policy transferability. In this study, urban logistics measures discussed in the literature were retrieved with a systematic literature review method and then the contexts were recorded, distinguishing between economic development levels and geographical regions. The analysis revealed that the economic level and geographical location of cities both have a strong association with the type of measure implemented. Barriers and drivers were identified by assessing policy transfer between developed and developing countries. Institutional and physical barriers appeared to be highly pertinent for a range of measures, while drivers or facilitators were identified from specific problems in developing countries and the respective measures in developed countries. Thus, the analysis of contextual factors can provide a first response to the key challenges and opportunities of sustainable urban logistics policies transfer to developing countries.

Keywords: urban logistics; city logistics; sustainable policies; developing countries; policy transfer; policy adaptability

1. Introduction

Today, more than half of the world's population resides in urban areas [1]. The increase in urban population and continued economic growth create a necessity for advanced urban logistics (UL) schemes [2]. These schemes help to sustain and maintain the urban way of life but also impose a range of external impacts in terms of congestion, air pollution, accidents, and noise [3]. Several trends drive the need for urban logistics, such as the rise of e-commerce and the sharing economy, the desire for speed in supply chains, and increased attention to sustainability [4]. Freight transport in urban areas is inherently complex, due to its multiple stakeholders, often with conflicting stakes [5], intricate routing patterns, and diverse goods types [6]. Urban logistics as a discipline specializes in coping with the sustainability problems encountered in urban freight transport [7]. The adoption of measures or policies that promote sustainability is thus essential [8].

Urban logistics challenges differ between cities in different regions of the world. For instance, cities in developed countries exhibit rapid changes, with lower store inventories and just-in-time (JIT) supplies to businesses, a significant increase in the type and variety of products on the market with the rise in the service economy, and more frequent and customized deliveries [9]. In contrast, developing countries are shifting towards more small-scale manufacturing in homes or small high-tech parks, creating a need for transport services. The diversity of urban logistics is even more evident when comparing cities worldwide [10]. Specifically, many European cities give priority to the protection of residents from noise and preservation of historic town centers, whereas developing countries focus on mitigating congestion and air pollution and enhancing the serviceability of urban centers [11].

Apart from differences in focus, cities at different levels of economic development also differ in their level of adoption of urban logistics measures. Emerging economies, such as China, India, Mexico, Chile, and Brazil, among others, are at an earlier stage of urban logistics development than more developed countries, such as France, the Netherlands, and Japan [12]. Moreover, the Middle East and Africa show less uptake of urban logistics measures than cities in developed economies [13]. Therefore, the transfer of measures as policy best practices based on experiences is required to narrow the exposure gap between cities at different economic levels.

In the political science literature, policy transfer is defined as "a process in which knowledge about policies, administrative arrangements and institutions in one time and/or place is used in the development of policies, administrative arrangements and institutions in another time and/or place" [14]. Policy transfer involves a range of specific needs and targets/objectives, but public organizations often look outside in search of promising solutions to address new and complex policy problems [15]. Practical transfer of policies can take various forms, from direct copying to taking inspiration from successful policies in other countries/states and transferring broad ideas [16].

Policy transfer or policy diffusion has been described as lesson-drawing, following one of five alternative transfer pathways: copying, emulation, hybridization, synthesis, and inspiration [17]. In contrast to copying and inspiration, emulation refers to adaptation that permits adjustment to programs already in effect. Hybridization combines recognizable elements of programs from two different places, while synthesis extends hybridization by combining elements from more than two places.

Transferability of policy does not simply refer to an individual technical or operational feature of instruments, but rather to how a series of policy instruments may fit to solve a problem within the context of the recipient city [18]. New solutions are sought either by looking at how the problem was dealt with in the same place in the past or by examining how the problem is (or has been) dealt with elsewhere. The ultimate goal is not simply to confirm that policy transfer has occurred, but also to evaluate whether it can facilitate better policy outcomes and under what conditions this can be achieved [19]. In the transport domain, policy transfer has been deemed a useful concept in terms of policy development, relations with stakeholders, scheme design, and administrative approaches [20].

In general, the transport domain is showing a growing interest in theory and practice [21]. City-to-city policy transfer is an active process but, according to Marsden et al. [22], not enough is known about its benefits or the conditions for success. Identification, analysis, and uptake of urban transport policy ideas, concepts, or instruments from elsewhere are subject to a range of different influences, including political, professional, institutional, economic, and social [23]. Understanding the context of dependencies associated with measures, standardized barriers, and drivers is reported to be the main precondition for the transfer of urban logistics policies [18]. Successful transfer to the target city depends strongly on an accurate understanding of the favoring contexts. Although there has been mention of policy transfer in the urban logistics literature [21], to our knowledge there has been no thorough review of existing literature on the issue. The aim of this study was to analyze the contexts of urban logistics measures or policies worldwide and to assess their significance for policy transferability. Thus, to achieve its aim, this study answers the following research questions:

What are the contexts of sustainable urban logistics policies worldwide with regard to economic development level and geographical region?

Can those contexts be used to identify barriers and drivers for the transfer process?

The remainder of the paper is structured as follows. Section 2 describes the research methodology used in the analysis, Section 3 presents the results obtained, and Section 4 discusses the main findings. Section 5 provides some concluding remarks.

2. Materials and Methods

The process of policy transfer involves a range of variables and multiple steps. The most common extensive framework, by Dolowitz and Marsh [24], comprises key policy transfer components and seven questions: (1) What is transferred? (2) Why do actors engage in policy transfer? (3) Who are the key actors involved in the policy transfer process? (4) From where are lessons drawn? (5) What are the different degrees of transfer? (6) What restricts or facilitates the policy transfer process? Finally, (7) how is the process of policy transfer related to policy "success" or policy "failure"? Addressing these questions provides a clear and complete picture of the feasibility of policy transfer. Several studies have applied the framework in the transport domain [19,21,22,25,26].

Macario and Marques [18] suggest a 10-step logical framework for the transfer of urban mobility measures which is capable of addressing the seven questions (Figure 1). Their framework sets the sequence and interrelations between various steps, to identify the potential for a successful transfer.

The work in this study was organized into four stages (I-IV), to cover the contextual variability in sustainable urban logistics policies around the world, and linked to five steps in the 10-step framework, as illustrated in Figure 1. Knowledge of the contexts of urban logistics measures can be useful input to cities when establishing the main problem/s (Step 1), looking for similar contexts (Step 4), and deciding on the practices to be adopted (Step 5). Identification of barriers and drivers specifies the particular assessment points of the measure(s) (Step 8) and provides insights when adjustments are required (Step 9).

2.1. Stage I: Retrieve Relevant Urban Logistics Measures from the Literature

The urban logistics literature is currently showing a steep increase in terms of both the number of studies performed and the diversity of discussion topics [5,27–29]. The challenge of retrieving representative results from existing studies can be simplified by applying a systematic literature review (SLR) method, which uses well-defined and rigorous criteria to identify existing studies and select contributions to further analyze and synthesize [30,31]. A step-by-step SLR approach was used here to retrieve relevant articles.

Keywords with the general term "urban logistics" (or other synonyms such as city logistics, urban delivery, urban freight transport, urban goods transport, urban goods distribution, urban goods delivery, last-mile logistics, and last-mile delivery) and the specific terms "measures" or "solutions" were combined with Boolean logic to formulate the search string. Two databases were searched, Scopus and Web of Science Core Collection, with the search restricted to peer-reviewed journal articles in the English language published after the year 2000. Relevant articles were retrieved from the database search and the duplicates of similar articles were removed from the search results. Then, inclusion/exclusion criteria were applied through abstract and content analysis to filter articles with the focus on sustainable urban logistics measures.

2.2. Stage II: Filter the Measures into Regional and Economic Development Categories

The retrieved and selected urban logistics measures were categorized based on geographical/regional location and economic development class of the source. The source of urban logistics measures in the papers reviewed was set as the country of the case study (if applicable) in the first instance, and then affiliation of the first author. The regional categorization followed the six continents (Africa, Asia, Oceania (including Australia), Europe, North America, and South/Latin America, with Antarctica excluded since it has no permanent human habitation).

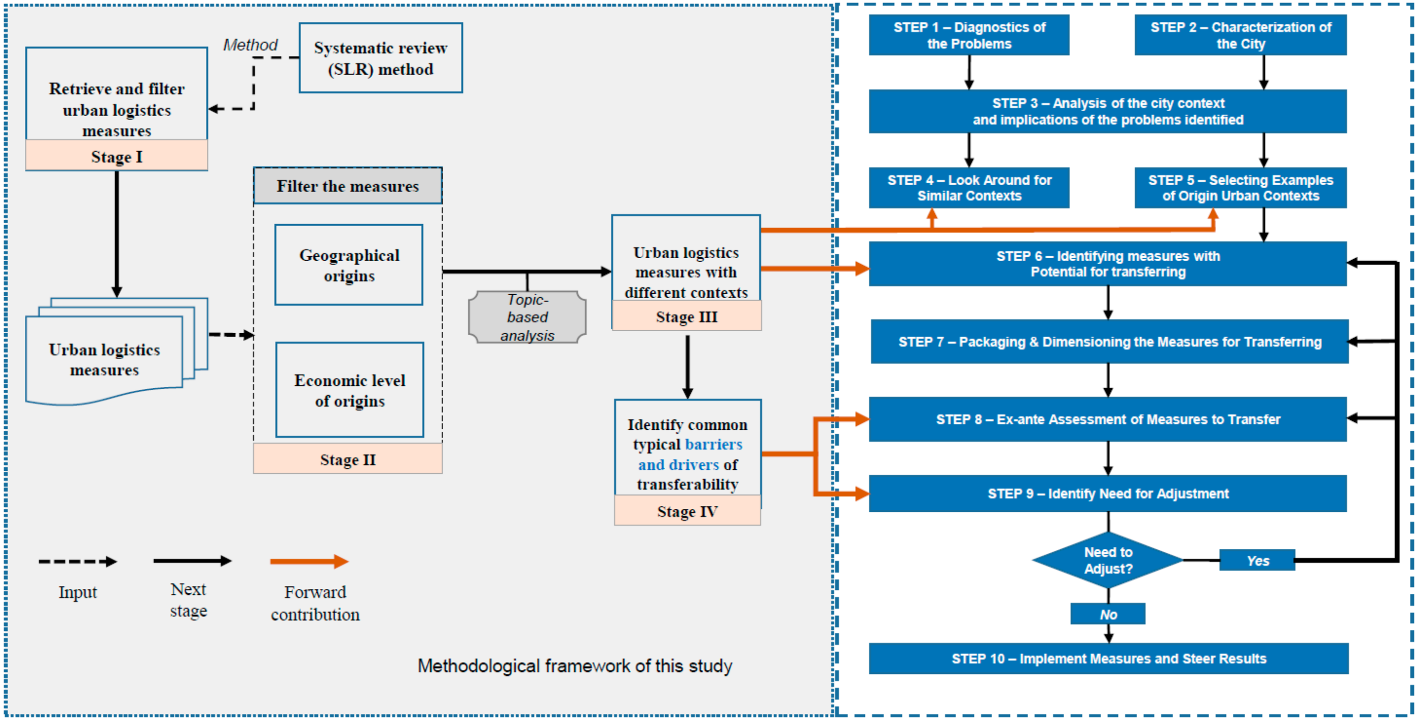

Figure 1. (Left) Methodological framework applied in this study, based on the 10-step logical framework devised by Macario and Marques [18].

The economic development categorization was based on a United Nations [32] report that divides countries into three broad categories: developed economies, economies in transition, and developing economies. Here, emerging market economies were considered as the fourth category in the discussion of the results. Emerging market economies are striving to become advanced and are generally on a more economically disciplined track. However, no universal consensus has yet been reached on exactly which countries qualify as emerging market economies. Different financial institutions have made up lists, including the International Monetary Fund (IMF), Dow Jones and Russell, and Morgan Stanley Capital International (MSCI)'s Emerging Market Index [33]. The MSCI list is the most comprehensive, comprising 26 countries, all of which were selected for this study (Argentina, Brazil, Chile, China, Colombia, Czech Republic, Egypt, Greece, Hungary, India, Indonesia, Korea, Malaysia, Mexico, Pakistan, Peru, Philippines, Poland, Qatar, Russia, Saudi Arabia, South Africa, Taiwan, Thailand, Turkey, and United Arab Emirates). Therefore, four economic development classes were recognized in this study: developed economies, emerging economies, economies in transition, and developing economies. Countries such as the Czech Republic, Greece, Hungary, and Poland, which can be categorized as both developed and emerging economies, were considered to be developed economies in this study.

2.3. Stage III: Establish the Contexts of the Measures with the Categories

The next stage involved two main tasks, identifying the main topics addressed and then distinguishing the contexts of the measures. Topic identification followed the method/approach used by Lagorio et al. [34], setting the dominant theme of measures or policies in the papers with the main emphasis on their application areas. Topics refer to the type of solution(s) being discussed in the article as recognizable by the title, keywords, or abstract. This approach is flexible in allowing multiple topics per article, which helps to attain broad visualization in establishing the contexts.

The inclusion of more factors in the analysis of contexts improves the credibility of policy transfer [16]. The task of distinguishing contexts was carried out using the topics identified as a basis and outlining three components of the papers reviewed:

- The main objective/research problem stated;
- The methodology used to attain the objective or solve the problem;
- Related considerations connecting the above two (objective–method combinations).

Each topic corresponded to at least one context. The contexts indicated the level of uptake of measures through their variability for each category.

2.4. Stage IV: Identify Barriers and Drivers in the Transfer of Measures between Contexts

Identification of barriers and drivers can facilitate the adoption of policies or measures between different economic development and geographical categories which exhibit different levels of exposure to urban logistics. Barriers are factors that undermine the success of policy transfer in the recipient city, while drivers are enablers or motivating factors/conditions or facilitators in the policy transfer. In this study, we used a more general approach both to generalize the contexts in the economic development categories, and then identify potential barriers and drivers in policy transfer across those categories.

TURBLOG [12] identified seven categories of barriers: financial, physical, technological, cultural, political, legal, and security. In this study, we considered four of these barrier types: financial, physical, technological, and cultural, for analysis of the respective topics. The other three categories (political, legal, security) are highly subject to local conditions of the city, or in general of the country.

The financial barrier accounts for the high cost of a measure in the recipient city. The natural or built aspects of the recipient city that make transfer unsuitable represent a physical barrier. Technological barriers include the unavailability of technological elements or deviation from the existing system. Cultural barriers involve the requirement to depart from the traditional culture operating in the recipient city through the measures [21]. There may also be institutional barriers, generated by the need to change the institutional framework and enhance its strength to implement and enforce a specific measure. The corresponding drivers are the opportunities that can be achieved through the transfer of measures to the recipient city.

In the analysis to identify barriers and drivers to transfer measures between developed and developing economies, we followed a more general approach. The basis for the analysis was the contexts of measures from developed economies and relevant sets of problems related to urban logistics in developing economies. However, due to the lack of literature describing pertinent problems in the case of developing economies, we had to conduct additional reviews of other published and gray literature. We rated the five barrier categories into three levels that indicated the necessity of transfer as: highly relevant, relevant, and irrelevant. Barriers rated highly relevant could strongly determine the success of policy transfer and possibly impose the highest negative impact on the transfer. Barriers rated irrelevant were inapplicable to the measure under discussion. Drivers were derived as potential opportunities or suitable conditions in the recipient city that could be obtained through the transfer of policy measures.

3. Results

3.1. Urban Logistics Measures and Topics

The database searches in Scopus and Web of Science Core yielded a total of 387 articles after the removal of duplicates. Application of inclusion/exclusion criteria to filter for articles with the focus on urban logistics measures resulted in 325 articles, which were further used for classification and context analysis.

Urban logistics measures covered by the articles were classified into different geographical and economic development levels based on the case study used in the article (if any) or the country of affiliation of the first author (Table 1). This classification of measures revealed the exposure level or the distribution of measures across the geographical regions and economic development classes. The majority of the measures were in Europe, in developed economies. The last row in Table 1 indicates the exposure level to urban logistics measures across the economic development classes.

Table 1. Distribution of papers in the selected dataset by geographical region and economic development class.

Region/Continent	Number (and Percentage) of Relevant Papers	Economic Development Class			
		Developed	In Transition	Emerging	Developing
Africa	1 (0.3)	-	-	-	1
Asia	61 (17.3)	8	-	43	10
Australia	7 (2.4)	7	-	-	-
Europe	200 (63)	171	4	25	-
North America	39 (12.7)	38	-	1	-
Latin America	17 (4.2)	-	-	17	-
Total	325 (100)	224	4	86	11

Topic identification involved outlining the dominant theme in the measures or policies mentioned in articles and their application area (see Section 2). A single article might comprise more than one topic; our analysis allowed up to four different topics to be identified. These classifications resulted in a total of 19 different topics, covered 343 times. A full list of the topics, their detailed description, and the frequency of occurance is presented in Table A1 (in the Appendix A to this paper)**.** The top five topics in terms of the total number of relevant articles were: *carrier operations optimization*, *stakeholder participation*, *solution performance*, *sustainability*, and *urban consolidation centers (UCCs)*. As with published articles on urban logistics measures, the topics of discussion also varied greatly across different regions and economic development classes.

3.2. Urban Logistics Topics in Different Economic Development Classes

The topics covered revealed significant variations between the different economic development classes, with 260 topics from developed economies, four topics from economies in transition, 68 topics from emerging economies, and 11 topics from developing economies.

The economic development class context was analyzed in terms of the distribution of topics and the detailed focus on individual topics. The analysis indicated that 80% of the topics in developed economies were from Europe (Figure 2), and the central topics were *carrier operations optimization*, *stakeholder participation*, and *solutions performance*. In emerging economies, around 66% of the topics were contributed by Asia (Figure 3), and the main topics were *carrier operations optimization*, *stakeholder participation*, and *sustainability*. The main topics found in economies in transition were *stakeholder participation* and *sustainability*. The topics in developing economies were *crowd-shipping, urban consolidation centers (UCC)/distribution centers (UDC)*, *e-commerce delivery*, *loading/unloading areas*, *alternative modes*, and *parcel lockers*.

The context of the topics was established from the measures' objective(s) and/or method(s), or combinations, used to solve the prevailing problems. These contexts can be categorized under the same topic while being found in different economic development classes. The major highlights of urban logistics contexts in the different economic development classes are presented in Table 2.

3.3. Urban Logistics Topics across Geographical Regions

Analysis of regional context by comparing different topics across geographical regions (continents, i.e., Africa, Asia, Australia (representing Oceania), Europe, North America, and Latin America) revealed that their contribution varied significantly (Table 1). The analysis involved checking the topics of discussion across the geographical regions, and also within the same economic development classes for more clarity (Supplementary Table S2). Europe contributed the most topics, while Africa contributed the least.

3.3.1. Regional Contexts in Developed Economies

Europe contributed to all 19 topics identified. North America contributed to the topics *solution performance, stakeholder participation, pick-up points, off-hour delivery (OHD), cargo bikes, carrier operations optimization, traffic congestion management related to UL*, and *crowd-shipping*. Asia contributed to the *topics of road pricing, solution performance, e-commerce delivery*, and *carrier operations optimization*. Australia contributed to the topics *solution performance, stakeholder participation, alternative modes, eco-friendly vehicles, UCCs*, and *traffic congestion management related to UL*. The main findings were:

(1) *Traffic congestion management related to UL*: The context in all regions with developed economies was on solving congestion to improve delivery performance.

(2) *Carrier operations optimization*: The objective was generally to optimize routing and other operations by the carrier. This was similar for all regions but differed in the problem/s tackled. The contexts in Europe involved single- and multi-echelon routing, electric vehicles, reducing emissions, truck-based drones, and intelligent transport systems. In North America, the contexts were time windows, network optimization, deployment of drones and eco-friendly vans, and carrier collaboration. The context in Asia was time windows.

(3) *Stakeholder participation*: The contexts in Europe involved stakeholder role, participation/preference, policy evaluation, and the multi-actor multi-criteria assessment (MAMCA) method for structuring stakeholder consultations. The context in both North America and Australia was collaborative decision support approaches.

Europe and Asia also contributed to the topics of *e-commerce delivery* and *road pricing*. The contexts in Europe on *e-commerce delivery* topics were e-retail experiences of customers, home delivery, and the engagement of local authorities in facilitation, whereas the contexts in Asia were policies to address home delivery issues. The contexts for *road pricing* topics in Europe were acceptance and equity, whereas the Asia context was the effects of pricing on actors.

Table 2. Major contexts of urban logistics (UL) policies in different economic development classes.

Topic	Developed Economies	Emerging Economies	Developing Economies
Urban consolidation centers (UCCs)	User perceptions and financial viability; policies and governance mechanisms; UCCs and electric vehicle combinations	Distribution models to spatially allocate retailers to UCCs	Manage UCCs facility operations
E-commerce delivery	Last-mile delivery and e-retail experience; customer availability during home delivery; performance levels of home delivery vs. nearby pick-up points; local authority's role in facilitation and policy formulations	Impact of carrier and consumer trips to local collection points; re-engineer the order fulfillment processes	Cost related to customers' flexibility on assigning delivery points
Pick-up points/ parcel lockers	Assessing parcel locker network performance, creating values based on understanding customer perspectives	Customer perceptions and spatial parcel locker network design; intentions to use self-service parcel delivery	Customer perceptions and parcel lockers network design
Cargo bikes	Policies for electric bikes to enhance performance and economic viability	Performance comparison of motorbike vs. bicycle for lightweight deliveries; environmental savings	
Stakeholder participation	Role and perceptions of stakeholders to formulate policy alternatives; multi-actor multi-criteria analysis (MAMCA) methods for consultations; collaborative decision support systems	Actors' perception of UL in their cities; opinion analysis of actors towards regulations; collaborative autonomic logistics	Consumer participation in co-creating logistics service values
Solutions performance	Measures comparison in different cities; economic and environmental impacts analysis; data and models for solutions evaluations; tools and index development for decision making and sustainability evaluations; adaptability level of implemented measures	Evaluation of total logistics cost minimization models; evaluate transferability of solutions between different cities	N/A
Sustainability	Analysis of greenhouse gas (GHG) emissions from trucking services; comparisons of sustainability practices between cities; innovative solutions involving multi-stakeholders and formulation of green policies; multi-criteria decision analysis on choice of sustainable measures	Assessment of sustainable development perspectives; life cycle assessment (LCA) of logistics systems; emission footprint of non-motorized modes; analysis of greenhouse gas (GHG) emissions from trucking services	N/A

Europe and Australia contributed to the topics of *alternative modes* and *UCCs*. The context in Europe for the *alternative modes* topic was on the use of urban intermodal, passenger rail network, and urban waterways, whereas the Australian context was urban intermodal for a port city. European contexts on *UCC* topics were perceptions of users and related benefits, policies and governance mechanisms, and integration of electric vehicles, whereas Australia focused on connecting UCCs with eco-friendly vehicles.

Both North America and Europe contributed to the topics *cargo bikes, off-hours delivery (OHD)*, and *crowd-shipping*. The European context was evaluating the use of electric cargo bikes from policy perspectives, whereas the North American context was the overall performance and economic viability. The European contexts on *OHD* topics were addressing stakeholder acceptability and evaluating policy gaps, whereas North America emphasized impact analysis. The context for *crowd-shipping* topics in Europe was existing mass transit systems, whereas the context in North America was assigning individual customers to the crowd-shipper.

In addition to the topics covered in common with the other regions, unique topics discussed in Europe were information and communications technology/intelligent transport systems (ICT/ITS), loading/unloading area, parcel lockers, policy making, sustainability, and limited traffic zones (LTZ).

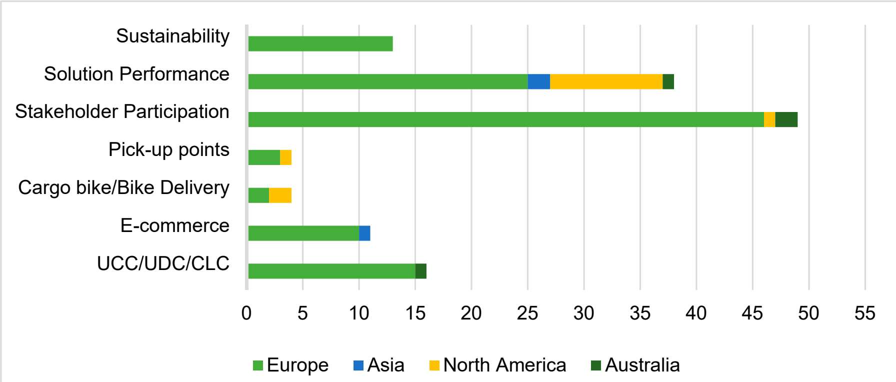

Figure 2. Distribution of urban logistics topics in developed economic regions of the world.

3.3.2. Regional Contexts in Emerging Economies

All the contributions of emerging economies were from Asia and Latin America. The topics *crowd-shipping*, *UCCs*, and *policy making* were unique to Asia, and *cargo bikes* to South America (Figure 3). The Asian context for *e-commerce delivery* topics was order fulfillment, whereas in South America the focus was emissions analysis on the use of local delivery points. The context for *stakeholder participation* in both Asia and South America was perceptions of the actors, while that for *solution performance* was adopting or transferring urban logistics solutions between cities. Similarly, emission footprint and sustainability plans were *sustainability* topics.

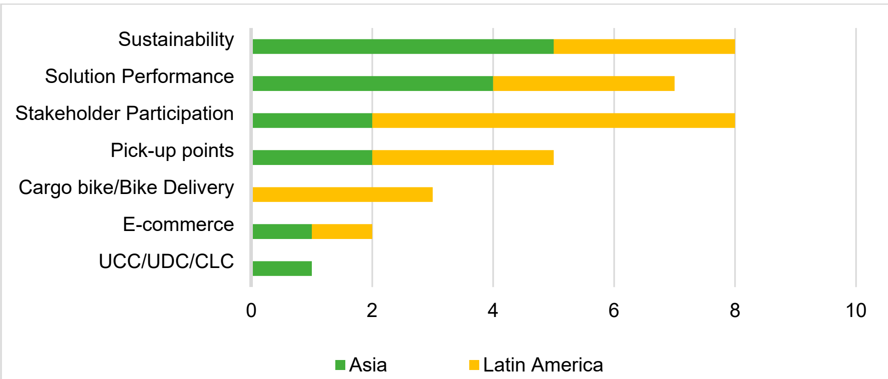

Figure 3. Distribution of sustainable urban logistics topics in emerging economies.

3.3.3. Regional Context in Other Economic Development Classes

The European countries in the economies in transition class only had two topics of discussion, *stakeholder participation* and *sustainability*. In developing economies, only a single topic on *alternate modes* was contributed by Africa, while the rest of the topics (*crowd-shipping*, *UCCs*, *e-commerce delivery*, *parking areas*, and *parcel lockers*) were covered by articles from Asia.

3.4. Barriers and Drivers of Transfer between Developed and Developing Countries

Transfer of measures is a multi-step and multi-variable process (Figure 1), where matching contexts is the core activity. In this study, we incorporated different contexts into transferability analysis to increase the reliability and success of the process. Among the range of relevant contexts, those in the source city and recipient city are of dominant importance. However, our analysis based on the identified topics revealed a variety of contexts for measures in different regions, even under the same topic. This variability made it necessary to identify the barriers (potential undermining factors) and the drivers (potential motivating factors) of success in policy transfer.

The identification of barriers and drivers was based on general problems in developing economies and the contexts of measures implemented in developed economies, as described in Section 3.1 and 3.2. However, the lack of published literature on urban logistics in developing economies meant that we had to seek additional information from other literature sources, such as gray literature. The review results were summarized into relevant general urban challenges and particular urban logistics problems (see Table A2 in the Appendix A). The problems ranged from institutional roles and set-ups to specific urban logistics operations. The general problems for the city development group were urban development and land use, institutional set-up and role, policy and planning, and general traffic systems, outlining the city traffic conditions. The problems related to specific urban logistics were grouped into three categories: freight infrastructures, urban logistics operations, and environmental impacts. These challenges and realities were directly used in the analysis of barriers and drivers.

Five barrier types were identified considering their suitability to the analysis in this study (as described in Section 2, Stage IV). Those barriers were rated for relevance in the transferability of the topic under consideration between the two contexts. The rating of relevance has three scale levels as highly relevant, relevant, and irrelevant. The ratings are given based on the contexts where the urban logistics topics measures were implemented at the source city in the developed economies and the existing challenges of cities in developing economies. Moreover, drivers or facilitators are the potential opportunities or suitable conditions in the recipient city that could be obtained or uncovered through the transfer of policy measures. The barriers, with their corresponding relevance scaling, and the drivers identified are shown in Table 3.

Table 3. Barriers and drivers to adopting urban logistics (UL) measures in developed and developing economies.

Topic of Measure	Rating of Barriers					Barriers	Drivers
	I	F	P	T	C		
Traffic congestion management related to UL	**	*	**	*	-	Lack of sufficient road network, the high proportion of old vehicles, weak regulatory institutions	Improved city traffic conditions through congestion management, and enhanced freight vehicle performance
Crowd-shipping	*	-	-	*	*	Limited capacity in policy implementation and dominance of traditional retail over online retail may hinder the larger benefits	High population density and urban sprawl provide potential to initiate crowd-shipping schemes
Urban consolidation/distribution centers, construction logistics centers	*	**	**	-	-	Needs initial investment to build the infrastructure, plus clear policies with stakeholder acceptance and feasible business model to ensure the long-term financial sustainability	Improved freight delivery performance to urban centers and the opportunity to integrate with other innovative measures, such as eco-friendly vehicles or crowd-shipping
Carrier/logistics service provider optimization of operations	-	*	*	**	-	Apart from the technological requirements, fragmented industry structure and extensive informal sector with presence of many nano-stores complicate goods distribution	Improved operational efficiency and reduced environmental burden from carrier operations
E-commerce delivery	**	-	-	**	*	Weak set-ups of regulatory institutions to cultivate the online market and install the required technological systems, and lack of urban logistics initiatives integratable to these systems	The change from traditional retail to modern e-retail market can enhance business development
Eco-friendly vehicles	**	*	*	**	-	Lack of investments and strategic policies on new vehicle technologies and their supportive facilities; absence of logistics schemes operated by eco-friendly vehicles	Reduced climate burden from urban logistic operations
Smart UL systems with ICT/ITS	*	-	-	**	-	Limited institutional capacity to adopt technological requirements and fragmentation of industry structures	Enhanced delivery performance and eased traffic management
Alternative modes	*	**	**	*	-	Low quality and availability of transport systems with low level of infrastructure development	Eased burden on road-based UL operations and more competition to foster innovative solutions
Cargo bike/bike delivery	*	-	**	-	**	Proper infrastructure for cycling and proper policy backings to better nurture the culture	Greater convenience in delivery to highly congested urban centers and slums, promotes innovative solutions

Table 3. *Cont.*

Topic of Measure	Rating of Barriers					Barriers	Drivers
	I	F	P	T	C		
Loading/unloading/parking areas	*	*	**	*	-	Lack of logistics infrastructure	Reduced times and costs of UL operations such as delivery activities
Off-hour deliveries (OHD)	**	-	*	-	**	Weak institutional set-up, lack of adequate infrastructure and working at night, fragmented industry structure, and acceptance from the stakeholders	Use of underused available infrastructure for UL operations at night
Pick-up points or parcel lockers	*	-	*	*	-	Lack of strong institutional and legal frameworks to manage systems. Industry structure fragmentation and extensive informal sector create more barriers	Use of nano-stores as potential pick-up points
Policy making	**	-	-	*	*	Limited institutional capacity to set up and implement proper policies. For specific cases, it can link with other barriers	Urban development and related logistics challenges
Limited traffic zones	**	-	*	*	*	Inadequate infrastructure and lack of strong regulatory institutions to enforce the restrictions	Reduced emissions from old vehicles and preservation of historic city centers
Solution performance	**	-	-	*	-	Lack of institutional strength in addition to freight and related data to conduct extensive assessments	Urban development challenges at the city level and market competitiveness at the sector or company levels
Sustainability/Emissions/Pollutions	**	*	*	*	-	Lack of strategic policies for old vehicles and the use of leaded gasoline along with inadequate transport infrastructure	A global call for healthy cities and environmental sustainability
Stakeholder participation	**	-	-	-	*	Fragmented industry structure and presence of an extensive informal sector, in addition to weak institutional and legal framework, ignored in the application stages	Economic development and business competition between companies
Road pricing	*	**	**	*	-	Low level of infrastructure development, and institutional strength to formulate and manage schemes	Need to increase available investments for new infrastructure developments
Delivery robots/drones	*	*	-	**	-	Higher technological capability and investments, along with proper policy backing. Convenience to integrate the applications with other transport modes	Shorter set-up time and functionality than developing infrastructure for other transport modes like roads and rail

Barriers: I = institutional; F = financial, P = physical, T = technological, C = cultural. *Rating:* ** = highly relevant, * = relevant, - = irrelevant.

4. Discussion

Policy transfer concepts can be important to both practitioners and researchers in the urban logistics domain, but there is a limited amount of literature on this topic. Related studies, e.g., in the transport domain, call for more research on the role of contexts and the overall transfer process [35,36]. Establishing the context for successful urban logistics measures is considered a core task and vital step in the process. Many relevant contexts need to be considered in policy transfer, with the accuracy of the process reported to increase with an increasing number of contextual factors accounted for in the analysis [16]. In the present analysis, we examined the contexts of urban logistics measures for economies at different stages of development and in different geographical regions (continents). Two types of contexts were considered in all cases: the context in the source city and contextual factors in the recipient city. Establishing a broad context of measures in the source city can expedite policy transfer.

The results provide responses to three of the seven questions posed by Dolowitz and Marsh [24], namely: "What is transferred?"; "From where are the lessons drawn?"; and "What restricts or facilitates the policy transfer process?". The "bottom-up" approach of Timms [25] was used to consider policy transfer from a "city perspective". The results also contributed to five major steps in the 10-step logical framework devised by Macario and Marques [18] (Figure 1). The broad contexts of urban logistics measures contributed to the search for similar contexts (Step 4), selecting urban contexts in the source city (Step 5), and identifying potential measures for their transferability (Step 6). The identified barriers and drivers in the analysis to transfer measures contributed to ex ante assessment (Step 8) and to identifying the need for adjustment of measures (Step 9) to improve transferability between developed and developing economies.

The contexts were found to be highly different across geographical regions, even for economies within the same development class. These differences can be explained by taking the case of Europe and the USA, where the contexts for sustainable urban logistics measures are quite different [37]. For instance, the European context for the *OHD* topic was stakeholder acceptability [38,39], whereas the USA context was the overall impact of OHD programs [40], which were rated as having medium applicability to the USA context [37].

European articles also covered unique topics of discussion, such as *ICT/ITS*, *LTZ*, *loading/unloading area*, *parcel lockers*, and *policy making*. The applicability rating of some of these topics to the case of the USA was highly variable [37]. *LTZ* was rated highly effective, but has low applicability to the USA context, while *ICT/ITS* was rated medium for both effectiveness and applicability.

In addition to the contributions from different economic development classes, the regional contributions on topics varied widely. Europe contributed most to the relevant literature and Africa contributed the least, confirming findings by Kin et al. [13] that the Middle East and Africa are underexposed to urban logistics measures. Policy transfer has a crucial role to play in bridging this exposure gap. The policy transfer process involves the identification of potential barriers and drivers. Five general barriers were considered in this study (institutional, financial, physical, technological, and cultural), and identification of barriers for each topic was based on prevailing problems in developing countries (Table A2). The drivers considered were the general opportunities or gains in the recipient city.

Among the barrier types considered, institutional barriers were rated highly relevant for most of the topics considered, as a strong institutional set-up is required for the transfer process but a weak institutional framework generally prevails in recipient countries. The next major barrier was physical, reflecting a lack of adequate infrastructure. The high relevance of these barriers is in agreement with Pojani [41], who identified institutional, financial, and physical barriers to the transfer of sustainable urban transport practices to Southeast Asian cities such as Jakarta, Manila, Kuala Lumpur, and Bangkok. A range of general drivers was also identified, most providing opportunities to increase the desirability of policy transfer from the specific case to cities in developing economies (Table 2).

Further comparisons between our findings and those in similar studies with different contexts revealed the broad reality and specific conditions. For example, Maria and Marcus [20] studied the transfer of *road pricing* policy from other European cities to Valletta, Malta, and identified the unique geography of the city as a barrier, while international events, local conditions, and a political champion driving change were seen as specific drivers. Macario and Marques [18] found high sensitivity to the barriers of political commitment and strategy, legislation and regulative institutions, information and public relations, and technology. Besides, our study identified financial and physical barriers as highly relevant, in addition to institutional barriers, whereas the need to increase available investments was considered a general driver.

In the case of *UCCs*, Nordtømme et al. [42] identified financial concerns and stakeholder acceptability as the main barriers to UCC implementation in Norway (Europe). We also found physical and financial barriers to be highly important for this topic, along with institutional barriers. In general, policy transfer faces a range of barriers when dealing with different topics and dimensions. Rye et al. [26] claim that language and planning traditions are even crucial barriers to transport policy transfer between European cities. TURBLOG (2011) recommended two approaches to overcome barriers, one by adapting the transferability of measures to remove or reduce the aspect weakened by the barriers, and the other by combining one or more measures (policy package) to counteract the barriers.

Drivers (enablers or facilitators) of the transfer of sustainable urban logistics measures to cities in developing economies were established from the particular problems and respective topics in developed economies (Table 2). In some cases, factors that acted as a barrier to one measure were a driver of other measures. A good example was the presence of many small traditional retail stores or nano-stores in cities in developing economies, which complicates delivery and was identified as a barrier to *carrier optimization of operations*, but nano-stores can also be a driver in the implementation of *pick-up points* by acting as pick-up stations. However, the identification of specific drivers required a detailed focus on the particular contextual factors of the recipient city. For example, Timms [21] identified a history of cooperation between local authority and stakeholders as enablers for the transfer of regulative measures to the city of Cariacica, Brazil.

Overall, the findings of this study contribute to portray worldwide contexts of sustainable urban logistics measures to analyze the transferability of policy experiences between different contexts. Theoretically, this study implies the strong association of the economic development level and geographical location of a city with the context in which measures were implemented. Besides, the categorization of urban logistics measures indicated which topics were given more attention and at which geographic locations.

Furthermore, this study has a practical implication to authorities considering policy transfer in urban logistics. The contextual factors analysis can provide a first response to the key challenges and opportunities for the transfer of sustainable urban logistics policies, especially to the ones in developing countries. Moreover, the establishments of barriers and drivers specific to urban logistics measures or policies also enhance the transferability process and help to focus only on the important and relevant factors.

This study has limitations in covering all available urban logistics solutions worldwide due to two reasons, namely limited literature published in scientific journals generally found before the year 2000 and little availability of published literature on the case of developing countries. Additional field research could reveal scientific work that has not been reported in the literature.

5. Conclusions

This study analyzed the wider contexts of urban logistics measures based on economic development classes and geographical regions, including their significance in the transfer of urban freight policy. Policy transfer is a process involving multiple steps and many variables, among which the characteristics of the source and recipient city and the context within which the measure (package of measures) is applied in the source city are the cornerstones. Understanding the context in the source city can thus ease the appraisal and selection of measures for the recipient city.

The SLR method was used here for retrieval of a relevant and representative sample of published articles describing urban logistics measures, to ensure transparency in drawing objective conclusions. The analytical approach was based on a broad categorization of topics/measures into different economic development levels and geographical regions, to obtain a comprehensive global perspective with an adequate level of detail. Generalization of topics to cities located within the same economic development class and region (continent) can facilitate the transfer of best policy on urban logistics.

The results revealed that the economic development class and regional location of urban logistics topics assessed in the selected dataset were highly diverse. The economic development level and geographical location of a city were both found to have a strong association with the context in which measures were implemented. The contexts for the topics also reflected the nature of existing problems, which permitted appraisal of the suitability of measures for transfer to cities with similar challenges. Finding favorable contexts for measures in the recipient city is central to the success of the whole process.

Barriers and drivers to the transfer of measures were identified based on the contexts when evaluating the potential for transfer between two different exposure levels (developed and developing countries). In particular, institutional and physical barriers were found to be relevant to the transfer of urban logistics measures. Weak institutional set-up to formulate and regulate policy was identified as an institutional barrier and lack of adequate physical infrastructure provision as a physical barrier. Cities in developing economies should thus aim to reduce or counteract the influence of those barriers. Specifically, the measures (or package of measures) chosen should not require strong institutional control and follow-ups, to reduce the impact of institutional barriers, and should not require additional physical infrastructures, to reduce the impact of physical barriers.

The drivers depended on the specific contexts in the recipient city. In some cases, barriers to implementing one measure were a driver for implementing another measure. Identifying the specific enabler of measures in the recipient city can thus be of prime importance in the overall transfer process.

There has been little research about the transfer of urban logistics policies and the overall success in meeting the intended purpose in the recipient city, so this study makes an important novel contribution by providing a global picture of contexts in urban logistics measures. The results can also help to identify a broad set of barriers and drivers for cities in developing countries on measures originating from developed countries.

Supplementary Materials: The following are available online at http://doi.org/10.5281/zenodo.4004037, Table S1: The complete list of retrieved and selected journal articles; Table S2: Full list of urban logistics measures contexts over economic classes.

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Appendix A

Table A1. Sustainable urban logistics (UL) topics identified in the selected dataset, with corresponding descriptions and the total number of articles in which they are mentioned.

Topic	Description	Total Number
Traffic congestion management related to UL operations	The effect of traffic congestion on urban logistics operations and vice versa	6
Crowd-shipping	Local people as carriers to pick up/drop off goods from automated parcel lockers or end-consumer locations, in dedicated or non-dedicated trips, to reduce environmental impact and possibly the cost of delivery	8
UCC/UDC/CLC	Infrastructure to consolidate goods before the last-mile journey. Depending on the activity type and the time spent at the facility, there are: urban consolidation centers (UCCs), urban distribution centers (UDCs), and construction logistics centers (CLCs)	18

Table A1. *Cont.*

Topic	Description	Total Number
Carrier/logistics service provider optimization of operations	Vehicle routing problems (VRP) plus scheduling or general operations optimization of paths and locations for the fleet(s) of vehicles to reduce travel time and distance, waiting times, a penalty for time windows, vehicular emissions, and traffic congestion	104
E-commerce delivery	Online purchasing/ordering goods that involve delivery operations to customers (end-consumers or ever retailers). Online market–customer interactions involving delivery have become a dominant trend in urban freight studies	14
Eco-friendly Vehicles	Considering vehicles emitting less pollutants and powered by sustainable/environmentally friendly sources (electric vehicles, compressed natural gas, bio-gas) for urban freight	16
Smart UL systems with ICT/ITS	Information and communications technology/intelligent transport systems (ICT/ITS) applications provide information, planning tools, and resource sharing between the actors to enhance the safety, efficiency, and more coordinated utilization of the logistics system	4
Alternative modes	Urban freight is dominated by road-based transport, other modes like rail or urban waterways or even intermodal transport being considered as an alternative modes	7
Cargo bike/ Bike Delivery	Use of human-powered or electric bike for freight delivery in urban areas	7
Loading/unloading area/Parking area	Related to management and utilization of infrastructures to serve trucks at cities for transfer of goods or other pertinent services	5
Off-hour deliveries (OHD)	Delivery of goods during low-traffic activities in the cities, usually between late nights and early mornings	5
Pick-up points/ parcel lockers	Pre-arranged places where people go to collect or retrieve online ordered parcels	10
Policy making	Choice and formulation of urban freight policies especially by local authorities serve for setting policy priorities and recommendations	5
LTZ	A limited traffic zone (LTZ) is an urban area subjected to restriction of traffic (trucks for the case of urban freight) such as a time window, or limitation of weight, width, and type of fuel	3
Solution performance	Analysis and evaluation methods to assess the performance of urban freight measures, and comparisons based on various criteria to select the optimal measure	45
Sustainability/ emissions/pollution	Environmental sustainability with ways to reduce vehicle pollutant levels, and related short- and long-term strategies, technologies, and applications in addressing the environmental effects of urban freight	23
Stakeholder participation	Ways to consult, manage, and involve stakeholders in the planning and implementation of urban freight measures. Also takes into account their interactions, perceptions/reactions, roles, and evaluations in making decisions regarding urban freight measures	60
Road pricing	All measures involving payment of a toll for use of particular infrastructures, such as city centers, LTZ, bridges, and bypasses	2
Delivery robots/drones	The use of drones or autonomous robots for urban deliveries, especially the last-mile segment	1

Table A2. General problems related to urban logistics in developing countries.

Categories	Summaries of Main Problems
Urban development and land use	High population density, low level of infrastructure development, fragmented industry structure, and extensive informal sector [11,22]; mixed land use [43]; urban sprawl [44]
Institutional set-up and role	Poorly developed municipal and regulatory institutions [45]; limited institutional capacity [46]; institutional and legal framework ignored in the application [47]; lack of freight and related data [11]
Policy and planning for urban logistics	Lack of initiatives for urban freight [48]; poorly defined strategic policies and limited implementation [46]
City traffic conditions	Lower availability and quality of transport system [44]; weak traffic management [45]; extreme variety in transport modes and vehicle sizes; frequent breakdowns and accidents [11]; walking and cycling often unpleasant or unsafe [49]
Freight infrastructures	Infrastructure for walking and cycling often lacking [49]; lack of logistics infrastructure like loading/unloading areas (with the few existing being used for other purposes) [43,46,48]; parking and road design problems, and insufficient road network [43]; a narrow and often unpaved road, congested intersection, obstructed sidewalks and roadways, and uncontrolled access of heavy delivery trucks [50]
Urban freight operations	The existence of many small traditional retail stores (nano-stores) complicates the distribution of goods [48,51,52]; increase in truck movement, lack of coordination, and overloading of trucks [11]; higher empty returns increase the cost of trucking even for short distances [53]
Environmental impacts	Emissions from old vehicles [43]; high pollution from trucks using leaded gasoline [45]

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Urban freight systems in developing economies present a significant challenge and require characterising and modelling the systems while considering local contexts. The spatial and locational determinants are key factors in improving freight (trip) generation models. Moreover, economic fluctuations impact the choice of shipment size. Tests of a policy restricting large trucks were generally counterproductive, whereas a two-tier distribution system is more advantageous among the alternatives. The proposed approaches enable the consideration of practical, local contextual conditions in decision-making processes.

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