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Article

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EURO Journal on Transportation and Logistics (EJTL)

Provided in Cooperation with:

Association of European Operational Research Societies (EURO), Fribourg

Suggested Citation: Su, Yijie; Hadi Ghaderi; Dia, Hussein (2024) : The role of traffic simulation in shaping effective and sustainable innovative urban delivery interventions, EURO Journal on Transportation and Logistics (EJTL), ISSN 2192-4384, Elsevier, Amsterdam, Vol. 13, Iss. 1, pp. 1-21, <https://doi.org/10.1016/j.ejtl.2024.100130>

This Version is available at:

<https://hdl.handle.net/10419/325198>

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The role of traffic simulation in shaping effective and sustainable innovative urban delivery interventions

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ARTICLE INFO

Keywords:

Traffic simulation
Urban freight
Last mile delivery
City logistics
Sustainable transport

ABSTRACT

Cities around the globe face major last mile delivery (LMD) challenges as a result of surging online commerce activity, increased parcel delivery demands, lack of parking capacity, and severe traffic congestion particularly in inner city areas. Although a number of innovative solutions and pathways have been proposed to address these challenges, their full impacts are still not well understood due to the lack of comprehensive field studies and real-world data on their performance. Traffic simulation techniques, which are widely used to model and evaluate the impacts of a wide range of urban mobility interventions, offer opportunities to investigate the impacts of city logistics interventions. However, research evidence on this topic remains fragmented, hindering constructive analysis of the role of traffic simulation and modelling in shaping sustainable urban delivery interventions. Given the growing research interest in the nexus of traffic simulation and city logistics, this paper aims to identify and evaluate primary studies related to the simulation forms, evolution, effectiveness, and their feasibility in evaluating the impacts of urban delivery interventions. The paper achieves this through a holistic systematic review that consolidates diverse perspectives on the topic. The paper analysed 79 articles, published by December 2023, that have used traffic simulation to model and evaluate a wide range of city logistics interventions. The review identified five main themes in the literature surrounding development and applications of traffic simulation, namely their use in evaluating the role of information and communication technologies, evaluations of advances in types and forms of delivery vehicles, their application in supporting policy interventions, evaluations of innovations in city logistics facilities and impacts of the collaborative economy. The review also helped in gaining insights about urban delivery interventions and their impacts as stand-alone or in combination with other solutions. The analysis confirms the validity and versatility of traffic simulation as an approach to model the impacts of urban delivery interventions on traffic flow, delivery service and customers, but also the sustainability implications of interventions. The paper also provides a future research agenda to guide future studies in developing and evaluating applications of various interventions with the leverage of traffic simulation.

1. Introduction

City logistics (also known as urban logistics or urban freight transportation) refers to processes and solutions for freight distribution that optimise the quality and efficiency of services, while reducing their negative impacts such as traffic congestion, emissions and air pollution (Lagorio et al., 2016). Taniguchi et al. (2012) have identified mobility, sustainability, liveability, and resilience as four primary considerations when implementing city logistics measures. In addition, a critical challenge of city logistics is to achieve a balance among diverse stakeholders that are heterogeneous in their interests (Anand et al., 2012).

In recent years, the rise of e-Commerce has contributed to a rapid growth in urban logistics. Significant volumes of freight traffic and movements are generated in urban areas, particularly in central business districts (CBDs), where a diverse mix of freight deliveries are required by both household consumers and businesses (Aljohani and Thompson, 2020). The COVID-19 pandemic and associated travel restrictions have in recent times increased the need for online deliveries, and also heightened consumer appetite for the convenience of rapid deliveries which further exacerbated the challenges for last mile delivery, and impacted the performance of transport networks in cities around the world (Pan et al., 2021a). To meet the rising demand for urban deliveries

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<https://doi.org/10.1016/j.ejtl.2024.100130>

Received 14 February 2023; Received in revised form 28 February 2024; Accepted 4 March 2024

Available online 11 March 2024

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and mitigate the negative impacts of freight movements, it is crucial to develop practical, effective, and sustainable urban delivery measures (Batarlienė and Bazaras, 2023; McKinnon et al., 2023; Mucowska, 2021; Silva et al., 2023).

The impact and effectiveness of these interventions need to be measured before they are implemented in real-life. Some researchers have used qualitative methods such as questionnaire and interviews to assess such interventions, while others used quantitative methods, simulation and modelling (Lagorio et al., 2016). Simulation and modelling techniques and applications of digital twins in transport have received significant attention in the context of city logistics, because of their ability to measure commodity and vehicle flows (Anand et al., 2015) and evaluate their impacts on road network performance. Among the many modelling techniques, mathematical or operational research (OR) solutions have been widely used and proven as effective evaluation methods (Giuffrida et al., 2022). Due to the increasing complexity and interaction of a number of dynamic entities in the context of urban mobility, the use of traffic simulation tools has recently gained additional momentum for modelling and understanding city logistics systems (Karakikes et al., 2019). This SLR aims to analyse key studies and literature on the topic to (i) reveal the current state of developments, the emerging trends, as well as understanding how traffic simulation is used to evaluate the impacts of urban delivery solutions, (ii) based on the review, identify effective urban delivery solutions that can promote sustainable transport principles, reduce congestion and emissions, and (iii) understand the feasibility and versatility of traffic simulation to examine city logistics interventions and guide future research to generate more impactful results. According to the information currently available, this work is considered to be the first in-depth review of literature on this specific topic.

1.1. Traffic simulation approaches in city logistics

The shared nature of transport networks and infrastructure means that urban freight issues do not affect just one stakeholder, but the overall urban transport system. Similarly, city logistics interventions may also have broader effects – both positive and negative – than anticipated. Modelling city logistics interventions is therefore necessary to assess the impact of these measures before actually implementing them (Taniguchi et al., 2014). The literature shows that evaluations of city logistics measures have been carried out using two types of modelling approaches: optimisation models that are mainly based on operations research techniques, and traffic simulation models that act like digital twins of the real-world environment (Taniguchi et al., 2012). An optimisation approach aims to find an optimal solution for a pre-determined objective (e.g., minimum transportation costs) or for multiple objectives simultaneously (e.g., maximisation of economic profits and minimisation of environmental impact) (Torre et al., 2021). Meanwhile, traffic simulation models are capable of characterising large and complex traffic flows in virtual environments and allow researchers to evaluate the impacts of various ‘what-if’ scenarios on the users and overall network performance (Passos et al., 2011). In recent times, these models have increased in complexity and degree of accuracy in replicating field conditions and are increasingly being recognised as an effective and realist digital twin solution for assessing impacts of new interventions before they are deployed in the real world.

In transport studies, traffic simulation models are able to represent complex transport networks, which are usually composed of a variety of entities (e.g., different types of vehicles, pedestrians, bikers, traffic signals, etc.) that interact according to certain rules and influence the performance of urban freight systems (Passos et al., 2011; Dia and Cottman, 2006; Dia and Panwai, 2008, Dia and Panwai, 2015; Thomas et al., 2001). Furthermore, traffic simulation can capture the dynamics of the urban transportation systems and provide more realistic evaluation of system performance (e.g., traffic delay, congestions, emissions) under different micro and macro level conditions (Nigarnjanagool and

Dia, 2005; Poon and Dia, 2005).

According to their level of complexity, traffic simulation models can be divided into three types: microscopic, mesoscopic, and macroscopic (see Table 1).

In microsimulation models, individual vehicles are distinguished and their dynamics (e.g., lane changes) are tracked to a great level of detail (Hoogendoorn and Bovy, 2001). Macrosimulation models, on the other hand, describe traffic flow at high levels (e.g., traffic density, link capacity) without considering the details of individual driving behaviours or vehicle interactions (Taniguchi et al., 2012). In meso-simulation models, which have levels of complexity between macro and micro models, traffic entities are simulated dynamically but in less detail than microsimulation models (Passos et al., 2011). Furthermore, as part of microscopic traffic modelling, agent-based models are becoming increasingly popular in state-of-the-art urban logistics research (Nguyen et al., 2021; Jlassi et al., 2018). Agent-based models (Dia, 2000; Dia et al., 2001; Panwai and Dia, 2005) add a behavioural component to individual drivers and can be used to simulate decision-making of actors under different scenarios (e.g., policy measures) providing a better understanding of the behaviour of agents in city logistics systems (Jlassi et al., 2018). During the past few decades, a wide variety of computer-based simulation tools have emerged across different modelling scales (see Table 1). However, researchers sometimes have difficulty to select the tool that best addresses their research needs (Nguyen et al., 2021). Meanwhile, some simulation environments have also been further developed or adapted by individual researchers with specific needs. Examples of such custom-made simulation models used in city logistics studies include Boussier et al. (2011) for simulating resource sharing and Deflorio and Castello (2017) for wireless vehicle charging.

1.2. Study objectives

Several reviews discussing city logistics interventions from a simulation perspective are available in the literature. For example, Taniguchi et al. (2012) reviewed city logistics studies that have used systems dynamics, multi-agent systems and game theory, as well as traffic simulation. Jlassi et al. (2018) and Gómez et al. (2018) each reviewed few city logistics topics from modelling and simulation perspectives. Meanwhile, Karakikes et al. (2019) discussed 26 distinctive city logistics solutions that were examined by various simulation techniques including systems dynamics, discrete event simulation, hybrid

Table 1

Traffic simulation models according to Hoogendoorn and Bovy (2001); Nguyen et al. (2021); Saidallah et al. (2016); Taniguchi et al. (2012).

Traffic simulation models	Descriptions	Examples of simulation software or tools
Microscopic	In microscopic simulations, an intensive level of detail of individual vehicles, pedestrians, traffic lights, etc. is being modelled. Microscopic simulations usually require longer computational time.	AIMSUN, VISSIM, PARAMICS, SUMO, SymuVia
Mesoscopic	Simulations based on mesoscopic models combine aspects of both macroscopic and microscopic models. The level of details being modelled is in between microscopic models and macroscopic models.	AIMSUN, DYNAMIT, DYNEMO, DYNASMART
Macroscopic	This type of model is better suited for representing and analysing large traffic networks without the need for modelling details (e.g., vehicle-to-vehicle interaction). Macroscopic simulations require the least computational time among traffic simulations due to the low level of details being modelled.	VISUM, AIMSUN, EMME

modelling, and traffic simulation. However, these reviews either do not use “traffic simulation” as a distinct category, or do not classify city logistics studies based on the traffic simulation approaches (micro, meso, or macro) that have been used. Karakikes and Nathanail (2017) was an exception and reviewed 16 articles among which 6 used micro/meso/macro traffic simulation, but this review was not systematically conducted and did not reveal the article selection protocol. Therefore, this study is the first that systematically reviews the research at the intersection of traffic simulation and city logistics and classifies city logistics papers based on microscopic, mesoscopic, and macroscopic traffic models they use. As urban freight transport and LMD are closely related, the authors examined both with a focus on LMD.

The key objective of this review is to provide answers to the following research questions.

- RQ1: What are the most prevalent topics discussed in traffic-simulation-based city logistics studies, and how have these topics evolved over time?
- RQ2: What is the role of traffic simulation in evaluating the impacts of city logistics interventions?
- RQ3: What is the status of literature in terms of promoting sustainable urban delivery and transport principles?
- RQ4: What are the main knowledge gaps, and what are the future research directions for improving knowledge in this field?

The remainder of the review is organised as follows. The methodology is presented in Section 2. A comprehensive bibliographic analysis of the selected papers is presented in Section 3. The role of traffic simulation approaches in evaluating the impacts of city logistics interventions is discussed in Section 4. The classification of urban delivery interventions is presented in Section 5, with the main sustainability drivers discussed in Section 6. Finally, directions for future research are summarised in Section 7, followed by a conclusion of this review in Section 8.

2. Methodology

A systematic literature review (SLR) is a common and widely used review methodology to comprehensively scan the literature and gain insights. In recent years, SLR has been used by a number of researchers to review city logistics studies including Viu and Alvarez (2020); Man-giaracina et al. (2019); Ranieri et al. (2018).

Certain characteristics that define a SLR have been summarised in Fig. 1 (Green et al., 2008). When undertaking this review, we adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Page et al., 2021). This involved utilising the flow diagram (see Fig. 2) to structure literature searches across various databases and other sources (i.e., reference list checking, Google Scholar). For database search, the reviewed records include journal articles, conference papers, and peer-reviewed book chapters published in English from three databases of Scopus, Web of Science (WoS), and IEEE Xplore (See Table 2).

This review focuses on the intersection of traffic simulation and city logistics. More specifically, it aims to examine research works that employ traffic simulation as the main or part of the methodological approach to model and test city logistics solutions. The search criteria to uncover the literature on the topic included a comprehensive list of search terms (in title, keywords, and abstract) relevant to traffic simulation and city logistics. The design of search string was based on the following considerations.

- As this review focuses on the intersection of urban logistics and traffic simulation, many freight/logistics search terms needed to be combined with “delivery” using the “AND” operators to exclude irrelevant papers. For example, search terms like “electric vehicle” and “autonomous vehicle” might lead to papers that were not at all related to urban delivery and the combination of these search terms and “delivery” improves the relevance of search results. Without such combination in search terms, the search string would generate a significant number of search results, majority of which would be irrelevant to this review. Meanwhile, some freight/logistics search terms (like “pick up point” and “loading bay”) were directly relevant to city logistics and thus not combined with “delivery”.
- During the literature search, it was discovered that a number of relevant papers were not captured in the search result from databases because they did not mention ‘traffic simulation’ or ‘transport simulation’, etc. in their title/abstract/keywords. The reason why these papers did not mention these terms was most likely that the use of traffic simulation was not regarded as a major contribution of the respective research but merely as a tool in the modelling/simulation process (which still fulfils the inclusion criteria of this review). Therefore, to increase the probability of capturing these papers in search results, the names of the mainstream traffic simulation tools were included in search terms, in addition to the general search terms like traffic simulation/transport simulation/microscopic simulation/etc.

The screening of papers was then carried out in accordance with the PRISMA guidelines (see Fig. 2). After the full-text assessment of selected papers for eligibility, 79 papers were selected to be included in the review while the rest were excluded for the following reasons.

- They were not related to city logistics.
- They did not adopt traffic simulation approach.
- They did not simulate any specific urban logistics interventions.

Many papers that adopted traffic simulation approach for city logistics actually focused on the building the model (e.g., generating traffic or freight demand, calibrating the model, integrating different roles or agents in modelling, etc.) or used the model to investigate the characteristics of current freight traffic. Since these studies did not simulate any specific city logistics solutions, they were considered outside of the review scope. Furthermore, papers with irrelevant context (non-urban/rural environment, non-road transport like intermodal

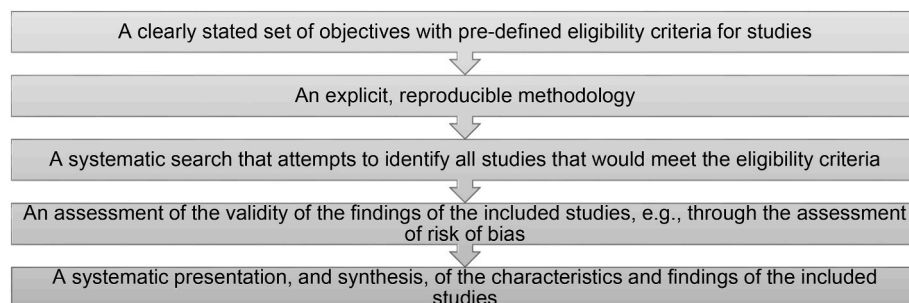


Fig. 1. Key characteristics of a systematic literature review according to Green et al. (2008).

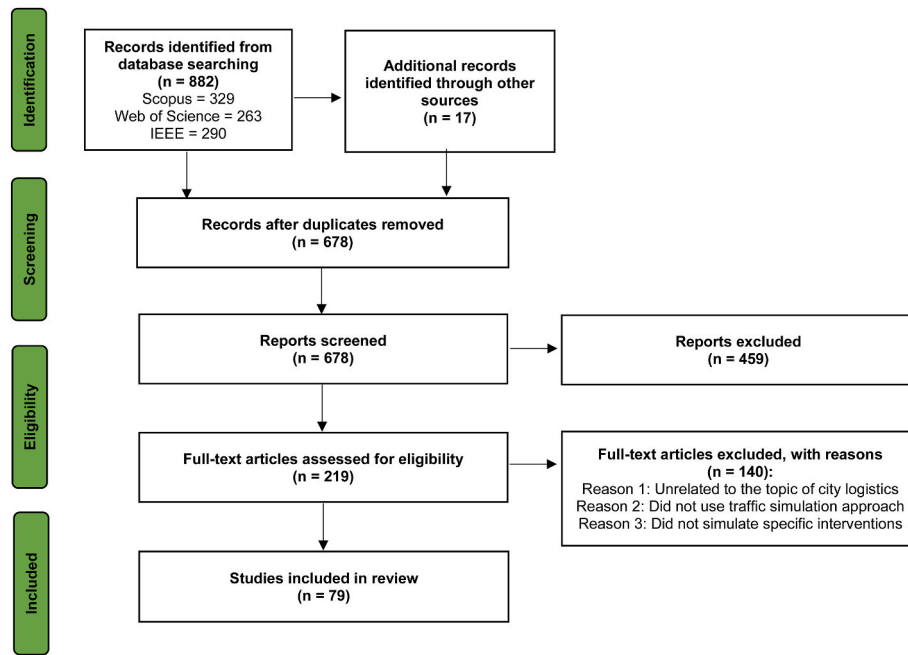


Fig. 2. PRISMA flow diagram for the review adapted from Page et al. (2021).

Table 2
Search criteria and keywords.

Search criteria	Description
Database	Scopus, Web of Science, IEEE Xplore
Search terms in title, keywords and abstract	(Aimsun, Vissim, Visum, Paramics, Polaris, Dynasim, Simtraffic, Dynameq, Corsim, Transmodeler, Tramos, Symuvia, Transims, Dynamit, Mitsim, Matsim, Vtsim, Opentrafficsim, Mainsim, Osmtraffic, Mobiliti, Dynemo, Emme, Emme2, Emme3, Emme4, Simulation of Urban Mobility, Contram, Mesots, Simmobility, Dynasmart, Microsimulation, Mesosimulation, Macrosimulation, Microscopic simulation, Mesoscopic simulation, Macroscopic simulation, transport simulation, traffic simulation) AND (city logistics, urban logistics, courier, freight, night delivery, loading bay, loading zone, unloading bay, unloading zone, packstation, load pooling, pick-up point, consolidation cent*, microconsolidat*, micro hub, parcel AND delivery, last mile AND delivery, last kilo AND delivery, locker AND delivery, crowdfsource* AND delivery, crowdship* AND delivery, electric vehicle AND delivery, autonomous vehicle AND delivery, cargo bike AND delivery, drone AND delivery, off-peak AND delivery, after peak AND delivery, off-hour AND delivery, after-hour AND delivery, parking AND delivery)
Language	English
Source types	Journal articles, conference papers, peer-reviewed book chapters
Publication year	All publication years (until December 2023)

transport, focus on internal operation of a logistics facility like container terminal, etc.) were considered outside of the review scope and excluded from the pool.

Lastly, the scope of traffic simulation needs to be clarified. Typically, researchers use off-the-shelf traffic simulation tools or packages such as AIMSUN and VISSIM for traffic modelling and simulation. A list of these tools has been provided in Table 2. The list is not exhaustive but has covered the mainstream tools. In addition, studies that had developed their own (custom-made) traffic simulation models to simulate city logistics interventions were included as well.

The final pool of 79 studies was then evaluated using a bibliographic approach, which is common in SLRs (Surwase et al., 2011). In addition to uncovering trends in keywords, chronological and geographical characteristics, such analyses are also useful to identify and visualise connections among different research groups by analysing citations and reference lists (Chang et al., 2015). Using co-citation analysis, insights are gained into the citation patterns of pairs of articles (Surwase et al., 2011) and common research themes or ‘clusters’ are identified that represent a scientific discipline’s intellectual structure (Chang et al., 2015).

3. Bibliographic analysis

Fig. 3 shows the chronological distribution of the selected papers, where two distinct periods can be identified, namely 2004–2012 and 2014–2023. Traffic simulation studies in urban logistics were relatively scarce during the first period (on average 1 paper per year). A clear trend emerged since 2014 for using traffic simulation for evaluating real-world urban logistics problems. The rise in the number of studies can be explained by emerging interest in the topic of city logistics, but also

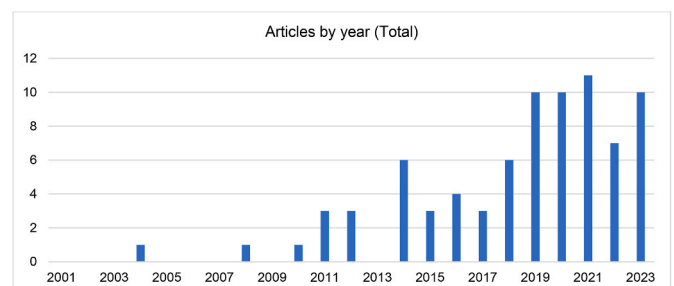


Fig. 3. Number of papers by publication year.

recent technological developments and scientific advances in traffic simulation methodologies. More specifically, traffic simulation tools have become more advanced in terms of modelling complexity and computational capability (Karakikes et al., 2019). In addition, with the advancement in sensing technologies, traffic data has become more available and embedded into traffic simulation tools.

Analysis of the geographical distribution of publications was also undertaken. As shown in Fig. 4, Europe, as a continent, had the largest share of publications, followed by North America, Asia, Africa, and Oceania. In terms of individual countries, Germany (19%) and the United States (18%) were the top-ranked countries in terms of papers published on the subject, followed by Portugal and Singapore. Compared to cities in the United States and the other countries, European cities have denser populations with more interaction between urban freight and passenger mobility, which may partly explain the higher research effort and motivation in European studies on the topic (Wu et al., 2021).

In the United States, a variety of simulation-related topics have been studied including off-hour delivery schemes (Liu and Kim, 2019; Ukkusuri et al., 2016) and applications pertaining to connected vehicles (Kari et al., 2014; Hao et al., 2021; Bashir and Zlatkovic, 2021), and traffic signal control (Zhao and Ioannou, 2016). In Germany, a clear and ambitious goal has been set to reduce greenhouse gas (GHG) emissions and achieve climate neutrality by 2050 (European Commission, 2019). The electrification of vehicles in urban environments was therefore given priority in research (Martins-Turner et al., 2020; Winkler et al., 2022; Ewert et al., 2021a). In a number of studies, researchers in Germany also assessed air pollution tolls and their long-term impact (Kickhöfer and Nagel, 2016), autonomous connected vehicle platoons for delivery (Haas and Friedrich, 2021), and the use of cargo bikes and pick-up points to deliver parcels (Zhang et al., 2018). In Portugal, researchers focused on the implementation of small-sized electric vehicles (EVs) for parcel delivery, such as cargo bikes (Melo et al., 2013; Melo and Baptista, 2017). In Singapore, off-hour delivery and parking policies in urban areas have been analysed using simulation to assess their impact and effectiveness (Gopalakrishnan et al., 2020; Sakai et al., 2020; Mepparambath et al., 2023).

3.1. Keyword analysis

Keyword analysis (see Fig. 5) revealed the chronological development of research focus during the identified period (2014–2023). Recent years have seen a rise in awareness of sustainability, energy consumption, and vehicle emission control (Lagorio et al., 2016). The simulation results showed increasing evidence that urban freight deliveries had a negative impact on citizen's quality of life with the issues of noise, air

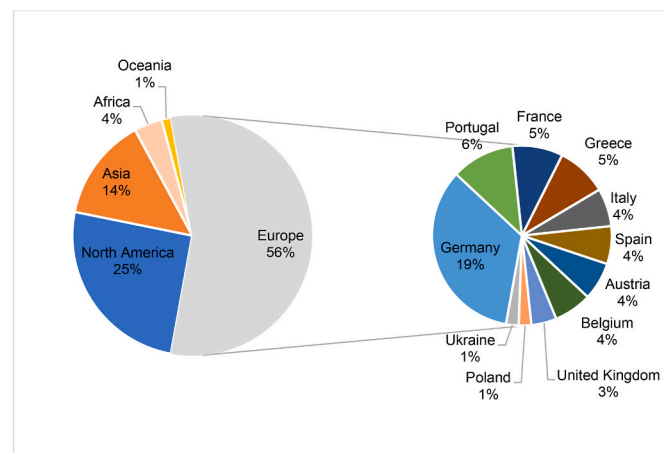


Fig. 4. The number of papers by geographical areas.

pollution, traffic congestion, and illegal street parking all impacting urban environments. Meanwhile, governments are recognising these issues and setting goals for reducing urban pollution and emissions (Martins-Turner et al., 2020). In response, urban freight research is growing, and strategies such as electrification and decarbonization are becoming more prevalent in research (Mucowska, 2021). The impact of greener delivery options like battery EVs (Winkler et al., 2022) and automated drones for delivery (Cokyasar et al., 2021) has also been highlighted in the recent traffic simulation approach related to urban logistics.

3.1.1. Co-citations analysis

A co-citation analysis was carried out to identify research clusters or similar topics shared by different authors and articles during the last two decades. As a result, a co-citation network (Fig. 6) was generated, which enables classification of the corpus into five distinct research clusters: **ICT Innovations** (blue), **Delivery Vehicle Innovations** (yellow), **Collaborative Economy** (green), **Innovations in City Logistics Facilities** (red), and **Policy** (purple). Frequency of citations is represented by the size of each node, and frequency of co-citations by the density of connection links.

Table 3 provides an overview of the classification of articles, along with a description of each cluster and its development over a period of five-year intervals. The last interval is an exception as the relevant data were extracted from the database in December 2023 to perform the literature review. In some cases, articles covered more than one theme and were listed more than once.

4. The role of traffic simulation approaches in city logistics

This review reveals that various traffic simulation packages, software, and tools have been used in the city logistics studies. Fig. 7 shows the frequency of these packages being used in the corpus. MATSim is the most prevalent agent-based tool in the domain due to its flexibility and suitability for a wide range of simulation studies (Horni et al., 2016). VISSIM is the second popular tool in addressing city logistics problems, followed by AIMSUN, SUMO, and bespoke simulation tools.

Table 4 presents the simulation tools, as well as their types and associated studies. Distinguished from other packages and tools, AIMSUN provides an integrated interface for micro, meso, and macro simulation. It also incorporates a feature that allows hybrid meso-micro simulation, which combines detailed microsimulation in a pre-defined area and meso-simulation for the rest of the model to better suit the needs of research (Aimsun, 2022).

In city logistics, the use of micro-simulation primarily began in the 2010s. The typical use cases of micro-simulation include cargo bikes for delivery, freight loading bay, road guidance, vehicle connection and platooning, and traffic signal control (Hao et al., 2021; Zhao and Ioannou, 2016; Melo et al., 2017; Ochoa-Olán et al., 2021). Among the micro-simulation models, agent-based models, mainly with MATSim, have been used to test VRP and delivery by autonomous vehicles (AVs) and EVs, etc. (Winkler et al., 2022; Schlenther et al., 2020; Jahn et al., 2021). It was noted that about 76% of the corpus have used microscopic models (Fig. 8) as deemed suitable for their particular case studies. Among the microscopic simulators, MATSim, VISSIM, and AIMSUN were the top 3 choices for modelling city logistics schemes.

Mesoscopic simulation is usually more suitable for simulating city logistics interventions that have broader effects on the traffic system than street and user level innovations. Several use cases appeared in the literature between 2014 and 2017, covering topics like EVs' wireless charging, off-hour delivery, and VRP (Deflorio and Castello, 2017; Ukkusuri et al., 2016; Jiang and Mahmassani, 2014). In terms of mesoscopic simulators, TransModeler, DYNASMART, and other bespoke simulation tools have been used.

As for macroscopic modelling, these models have been utilised in city logistics research throughout the last two decades in topics related to

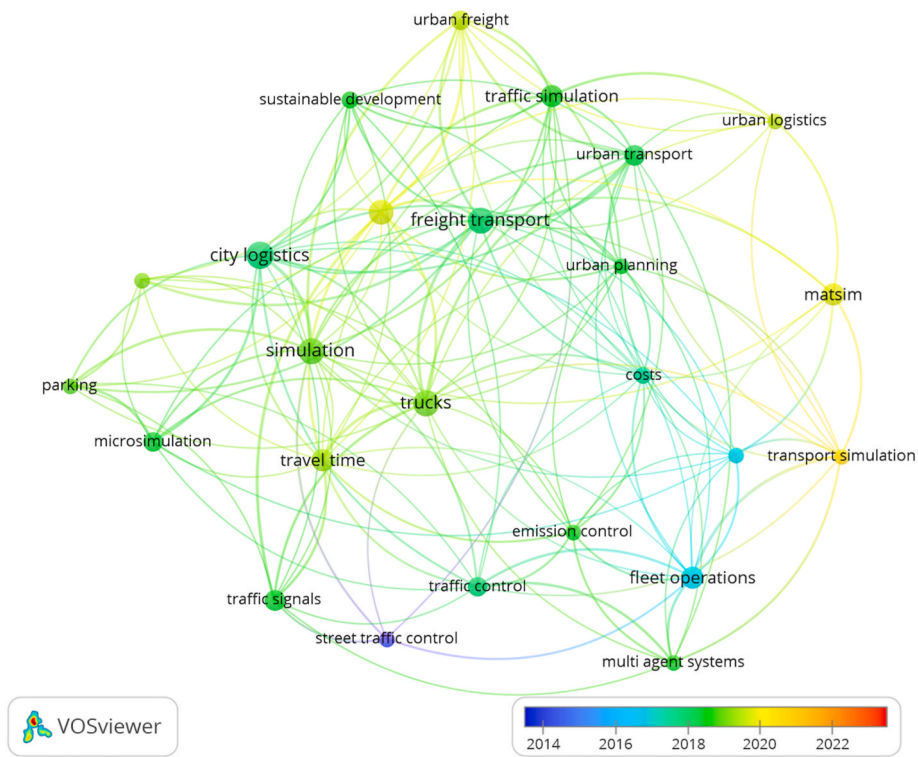


Fig. 5. VOSviewer keyword analysis: chronological development.

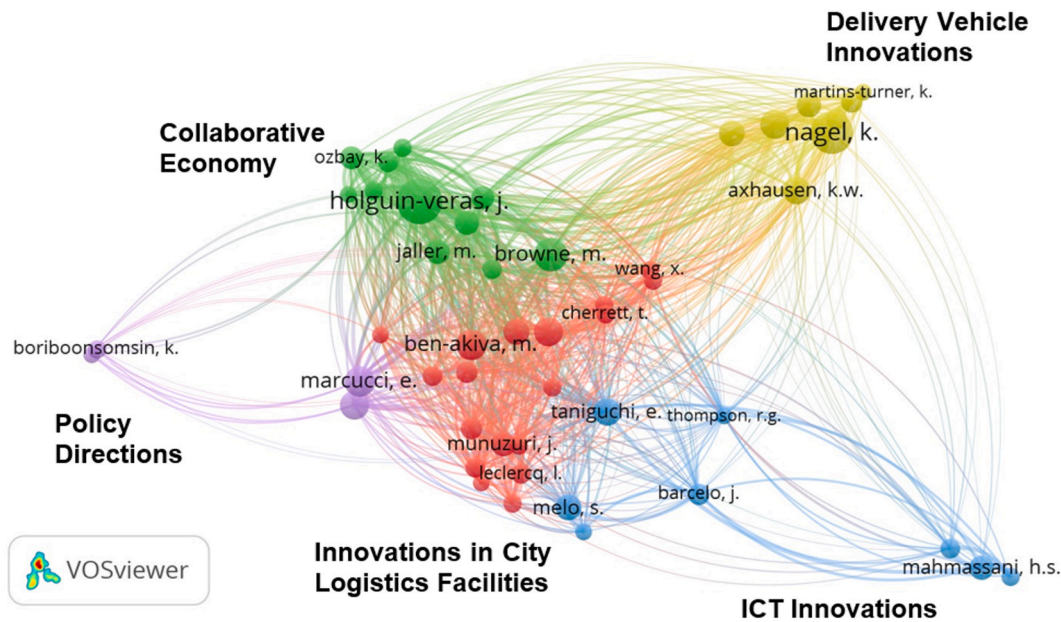


Fig. 6. Co-citation analysis.

off-hour delivery and policy measures (Savado and Beziat, 2021; Zhao et al., 2019). It is also possible to adopt a hybrid micro-meso or macro-micro approach such that the simulation is less time-consuming while the microscopic aspects of delivery operations (e.g., tracking delivery vehicles) are reproduced for analysis (Simoni and Claudel, 2018; Sakai et al., 2023). Furthermore, this review has conducted further analysis on the performed simulations in the reviewed articles. The analysis is presented in the format of a table which elaborates on the type of data inputs for

simulation, data collection method, and the context of case study in each individual paper (see Appendix A). The data input, if specified by authors, was either real-world data, artificial (completely made-up) data, or synthetic data (computed, derived or estimated based on real data) due to the lack of available data (Hammami, 2020). While majority of the studies built their simulation on a realistic case study with specific geographical location and road network, some utilised artificial network with mostly artificial traffic demand such as Haas and Friedrich (2021), Maciejewski and Nagel

Table 3
Main clusters identified and their descriptions.

Clusters (number of papers)	Definitions	Years				
		2001–2005	2006–2010	2011–2015	2016–2020	2021–Dec 2023
ICT Innovations (28)	The implementation or adaptation of information and communication technology (ICT) to improve traffic management, increase safety and network efficiency.	Wang et al. (2004)	Barceló et al. (2008)	Kari et al. (2014); Jiang and Mahmassani (2014); Maciejewski and Nagel (2012); Walker and Manson (2014); Qureshi et al. (2011); Deflorio et al. (2015); Liedtke et al. (2015); Orozco and Barcelo (2011) Melo et al. (2013)	Deflorio and Castello (2017); Zhao and Ioannou (2016); Melo et al. (2017); Martins-Turner et al. (2019); Rifki et al. (2020); Karatsoli et al. (2019); Karakikes et al. (2018); Simoni et al. (2020)	Hao et al. (2021); Bashir and Zlatkovic (2021); Haas and Friedrich (2021); Chowdhury et al. (2023); Sasaninejad et al. (2023); Naeem et al. (2023); Xie et al. (2022); Karakikes and Nathanail (2022); Kwon and Jeong (2022); Beliaev et al. (2022)
Delivery Vehicle Innovations (22)	The use of vehicles with cleaner fuels, less pollution and emissions, or more mobility during LMD.				Martins-Turner et al. (2020); Zhang et al. (2018); Melo and Baptista (2017); Karakikes et al. (2018); Schlenther et al. (2020); Martins-Turner and Nagel (2019); Choubassi et al. (2016); Stolfi et al. (2018); Ben Rajesh and John Rajan (2020); Rossolov et al. (2019)	Winkler et al. (2022); Ewert et al. (2021a); Cokyasar et al. (2021); Naeem et al. (2023); Beliaev et al. (2022); Jahn et al. (2021); Bell et al. (2023); Adeniran et al. (2023); Bienzeisler et al. (2022); Krendeleva et al. (2023); Llorca and Moeckel (2021)
Collaborative Economy (18)	The engagement or collaboration of stakeholders in urban deliveries to enable solution optimisation.		Aschauer and Starkl (2010)	Aschauer and Starkl (2014); Boussier et al. (2011); Melo et al. (2011)	Liu and Kim (2019); Ukkusuri et al. (2016); Sakai et al. (2020); Schlenther et al. (2020); Melo et al. (2019); Mommens et al. (2018); Validi et al. (2020); Simoni and Claudel (2018); Bean and Joubert (2020)	Mepparambath et al. (2023); Bean and Joubert (2021); Savadogo and Beziat (2021); Samudio Lezcano et al. (2023); Maxner et al. (2023)
Innovations in City Logistics Facilities (19)	The location, number, configuration, usage, of the physical equipment, designated areas, or facilities for logistics and delivery activities.			McLeod and Cherrett (2011)	Zhang et al. (2018); Martins-Turner et al. (2019); Martins-Turner and Nagel (2019); Choubassi et al. (2016); Rossolov et al. (2019); Alho et al. (2018); Hammami (2020); Lopez et al. (2019); Kiouis et al. (2019)	Mepparambath et al. (2023); Karakikes and Nathanail (2022); Bell et al. (2023); Bienzeisler et al. (2022); Krendeleva et al. (2023); Llorca and Moeckel (2021); Maxner et al. (2023); Ochoa-Olán et al. (2021); Mommens et al. (2021)
Policy (12)	Restrictions to limit traffic volume in high density areas or during peak hours from the point of view of governments and regulatory authorities.			Melo et al. (2011); Nourinejad et al. (2014); Bhuiyan et al. (2015)	Kickhöfer and Nagel (2016); Gopalakrishnan et al. (2020); Sakai et al. (2020); Karatsoli et al. (2019); Simoni and Claudel (2018); Zhao et al. (2019); Joubert (2019)	Billhardt et al. (2022); Sakai et al. (2023)

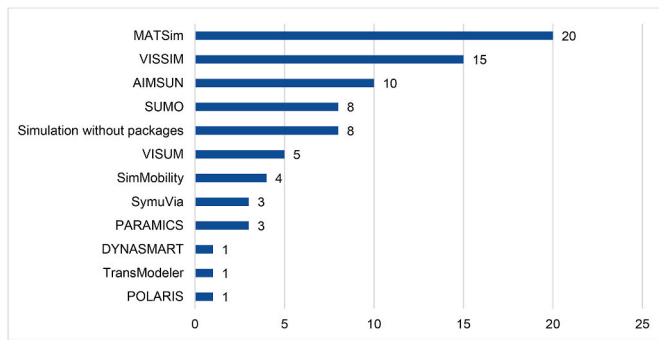


Fig. 7. Use of different traffic simulation packages.

(2012), and Billhardt et al. (2022). Some of the studies focus on a particular industry such as food retailing (Martins-Turner et al., 2019, 2020; Jahn et al., 2021) and postal service (Choubassi et al., 2016). Among the realistic case studies, majority used synthetic data inputs for traffic simulation, such as optimised vehicle routes generated in advance (Winkler et al., 2022; Ewert et al., 2021a), followed by real-world data. Only few studies with realistic scenarios used artificial data (Wang et al., 2004; Krendeleveva et al., 2023).

The data input for traffic models may include freight demand (e.g., origin-destination matrices or “OD”), vehicle characteristics, traffic counts, traffic signal timings, and related delivery patterns, etc. Depending on the type of data input required, the data collection may take place in forms of survey (online or off-line) or interview with stakeholders. These data collection methods can provide qualitative or quantitative data such as the real-life delivery experience of truck drivers for modelling input (Simoni et al., 2020; Nourinejad et al., 2014) and the confirmation of model validity (Cokyasar et al., 2021). On-site observation is another approach to collect quantitative data such as traffic count (Bashir and Zlatkovic, 2021; Nourinejad et al., 2014), delivery patterns (Ochoa-Olán et al., 2021), and characteristics of logistics operation (Zhao et al., 2019). Such data can also be obtained from installed sensors (Melo et al., 2017) or vehicle GPS (Sakai et al., 2020; Karakikes and Nathanail, 2022). Other sources of simulation input include data provided publicly or privately by local authority, census data, online map, open databases, existing traffic model, and previous literature, etc. For example, realistic road networks used in traffic simulation in these studies can usually be obtained from online maps such as OpenStreetMap and Google Maps (Alho et al., 2018) or extracted from existing traffic models such as MATSim Open Berlin Scenario (Martins-Turner et al., 2020; Winkler et al., 2022; Ewert et al., 2021a).

These analyses have profound implications on the network fidelity, data transparency, and input data reliability of the reviewed simulation studies. Majority of the studies had high network fidelity based on the real-world context, while the others had low fidelity of simulation network as they were artificial. 68 studies (86%) revealed the data sources for simulation input (including the made-up data) and contributed to data transparency. Among these 68 studies, 10 used only made-up data for simulation input which reduced the reliability of simulation results. Among the other 58 studies (that used real-world or synthetic data and revealed the data sources), 36 obtained input data from a single source which may also affect the data reliability. In terms of the popularity of each data collection method being used, “others” is the most frequently used, followed by “observation”, “survey”, and “interview”.

5. Classification of interventions

The bibliographic analysis revealed that majority of the papers discussed standalone interventions, while the rest explored combined solutions. To gain more insights into this aspect, additional analyses were conducted. It should be noted that the papers involving more than one

category were counted more than once, and two of the selected papers (Zhang et al., 2018; Mepparambath et al., 2023) were counted in both groups. Table 5 presents a detailed classification of standalone solutions identified in the literature and their development during the last two decades divided into 5-year intervals with the exception of the last interval from January 2021 to December 2023.

It is evident that the research direction in this area has evolved over the years. During 2001–2005, barely any city logistics topic received attention except for road guidance (Wang et al., 2004). During the second period (2006–2010), routing problems and off-hour delivery involving the collaboration of different stakeholders gained attention (Barceló et al., 2008; Aschauer and Starkl, 2010). Between 2011 and 2015, the number of research papers increased significantly, particularly in areas like ICT innovations (Jiang and Mahmassani, 2014; Walker and Manson, 2014; Deflorio et al., 2015), parking and vehicle access restrictions (Melo et al., 2011; Nourinejad et al., 2014), and various ways of coordination among stakeholders (Boussier et al., 2011; Melo et al., 2011; Aschauer and Starkl, 2014).

This growing trend continued during 2016–2020, when the rise of e-commerce boosted crowdsourced deliveries (Simoni et al., 2020) and the advancement of intelligent traffic system (ITS) facilitated traffic signal solutions for improving freight transportation (Zhao and Ioannou, 2016; Karakikes et al., 2018). Meanwhile, new vehicle alternatives for delivery such as EVs (Martins-Turner et al., 2020; Karakikes et al., 2018), cargo bikes (Melo and Baptista, 2017; Ben Rajesh and John Rajan, 2020) and innovative facilities such as parcel lockers gained increased popularity (Zhang et al., 2018; Kiouis et al., 2019). Over the last three years (2021–December 2023), vehicle connectivity has emerged as a pressing research theme (Hao et al., 2021; Bashir and Zlatkovic, 2021), while technology-based solutions like drones for freight delivery have also been explored (Cokyasar et al., 2021).

Among the identified standalone solutions, after-hour delivery and routing optimisation received most continuous academic attention over periods of time, as shown in Fig. 9. This was followed by EVs, loading facilities, and parking restriction policies. Table 6 presents a classification of combined solutions identified in the papers and their evolution over the study period. Interestingly, the first study involving combination of solutions appeared in 2014. Since 2016, however, there was an obvious increase in research involving multiple solutions to improve urban delivery practices. Among all combinations identified, the hybrid use of cargo bikes and micro hubs for LMD seems to be the most popular solution.

The following subsections provide more details about the solutions identified. The individual solutions are discussed in relation to clusters (in the sequence of ICT innovations, Delivery vehicle innovations, Collaborative economy, Innovations in city logistics facilities, and Policy directions). The combined solutions are presented as a separate subsection.

5.1. ICT innovations

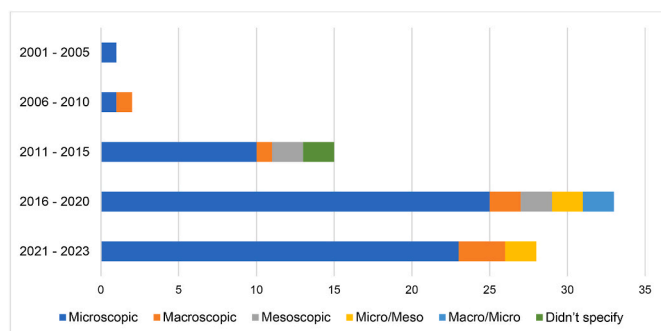
A number of simulation-based approaches have been used to evaluate impacts of ICT innovations. In city logistics, for example, VRP is a widely researched topic about optimisation and planning of delivery locations, routes, and scheduling. In VRP with time window (VRPTWs), the inclusion of time-dependent travel times makes the simulation results more relevant to real life, where travel speeds vary according to time of day (Jiang and Mahmassani, 2014; Rifki et al., 2020). Further, considering the possibility of late deliveries that come with penalty costs, simulations based on dynamic VRP with soft time windows (D-VRPSTW) minimise additional cost and delays for freight carriers (Qureshi et al., 2011).

Another ICT innovation that has received considerable attention in the past two decades is related to connected and automated vehicles and especially vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. These innovations enable wireless information sharing

Table 4

Traffic simulation tools and models identified in the corpus.

Traffic Simulation Packages (Number of papers)	Models/ Representation	Years				
		2001–2005	2006–2010	2011–2015	2016–2020	2021–Dec 2023
MATSim (20)	Microscopic			Maciejewski and Nagel (2012); Liedtke et al. (2015)	Martins-Turner et al. (2019); Martins-Turner et al. (2020); Kickhöfer and Nagel (2016); Zhang et al. (2018); Schlenther et al. (2020); Martins-Turner and Nagel (2019); Choubassi et al. (2016); Mommens et al. (2018); Bean and Joubert (2020); Joubert (2019)	Winkler et al. (2022); Ewert et al. (2021a); Jahn et al. (2021); Adeniran et al. (2023); Bienzeisler et al. (2022); Llorca and Moeckel (2021); Bean and Joubert (2021); Mommens et al. (2021)
POLARIS (1)				Qureshi et al. (2011); Bhuiyan et al. (2015)	Liu and Kim (2019); Zhao and Ioannou (2016); Karatsoli et al. (2019); Karakikes et al. (2018); Ben Rajesh and John Rajan (2020); Kioussis et al. (2019)	Cokyasar et al. (2021)
VISSIM (15)						Hao et al. (2021); Bashir and Zlatkovic (2021); Chowdhury et al. (2023); Sasaninejad et al. (2023); Karakikes and Nathanail (2022); Krendeleva et al. (2023); Maxner et al. (2023)
PARAMICS (3)		Wang et al. (2004)		Walker and Manson (2014); Nourinejad et al. (2014)		
SUMO (8)				Kari et al. (2014)	Stolfi et al. (2018); Validi et al. (2020)	Haas and Friedrich (2021); Naeem et al. (2023); Kwon and Jeong (2022); Beliaev et al. (2022); Billhardt et al. (2022)
SymuVia (3)					Rifki et al. (2020); Hammami (2020); Lopez et al. (2019)	
SimMobility (4)	Micro/Meso				Gopalakrishnan et al. (2020); Sakai et al. (2020)	Mepparambath et al. (2023); Sakai et al. (2023)
TransModeler (1)	Mesoscopic				Ukkusuri et al. (2016)	
DYNASMART (1)				Jiang and Mahmassani (2014)		
VISUM (5)	Macroscopic		Aschauer and Starkl (2010)		Rossolov et al. (2019)	Bell et al. (2023); Savadogo and Beziat (2021); Samudio Lezcano et al. (2023)
AIMSUN (10)	Microscopic		Barceló et al. (2008)	Melo et al. (2011)	Melo and Baptista (2017); Melo et al. (2017); Melo et al. (2019); Alho et al. (2018)	Ochoa-Olán et al. (2021)
	Macroscopic				Zhao et al. (2019)	
	Didn't specify			Melo et al. (2013); McLeod and Cherrett (2011)		
Simulation without packages (8)	Microscopic			Boussier et al. (2011); Orozco and Barcelo (2011)		Xie et al. (2022)
	Mesoscopic			Deflorio et al. (2015)	Deflorio and Castello (2017)	
	Macroscopic			Aschauer and Starkl (2014)		
	Macro/Micro				Simoni et al. (2020); Simoni and Claudel (2018)	

**Fig. 8.** The number of articles using each traffic simulation approach.

and collaboration among vehicles (Jawhar et al., 2013) leading to improved safety and efficiency. Freight vehicles have the potential to improve safety and efficiency by connecting with each other and

adjusting their operations accordingly. Aiming to reduce unnecessary delays, Bashir and Zlatkovic (2021) developed and tested a queue warning application (QWARN) that allows heavy freight vehicles queuing at signalised intersections to pass on queue information to upstream vehicles to adjust their speed such that they spend less time waiting at the red light, leading to a 2%–5% reduction in delays. Similarly, Hao et al. (2021) described an ‘eco-driving’ approach to reduce energy consumption for connected freight trucks at signalised intersections in urban areas. Utilising real-time traffic information (e.g., signal phases and signal timing plan of approaching traffic signals), the eco-driving system determines trucks’ speed trajectory at intersections. Simulation results showed that the eco-driving system is beneficial in saving energy by optimising speed; however, more research is needed to better understand the levels of energy savings under different scenarios.

A use case of connected and automated freight vehicles and platooning has also been investigated as a solution to enhance goods deliveries. For example, Haas and Friedrich (2021) proposed a concept that involves multiple platoons on fixed routes with autonomous delivery vans to perform transfers between platoons until they reach their

Table 5
Standalone solutions and their chronological development.

Topics (Number of papers)	Standalone solutions	Years				
		2001–2005	2006–2010	2011–2015	2016–2020	2021–Dec 2023
ICT Innovations (19)	Routing optimisation		Barceló et al. (2008)	Jiang and Mahmassani (2014); Maciejewski and Nagel (2012); Qureshi et al. (2011); Orozco and Barcelo (2011)	Rifki et al. (2020)	Kwon and Jeong (2022)
	Vehicular connection					Hao et al. (2021); Bashir and Zlatkovic (2021); Haas and Friedrich (2021)
	Road guidance	Wang et al. (2004)		Walker and Manson (2014)	Melo et al. (2017)	
	Traffic signal control				Zhao and Ioannou (2016); Karakikes et al. (2018)	Sasaninejad et al. (2023)
	Wireless charging			Deflorio et al. (2015)	Deflorio and Castello (2017)	
Delivery Vehicle Innovations (11)	Crowdsourced delivery				Simoni et al. (2020)	
	Electric vehicle				Martins-Turner et al. (2020); Karakikes et al. (2018)	Winkler et al. (2022); Ewert et al. (2021a); Jahn et al. (2021); Adeniran et al. (2023)
	Cargo bike			Melo et al. (2013)	Melo and Baptista (2017); Ben Rajesh and John Rajan (2020)	
	Replace truck with van				Stolfi et al. (2018)	
Collaborative Economy (16)	Drone					
	Off-hour delivery		Aschauer and Starkl (2010)	Aschauer and Starkl (2014)	Liu and Kim (2019); Ukkusuri et al. (2016); Sakai et al. (2020); Mommens et al. (2018); Simoni and Claudel (2018); Bean and Joubert (2020)	Cokyasar et al. (2021); Mepparambath et al. (2023); Bean and Joubert (2021); Savadogo and Beziat (2021); Samudio Lezcano et al. (2023)
	Shipping consolidation			Melo et al. (2011)	Validi et al. (2020)	
	Resource sharing between different transport users			Boussier et al. (2011)	Melo et al. (2019)	
Innovations in City Logistics Facilities (9)	Loading areas			McLeod and Cherrett (2011)	Alho et al. (2018); Hammami (2020); Lopez et al. (2019)	Ochoa-Olán et al. (2021)
	Parcel locker/Pick-up point				Zhang et al. (2018); Kiouisis et al. (2019)	Mommens et al. (2021)
	Urban consolidation centre (UCC)					Mepparambath et al. (2023)
Policy (12)	Parking restriction			Melo et al. (2011); Nourinejad et al. (2014)	Gopalakrishnan et al. (2020); Simoni and Claudel (2018)	
	Vehicle restriction			Bhuiyan et al. (2015)	Joubert (2019)	Billhardt et al. (2022)
	Time restriction			Bhuiyan et al. (2015)	Sakai et al. (2020)	
	Toll			Liedtke et al. (2015)	Kickhöfer and Nagel (2016)	Sakai et al. (2023)

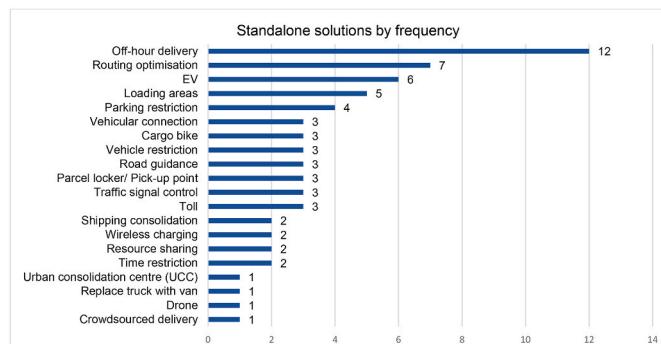


Fig. 9. Number of papers involving each standalone solution.

destinations. Simulation results showed that in nearly half of the cases, platoon-based systems were effective in reducing the total travel time of delivery vehicles.

Advancement in wireless charging technologies can also help to promote the use of EVs for urban freight delivery. By incorporating dynamic charging infrastructure and V2I communications, Deflorio and Castello (2017) and Deflorio et al. (2015) used simulation

methodologies to demonstrate the potential of charging-while-driving (CWD) to overcome the range limitation of EVs. According to these studies, each vehicle is required to submit a request to the charging station operator through its on-board unit (OBU) before entering the CWD lane, which is installed in the slowest lane of the motorway. While this technology could improve the efficiency of urban freight operations involving EVs, further analysis should be conducted to assess more complex scenarios involving different vehicle types and traffic flow patterns.

Crowd-shipping (also known as crowdsourced delivery) has recently emerged in urban logistics as a use case of the ‘sharing economy’ (Buldeo Rai et al., 2017). Crowd-shipping is an approach that matches delivery demand with transportation supply through digital platforms, allowing individuals to perform deliveries as they travel on their normal routes (Le Pira et al., 2017). As a relatively new topic in urban freight, crowd-shipping has received considerable research interest (Mucowska, 2021). A recent case study used simulation techniques to examine the impact of replacing traditional truck delivery with car-based and public-transport-based crowdsourced delivery modes (Simoni et al., 2020). Based on the simulation results, crowd-shipping by public transport had evident benefits in reducing CO₂ emission and traffic delays, though no clear benefits were observed for the car-based crowd-shipping.

Table 6

Combination of solutions and their chronological development.

Topics (Number of papers)	Combined solutions	Years				
		2001–2005	2006–2010	2011–2015	2016–2020	2021–Dec 2023
Vehicle & Facility (6)	Cargo bike + Micro hub				Zhang et al. (2018); Martins-Turner and Nagel (2019); Choubassi et al. (2016); Rossolov et al. (2019)	
	Autonomous robot + Micro hub					Krendeleve et al. (2023)
ICT & Vehicle (2)	AV + Micro hub					Bienzeisler et al. (2022)
	Routing optimisation + EV					Naem et al. (2023)
	Routing optimisation + Drone					Beliaev et al. (2022)
ICT & ICT (3)	Vehicular connection + Traffic signal control			Kari et al. (2014)		Chowdhury et al. (2023); Xie et al. (2022)
Vehicle & Vehicle & Facility (2)	Cargo bike + EV + Micro hub					Llorca and Moeckel (2021)
	Cargo bike + AV + Micro hub					Bienzeisler et al. (2022)
ICT & Facility (2)	Routing optimisation + urban consolidation centre				Martins-Turner et al. (2019)	
	Crowdsourced delivery + Parcel locker					Karakikes and Nathanail (2022)
ICT & Policy (1)	Traffic signal control + Parking restrictions				Karatsoli et al. (2019)	
Vehicle & Facility & Facility (1)	EV + Parcel locker + Pick-up point					Bell et al. (2023)
Collaborative & Vehicle (1)	Resource sharing + AV				Schlenther et al. (2020)	
Collaborative & Facility (2)	Resource sharing + Loading areas					Maxner et al. (2023)
	Off-hour delivery + UCC					Mepparambath et al. (2023)
Policy & Policy (1)	Time restrictions + Logistics sprawl				Zhao et al. (2019)	

5.2. Delivery vehicle innovations

In order to reduce emissions of freight trucks in urban areas, researchers such as [Stolfi et al. \(2018\)](#) have explored the potential of replacing heavy-duty trucks with vans, as a more flexible and less polluting option. Simulation results demonstrated that this measure could considerably reduce emissions. In the same vein, the last decade has witnessed a growth in the number of publications around alternative types of delivery vehicles besides trucks. EVs, and in particular, battery electric vehicles (BEVs), hold promise when it comes to the decarbonization of the transport sector. Research conducted in Greece demonstrated that an application of mixed electric and Compressed Natural Gas (CNG) heavy goods vehicles (HGVs) could lead to 3% reduction in NO_x and 2% reduction in PM₁₀ ([Karakikes et al., 2018](#)). Furthermore, fuel cell electric vehicles (FCEV) powered by hydrogen were proposed by [Winkler et al. \(2022\)](#) for their potential to address BEVs' range and recharging shortcomings as an alternative green vehicle solution. Nonetheless, the simulation results demonstrated that BEV would be a better option compared to FCEVs, and the comparative advantage of FCEVs over BEVs exists only when there's a widespread usage of electricity and hydrogen as energy mixes.

Meanwhile, simulation-based studies exploring the use of BEVs for delivery exposed many downsides of the solution. While the lower emission levels of BEVs is promising, economically, they are less competitive when compared with internal combustion engine vehicles (ICEVs). Using a case study in food retailing industry in Berlin, [Martins-Turner et al. \(2020\)](#) generated synthetic tours, fleet sizes, and vehicle compositions, which were used to calculate total cost of ownership and well-to-wheel emissions of ICEVs and BEVs. The results revealed that transitioning from ICEVs to BEVs would incur a 17% increase in costs, assuming equivalent chassis costs for ICEVs and BEVs. This cost increment would rise to 23% when considering a 60% higher chassis cost for BEVs. Moreover, [Ewert et al. \(2021a\)](#) revealed that a greater number of BEVs would be required to fulfil customer demands

than an ICEV fleet due to the limitations in charging time, battery capacity and usage of energy. In addition, charging electric delivery vehicles requires adequate infrastructure. Using multi-agent transport simulation, [Jahn et al. \(2021\)](#) concluded that for a fleet of 279 trucks, 214 normal charging points and 65 fast charging points would be required; and if the trucks can share the charging points during night-time, the required infrastructure could be reduced to 71 fast charging points.

Compared to EVs, cargo bikes seem to be more widely accepted as an environmental-friendly option for future urban freight transport with promising economic performance. While they are known for their 'green' characteristics that help to mitigate the negative impacts of freight traffic, cargo bikes also seem to be more effective in densely populated CBD areas due to their flexibility in use and applications ([Choubassi et al., 2016](#)). Such benefits are confirmed by a simulation-based case study in Portugal, which demonstrated that cargo cycles were more suitable for small scale (street level) implementation ([Melo et al., 2013](#)). The study also found that reduction in traffic delays and travel distances was reached at 10% replacement of ICEVs by cargo cycles. Similarly, a study on freight movements in the city of Porto revealed that replacing up to 10% of conventional vans by electric cargo bikes could reduce traffic delays by up to 4% ([Melo and Baptista, 2017](#)). Moreover, researchers in India ([Ben Rajesh and John Rajan, 2020](#)) found that increasing the percentage of cargo bikes in the total traffic volume from the current 37.04%–47.04% would enhance the speed of cargo bikes and light vehicles during peak hours, leading to a reduction in delivery time of cargo. While the most beneficial penetration rates of cargo bikes differ under various traffic situations and logistics demands, market coverage of cargo bikes does not always lead to positive effects on transport systems. For example, it was revealed by [Melo and Baptista \(2017\)](#) that with 20%, 30%, and 100% penetration rates of cargo bikes for freight delivery, traffic delays, queue, and idling times all increased while traffic flow was reduced, according to their simulation results.

Another type of innovative delivery vehicle that has gained

momentum in recent years is unmanned aerial vehicles (UAVs), also known as drones. While drones have potential to transform the delivery of goods in cities, their short range poses an issue. To help resolve the range issue, Cokyasar et al. (2021) designed a drone delivery network using automated battery swapping machines (ABSMs). The study proposed a possible approach to deliver goods to customers from a single distribution centre (DC) where drones are loaded, and during the trip drones' batteries can be exchanged with fully charged replacements at various ABSM locations. According to the simulation results, among all the parameters studied, ABSM service times and costs had the most significant long-term impacts for such hybrid systems and thus should be further explored.

5.3. Collaborative economy

Primarily, the collaborative economy refers to collaboration between different stakeholders in city logistics, and involves sharing of excess resources and capacity to maximise utilisation, which benefits all stakeholders.

Three types of stakeholders are identified by Viu and Alvarez (2020): private enterprise (shipping companies, retailers, and logistics operators), public administrators, and citizens. With the emergence of the 'sharing economy' and strengthened connections among people by various technologies, stakeholders in city logistics ecosystem have multiple ways to collaborate.

Parking infrastructure in urban areas, due to its scarcity, is one of the top choices when it comes to the sharing of excess capacity. Boussier et al. (2011) proposed a strategy to share on-street parking bays between private cars and delivery vans through an in-advance booking system. In this scheme, private vehicles could utilise the empty parking places that are not reserved. Similarly, Melo et al. (2019) examined the potential of sharing the parking spaces dedicated for freight vehicles with other private users who need access. As demand for parking space by freight vehicles and private users happen at different times of the day, it is beneficial to arrange a collaborative scheme that fulfils both needs. Their simulation results demonstrated that the total travel time within the study area witnessed a 11% reduction and a decrease in double-parking behaviour.

Shipping consolidation among freight carriers can be advantageous from both economic and environmental standpoints. By pooling truckloads or bundling deliveries within the same region, freight vehicles can reach higher load factors and thus a reduction in number of vehicles can be achieved. According to Validi et al. (2020), bundling transport deliveries into one single truck (rather than in multiple trucks) could reduce fuel consumption by 28% and CO₂ emissions by 34%. However, the effects of such cooperation seem to vary in different studies. In another simulation study, the implementation of shipping consolidation did not show positive impacts due to various factors including stakeholders' unwillingness to participate, additional trips during consolidation, and longer parking period during delivery, etc (Melo et al., 2011).

Off-peak delivery of urban freight has been explored by researchers as a way to save costs and reduce environmental impacts (Aschauer and Starkl, 2010). This strategy can benefit the urban road networks and ease congestion, as fewer delivery vehicles would be on the road during peak hours (Aschauer and Starkl, 2014). The key to successful after-hour delivery models seems to be the economic incentives for participating stakeholders. A study in Cape Town, South Africa adopted a cost-sharing approach by which freight receivers who collaborate in after-hour delivery could take a share of the cost savings (Bean and Joubert, 2021). This approach seemed to be beneficial as freight receivers were motivated to extend their delivery timeframes, and as a result, carriers' daily delivery cost could be reduced by up to 15.8% on average. Similarly, research conducted in New York City utilised economic incentives to prompt businesses in Manhattan to shift the delivery to less congested hours (Ukkusuri et al., 2016). Based on the simulation results in this

study, off-peak delivery schemes could noticeably reduce vehicle-kilometres travelled (VKT), total travel time, and congestion. It was also revealed that participation rates beyond 7% would not bring noticeable increase in the benefits. In addition, studies have revealed that after-hour deliveries are more suitable for large-scale networks and dense congested urban areas (Savado and Beziat, 2021). These findings are in line with another study conducted in Georgia, the United States, which emphasised that in case of high traffic demand and high truck volumes, off-peak delivery schemes can be beneficial (Liu and Kim, 2019).

Despite the positive effects of off-peak delivery schemes, potential disadvantages such as higher average concentration of pollutants and increased noise during nights should also be considered. A study in Belgium assessed the impact of night-time distribution and revealed that, among multiple distribution scenarios, the increase of external costs from noise nuisances during delivery operations (e.g., manoeuvring, loading, and unloading) to the supermarkets in Wallonia could be minimised to 2% compared to the Business as Usual. In this scenario, all small supermarkets would shift to night delivery and large supermarkets would receive deliveries evenly across daytime, night-time, and day-night transition time (Mommens et al., 2018). This scenario could also reduce emissions by 8% and congestion by 15%. Furthermore, the identified issues may be mitigated in the future with the deployment of electric commercial delivery vehicles, capable of operating without emissions or noise (Margaritis et al., 2016).

5.4. Innovations in city logistics facilities

Parking facilities are essential to goods delivery and pick-up by couriers. However, the lack of appropriate planning and provision of loading zones and bays has been identified as a common issue in the city logistics literature (Hammami, 2020; Jaller et al., 2013). This not only leads to low efficiency of delivery activities, but also causes multiple issues including congestion, emissions, and illegal parking (Alho et al., 2018). Research on managing loading facilities primarily takes three approaches. First, to implement policies on parking price and penalties; second, to simply increase the supply of freight loading zones; and third, to manage time and space availability of parking areas more efficiently.

The first approach is generally believed to be reactive strategy (Figliozzi and Tipagornwong, 2017). The second approach may minimise the tension between multi-modal users but requires significant investment, and is not always feasible because it would compromise urban space. The third approach, which appears to have less limitations than the other two, has been explored in various research. For example, Ochoa-Olán et al. (2021) optimised the spatial configuration (location, number, and size) of loading bays during peak hours in the city of Querétaro, Mexico, by considering various factors including sidewalk width, surrounding infrastructure, and carrying capacity of freight vehicles. As a result, the number of freight parking spaces was reduced by 38.46% and the length of loading/unloading parking space by 69.6%. Furthermore, McLeod and Cherrett (2011) tested the usefulness of a pre-booking system for parking space to ensure effective utilisation and reduction of double-parking.

With the growth in e-commerce, pick-up and drop-off points are increasingly popular in LMD. Mommens et al. (2021) compared the impacts of deliveries-to-home and deliveries-to-collection-points on the economic and environmental sustainability. Their findings revealed that e-commerce deliveries via collection points were more sustainable within urban areas. Furthermore, a typical application of collection points - parcel locker - is usually located within or close to residential areas to provide a temporary storage location for packages and introduce network efficiency (Pan et al., 2021b). Research in Germany examined the benefits of using parcel lockers and found that travel time was reduced by 16.8% and number of deliveries per tour was increased by 11%, due to the consolidation of deliveries to each parcel locker and less unloading time required (Zhang et al., 2018). Similarly, research in

Greece revealed that fleet size and average travel time could be reduced by 80% and 82.4%, respectively (Kiousis et al., 2019). Interestingly, both studies identified the level of convenience and willingness for receivers to access the lockers as key limitations. This has practical implications for shipper and receivers in terms of travel time and costs.

5.5. Policy directions

As demand for urban infrastructure continuously increases, cities are facing the challenge of managing limited transport resources such as curb and street availability. Appropriate policies and regulations can reduce congestion and increase efficiency of delivery operations (Simoni and Claudel, 2018). Mainstream freight regulations include restricting certain types of truck activity by hour of the day, size or type of the vehicle, or access to certain areas for parking. Their effects, however, need to be carefully evaluated and simulation can be an effective tool in this regard particularly when examining the impacts of new interventions that have not been previously deployed. For example, the impacts of parking enforcement (ensuring freight vehicles park legally without blocking roads and facilities) on a transport system was investigated by Melo et al. (2011). The simulation results showed that the enforcement could reduce operational costs by 21% at the street level and by 10% at the unit level.

Access restriction on freight vehicles is also a common strategy for municipalities to reduce congestion and ease externalities, particularly in congested areas (Nourinejad et al., 2014). Billhardt et al. (2022) proposed a restriction strategy, by which vehicles must seek permission to enter a controlled area during LMD. According to the simulation results, the highest reductions in NO_x emissions of the area and delivery time per parcel was reached when the access priority was given to less polluting vehicles with more packages. Comparing different types of freight regulations can also help authorities sort out the right approach for traffic management. Bhuiyan et al. (2015) assessed three different freight restriction policies and revealed that restrictions on access and timing could have more benefits in improving traffic conditions than restrictions on vehicle types.

Furthermore, research has found that not only the amount of penalty, but also the intensity and efficiency of enforcement had impacts on the compliance of heavy vehicle drivers (Joubert, 2019). Further, unexpected benefits of these restrictions may also occur. As Liedtke et al. (2015) revealed, by introducing a moderate toll (2600 yen) in the Tokyo metropolitan area, direct carriers tended to switch to a hub-and-spoke transport mode, which led to an overall reduction in logistics costs for shippers.

5.6. Combination of solutions

Studies in the literature also assessed the combined and hybrid utilisation of various urban delivery solutions to maximise their benefits. Among the proposed combinations, the majority are related to alternative delivery vehicles. For example, Schlenker et al. (2020) explored the idea of sharing AVs for freight and passenger transport, thus increasing vehicle occupancy and reducing traffic volume. The idea was assessed from the perspective of transport service providers, concluding that by hiring private autonomous cars for delivery tasks, instead of managing their own fleets, could reduce total costs by nearly 84.5%. Despite the economic benefits, however, this measure increased overall vehicle miles due to increased empty trips between depots. Also, transfer costs and possible risks like vehicle inaccessibility were important. Moreover, as private vehicles seem to have less carrying capacity than freight vehicles, the number of tours will possibly increase (Schlenker et al., 2020).

There are also considerable research interests in analysing cargo bikes in combination with micro hubs (also called carrier hubs or micro-consolidation centres). Most suited for LMD at dense city centres, cargo bikes have relatively small capacity for carrying parcels and can only

travel short distances (Melo and Baptista, 2017). In this context, micro hubs can act as transshipment points, where freight trucks and vans drop the packages and cargo bikes pick up and deliver these packages. As a result, heavy freight vehicles do not need to enter dense and narrow urban roads where cargo cycles have more flexibility. As revealed by Zhang et al. (2018), the hybrid use of cargo bikes and micro hubs could reduce costs and emissions by 28% and 22%, respectively. Similarly, Martins-Turner and Nagel (2019) revealed that as cargo bikes could reload at micro hubs during the delivery tour, the number of vehicles needed and carrier's costs could be reduced. Meanwhile, some researchers have considered electrically-assisted cargo bikes for advantages including higher speed and less time for delivery. In a case study in Germany, Llorca and Moeckel (2021) examined the impact of introducing electric cargo bikes and electric vans for delivery. The results demonstrated that despite a slight increase in travel time when there was a higher percentage of cargo bikes, the hybrid use of electric vans and cargo bikes was effective in reducing CO₂ emissions. In addition, Choubassi et al. (2016) found that, compared to electric cargo bikes (two-wheeled), electric cargo trikes (three-wheeled) have less economic and environmental costs in the long-term.

Bundles of measures have also been evaluated from the perspectives of policies. For example, Karatsoli et al. (2019) modelled the combined effects of freight vehicles' parking restrictions and adjusted signal time offsets. Results demonstrated significant reductions in a network's total delays and increases in average speeds. Zhao et al. (2019) also examined the impacts of combining two urban freight policies of logistics sprawl and time restrictions for freight vehicles. Interestingly, although these policies could not individually benefit carriers and the environment in a significant way, the combination could reduce delivery costs and carbon emission by 4% and 6.12%, respectively. This is because carriers are more encouraged by the combined policy to improve their operational strategies and increase distribution efficiency.

6. Drivers of research

This review has analysed the impacts of urban logistics interventions and strategies based on traffic simulation studies that were used to assess their benefits. In this section, an assessment of the literature in terms of implementing transport sustainability concepts is presented.

Table 7 illustrates how sustainability can be improved by transport activities (Victoria Transport Policy Institute, 2017). Based on this framework, articles in the corpus with their objectives and outcomes were investigated from all three perspectives, namely economic, social, and environmental. The review revealed that both economic and environmental aspects have been frequently addressed by the research during the last two decades (Choubassi et al., 2016; Validi et al., 2020; Kiousis et al., 2019). Obviously, some of the negative economic impacts are closely related to the environmental aspects. For example, air pollution is generally reduced when traffic congestion decreases, and hence these two impacts are often bundled together in studies and used as key indicators measuring the impacts of urban freight interventions (Mommens et al., 2018, Mommens et al., 2021). The review also revealed that among the transportation impacts on economic sustainability, traffic congestion has been most frequently addressed in studies, while transportation facility costs and consumer transportation costs were explored in fewer studies (Zhang et al., 2018; Kiousis et al., 2019). From the environmental perspective, air pollution, noise pollution, and climate change were discussed (Simoni et al., 2020). It was also found that among various environmental indicators (e.g., CO₂, NO_x, PM_{2.5}, PM₁₀) for GHG emissions and air pollution, the reduction in CO₂ emissions was most frequently discussed in the studies of urban freight and LMD (Mucowska, 2021).

The direct and indirect impacts that have been discussed in the studies of urban freight and LMD are italicised in Table 7. The transportation impacts on social sustainability have rarely been directly addressed as a research objective, but they are sometimes indirectly

discussed in the studies. For example, communities can benefit from better planning, shared use, and dynamic management of public parking infrastructure, which lead to improvements in liveability and local mobility (Melo et al., 2019). Research has also shown that the use of cargo bikes or EVs for freight deliveries could reduce local exposure to air and noise pollution, which has a positive impact on human health (Zhang et al., 2018; Melo and Baptista, 2017; Karakikes et al., 2018; Jahn et al., 2021).

To achieve sustainable urban mobility, freight delivery strategies that improve one sustainability objective at the cost of worsening another should be avoided (Victoria Transport Policy Institute, 2017). Two typical scenarios are provided. First, some interventions have economic benefits, but may negatively impact the environment. For example, time restrictions for freight vehicle may increase freight costs and carbon emissions in an unintended manner (Zhao et al., 2019; Joubert, 2019). Further, rescheduling truck delivery operations to night-time operations has been demonstrated to be effective in reducing traffic congestion and emissions during the day. Nevertheless, night delivery may have an effect on citizens' quality of life, which was found by Liu and Kim (2019). Moreover, the effects of after-hour delivery are generally a trade-off between noise nuisances, traffic congestion and emissions, unless combined with other noise-reducing measures (Mommens et al., 2018).

Second, many urban freight strategies focus on improving traffic and network efficiency without paying equal attention to economic impacts. Examples include double-parking fines, which is one of the traditional policies for municipalities to manage public parking facilities (Lopez et al., 2019). This approach, however, doesn't necessarily reduce illegal parking behaviour or the incurred road blockages, since it is often the case that drivers are 'forced' to double park when there is not enough supply of parking spaces. Meanwhile, rerouting to find other available parking spaces not only incur extra delivery time and transport costs, but also potentially contribute to more traffic congestion due to longer 'search times'. Another example is the pick-up/drop-off points, an increasingly popular measure for parcel deliveries at the last mile, which can be used to mitigate common delivery issues like non-availability of receivers (Kioussis et al., 2019). Parcel lockers can effectively reduce travel times of freight vehicles and increase delivery efficiency, but they may incur additional time and costs for customers (Zhang et al., 2018).

In order to promote urban mobility sustainability, the most advantageous interventions are those that have joint benefits for economic, environmental and social outcomes (Victoria Transport Policy Institute, 2017). More specifically, these include a growing number of solutions such as the use of EVs, connected vehicles, drones, cargo bikes, and micro hubs. It is important to acknowledge there are ongoing debates about the sustainability implications of emerging solutions such as EVs. Freight carriers usually incur a small increase in costs when they switch to electric fleets but the environmental benefits may outweigh the economic costs by a wide margin, as suggested by Ewert et al. (2021b) and Martins-Turner et al. (2020). Meanwhile, charging infrastructure will be necessary for large-scale implementations of EVs, and detailed charging strategies need to be put in place. Similarly, connected vehicles require additional support in systems or infrastructure (Bashir and Zlatkovic,

2021). Connected freight vehicles may improve mobility and traffic safety, but maximising their benefits from economic and environmental perspectives remains a challenge (Hao et al.). Using cargo bikes or drones for delivery is another hot topic in recent years, but these vehicles' short range can be a problem unless they can be used together with intermediate facilities or transshipment points like micro hubs or parcel lockers (Melo and Baptista, 2017; Cokyasar et al., 2021). Combined solutions of alternative vehicles and facilities also tend to have more positive effects overall, as the disadvantages of each single intervention can be mitigated and advantages maximised.

7. Future research directions

This section draws upon existing literature to identify research gaps and future directions. Building upon the topics covered in the review, the areas for future research are discussed to encourage more targeted and impactful studies on simulating the impact of urban logistics measures. The recommendations for future research are divided into four areas: leverage of traffic simulation, efforts of data collection, trends of urban logistics intervention, and evaluation of simulation outcomes. In addition to offering research recommendations, the framework is also visualised in Fig. 10.

7.1. Leverage of traffic simulation

Traffic simulation is a versatile tool and has played various roles in city logistics studies, from evaluating the overall traffic impact and performance of a city logistics intervention (Alho et al., 2018; Ochoa-Olán et al., 2021; Zhao et al., 2019), to providing information like agents' decision-making (Jahn et al., 2021; Bean and Joubert, 2021) and traffic dynamics over a period of time (Winkler et al., 2022; Barceló et al., 2008; Jiang and Mahmassani, 2014). In addition, traffic simulation can also serve various purposes like generating particular vehicle behaviours, tracking in real-time the locations of fleet vehicles, and reproducing traffic patterns overall. Utilising traffic simulation tools, future research in urban logistics can benefit in various ways depending on the need of each individual study.

Various traffic simulation packages are available, easy to use, and can usually be tailored to the need of researchers. Some of these packages are commercialised such as VISSIM and AIMSUN while others are open-source and publicly available like the agent-based simulator MATSim. Future research can also utilise existing and open traffic models like the MATSim Open Berlin Scenario (used by Martins-Turner et al. (2020); Winkler et al. (2022); Ewert et al. (2021a)) to expedite the study without additional costs.

Furthermore, future city logistics studies can expand the traffic simulation models in various ways. For example, urban traffic flow has different patterns depends on the day of a week (weekly profile), and the congestion severity during traffic peak-hour are different in weekdays than at weekends (Mohammed Almatar, 2023). The simulation outcome of off-hour delivery may fluctuate based on which day of a week is being simulated. Similarly, different hours of a day also demonstrate different traffic patterns (daily profile) and the impact of an intervention at different hours should be simulated and investigated (Chen et al., 2019). For example, the impact of traffic signal priority for freight vehicles crossing intersections may change or even reverse at a different hour and these insights are critical for the future implementation of the intervention.

The network coverage of traffic simulation models can also be expanded in future studies. It was revealed by this review that there is a lack of studies that examined the impacts of large-scale implementations. The majority of studies used microscopic simulation models, which focus on relatively small areas of implementation and lack the ability to demonstrate the benefits of the interventions at a broader level. Granted, large-scale models are more difficult and costly to calibrate, but they are instrumental in investigating whether an intervention

Table 7

Transportation impacts on sustainability adapted from Victoria Transport Policy Institute (2017).

Economic	Social	Environmental
Traffic congestion	Inequity of impacts	Air pollution
Mobility barriers	Mobility disadvantaged	Climate change
Crash damages	Human health impacts	Habitat loss
Transportation facility costs	Community cohesion	Water pollution
Consumer transportation costs	Community liveability	Hydrologic impacts
Depletion of non-renewable resources	Aesthetics	Noise pollution

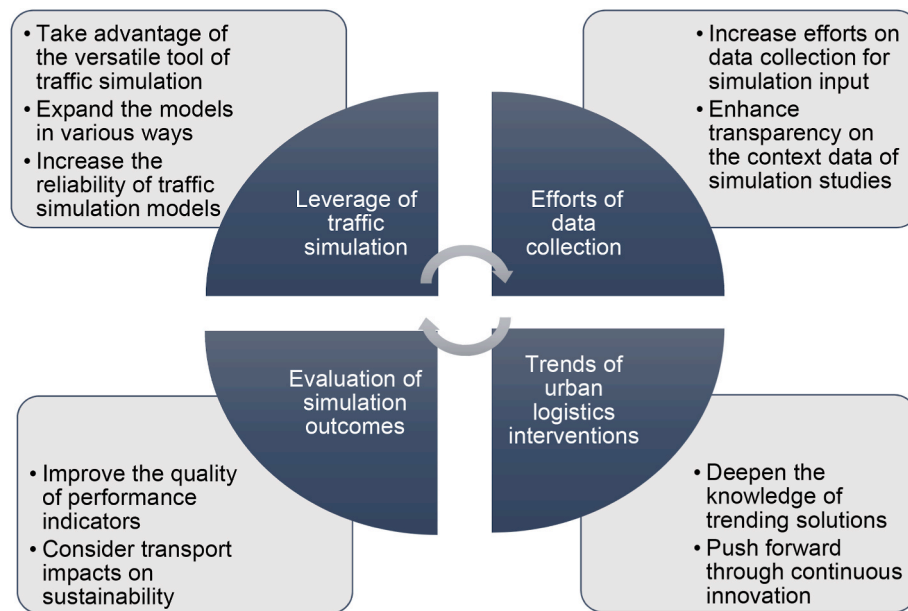


Fig. 10. Future research agenda.

would have the potential to scale up in the future, and what the impacts on the transport system would be (Zhang et al., 2017). To fulfil this gap, future research should consider adopting a mesoscopic modelling approach to understand the strategic impacts of urban freight interventions, or a hybrid approach of meso-micro or macro-micro simulation to reproduce microscopic aspects of delivery operations where necessary.

Also, forecast horizons can be applied to traffic simulation models in order to investigate future scenarios. By encompassing various background traffic growth and infrastructure scenarios, the modelling of urban logistics interventions can expand to short-term horizons and long-term horizons (FHWA, 2019). With forecast horizons, the future impacts of the simulated interventions can be predicted and form an additional dimension to evaluate the feasibility of urban delivery solutions.

In addition, future research should also enhance the reliability of the traffic simulation approaches used in city logistics studies. Calibration and validation are crucial for traffic simulators to allow for reliable reproduction of real-world conditions, although this process involves inherent difficulties such as the amount of data required, uncertainty, and exponential impact of small errors (Zhang et al., 2017; Jha et al., 2004). However, only some of the reviewed studies explicitly stated that their traffic models had been calibrated and validated such as Melo and Baptista (2017) and Melo et al. (2017). To improve the quality and accountability of simulation studies, future research is encouraged to use calibrated and validated traffic models while properly and sufficiently document this process.

7.2. Efforts of data collection

Lack of urban freight data is a frequently-discussed drawback in literature that hinders the development and improvement of traffic simulation models (Sakai et al., 2020; Mepparambath et al., 2023; Karakikes and Nathanail, 2022). Future research should therefore increase the efforts on data collection before simulation. Collection of input data is a critical step when conducting a traffic simulation study (Olstam and Tapani, 2011). The transparency and quality of input data directly influences the accuracy and credibility of simulated impacts of urban logistics interventions. While many of the reviewed studies collected data from more than one source and clearly stated the sources, about 27% of the studies simply used artificial data or did not specify the

data sources. Therefore, future studies are encouraged to attach more importance to the data collection process and relevant documentation to enhance the study reliability. Meanwhile, many researchers chose to use available data from existing surveys or previous studies such as Kickhöfer and Nagel (2016). Although using existing dataset saves time and effort, future research should pay attention to how outdated the existing data are to ensure that the data can still be reasonably used (Flitsch et al., 2018).

Moreover, future studies should increase the transparency on the context data of simulation studies. Traffic conditions significantly differ based on geographical locations, and thus simulation outcomes are largely dependent on the context of case studies. An urban logistics measure can demonstrate different impacts when simulated in the context of one city from another. Therefore, geographical context is an important factor when evaluating an urban logistics measure and comparing simulation results among studies. It would be desirable for future simulation studies to use real-world network and include sufficient description on the local traffic condition of the study area.

7.3. Trends of urban logistics intervention

The analysis conducted in this review has revealed that in the past 3 years (2021–2023), the most popular interventions in research were EV, vehicular connection, and off-hour delivery. If considering a time window of the past 5 years (2019–2023), the most popular interventions remain the same with the addition of loading areas. This indicates a strong focus of recent research on the new vehicle technologies including electrification, autonomous driving, and V2I. Future research can build on these trending solutions and deepen the knowledge in these fields by conducting realistic case studies and examining the relevant requirements for implementation and thus critically assessing the added value of infrastructure investments in novel technologies such as 5G, for vehicular connection and traffic management as proposed by Bäßmann et al. (2023).

Moreover, hybrid utilisation of various solutions is a clear branch of urban logistics studies and has attracted an increasing research interest since the last ten years. Among the hybrid solutions, the combination of vehicle solutions (i.e., cargo bike, autonomous robot, AV, and EV) and facility solutions (i.e., micro hub, parcel locker, pick-up point) is the most popular due to a shared benefit: These vehicles are more flexible, versatile, and environmentally friendly during LMD while the facilities

can act as transshipment points between these LMD vehicles and traditional delivery trucks and vans, which are more efficient before reaching the last mile. As parcel lockers have already been put into use in real-world (Lagorio and Pinto, 2020), combining them with cargo bikes, which do not require additional technology, can be implemented in a relatively straightforward manner. Considering the potential benefits and feasibility, future research can build upon the existing knowledge on this solution and further investigate its impact under different geographical and traffic conditions.

Furthermore, the frontiers of knowledge in this field can be pushed forward through continuous innovation. Despite the growing number of studies on urban delivery interventions, research on urban freight is still limited and the knowledge in the field is rather incomplete (Mangiaracina et al., 2019; Bhuiyan et al., 2015; Lim et al., 2018). There is room for future research to propose more dynamic interventions that help accommodate the surging delivery demand and reduce the negative impact of urban freight. For example, the fluctuating freight traffic volume during different hours of a day can be difficult for on-street parking management, but these patterns can also be utilised to develop resource-sharing schemes of parking spaces (Melo et al., 2019) and time-differentiated and dynamic urban logistics measures (Wilson et al., 2022). Similar to stand-alone solutions, new combined solutions need to be considered and examined. For example, multiple studies on EVs have indicated that due to the conflict between payload and battery size, it could be advantageous to connect EVs with micro hubs where they can exchange their batteries (Martins-Turner et al., 2020; Vleugel and Bal, 2018). However, such innovation has not been investigated despite the fact that they lend themselves to evaluation using traffic simulation.

7.4. Evaluation of simulation outcomes

The evaluation of urban freight delivery interventions is quite fragmented and lacks a holistic approach. This shortcoming shows itself in multiple ways. First, there is inconsistency in the choice of performance indicators among studies. Various simulation studies have been carried out, but due to the different measurements and performance indicators that are applied, it is challenging to compare the results of solutions from different studies (Patier and Browne, 2010). For example, some studies assess interventions according to the reduction in network delay time while others assess interventions according to the number of parcels being delivered.

Second, it is often the case that studies select only few indicators for measuring the impact of an intervention on the environment or transport system, whereas multiple indicators can be used to measure a criterion of an intervention's performance and together they can better provide an all-round measurement of the impacts (Kraus and Proff, 2021). For example, one can assess the traffic impact of an intervention based on average vehicle speed, congestion level, or delay time, etc. Each of these indicators has a particular definition and can demonstrate different degree of change (FHWA, 2005). Therefore, future studies should select a comprehensive set of performance indicators for each criterion being measured to ensure that the overall impacts of a simulated intervention are captured.

These shortcomings call for a universal guideline for future studies to improve the quality of evaluation when measuring the impacts of urban logistics interventions. For future research, establishing and applying guidelines for comparison and evaluation of different interventions across studies would be essential to fully understand the implications of various strategies.

Furthermore, the transport impacts on sustainability should be considered in future research as part of the evaluation criteria. By comparing the existing studies to the sustainable transport objectives (Victoria Transport Policy Institute, 2017), it was revealed that the existing studies have rarely considered all the sustainability aspects but rather focus on one or two of them. This review has also found that the

social sustainability has been commonly overlooked by the reviewed studies and the social impacts of urban logistics interventions should be attached more importance in urban logistics studies. For example, aesthetics (e.g., street or roadway aesthetic conditions), community cohesion (e.g., quality of sidewalks, streets and parking lots, traffic volumes on local roads, the amount of walking that occurs in a neighbourhood, and mixed land use that increase social interactions, etc.), and mobility disadvantaged (e.g., quality of transport facilities and services for people with disabilities) are hardly considered in the reviewed studies.

Meanwhile, some other social impacts were considered in the studies but not measured. For example, community liveability (e.g., safety and security), affected by many public policy and planning decisions, were mentioned in some of the reviewed studies, but no quantitative or qualitative indicators were applied to measure the impact. Similarly, the criterion of human health impacts, which is affected by the use of active transport modes like walking and cycling, was not measured in related studies.

It should be noted that output of traffic simulation tools typically focuses on economic and environmental factors instead of social factors like noise, human health, and local liveability. This may explain the above observations as the social impacts of an intervention will most likely require additional evaluation methods (e.g., survey and interview) to the outcome of traffic simulation. However, it would be advantageous for future research to investigate the joint impacts on economic, environmental, and social sustainability of urban logistics interventions and reach a balance among the sustainability objectives.

8. Conclusions

This paper presented a systematic literature review, analysing 79 selected articles published by December 2023 that have used traffic simulation approach to model and evaluate a wide range of city logistics interventions. The review provided a rigorous and comprehensive discussion of existing literature from multiple perspectives. By classifying city logistics interventions into different categories, we examined the development and trends of the domain. An emphasis was put on the context, input parameters, and performance indicators in the reviewed traffic simulation studies. The outcomes of the reviewed articles were also analysed from the perspective of transport sustainability objectives (economic, environmental, social) to identify interventions that have greater joint benefits in improving transport sustainability in the long-term. The analyses provided in this article have shown that traffic simulation is versatile in city logistics studies, which already utilised various traffic simulators and tools, applied different modelling and simulation scales, and used the traffic simulation approach for various purposes. Meanwhile, these analyses point to a number of gaps and practical suggestions for future research to generate more impactful results, considering the leverage and quality of traffic simulation, the transparency of data collection and simulation input, the trends of urban logistics intervention and future innovation, as well as the standardised evaluation of study outcomes.

Author contributions

Yijie Su, Hadi Ghaderi and Hussein Dia: Paper conceptualisation, planning and formalization of research methodology. Yijie Su: Undertaking the systematic literature review, generation of results, formal analysis of findings, visualization of results and drafting of paper content. Hadi Ghaderi and Hussein Dia: Verification of results and outputs, critical evaluations and editing. Yijie Su: Paper re-drafting and restructuring. Hadi Ghaderi and Hussein Dia: Research management, supervision, and mentoring of PhD student.

Funding

This research is funded by iMOVE CRC and supported by the

Cooperative Research Centres program, Australia an Australian Government initiative. Yijie Su acknowledges her PhD scholarship provided by iMOVE CRC and tuition fee scholarship provided by Swinburne University of Technology, Australia.

Data availability statement

The full set of data used in this analysis can be accessed publicly to ensure transparency and allow other researchers to verify and reproduce

the results presented in this paper. The data can be accessed from this link: https://www.dropbox.com/scl/fi/jb9addi68bzppxp7qef4/SLR-d_ata_revised.xlsx?rlkey=ykpse9se2e5pp8j6dzmi6dnjb&dl=0.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Analysis on the reviewed studies from simulation perspective

Papers	Context of case study	Data input to simulation	Method of data collection for simulation input
Adeniran et al. (2023)	Berlin, Germany	Synthetic	Others
Alho et al. (2018)	Lisbon, Portugal	Real-world	Survey, Observation, Others
Aschauer and Starkl (2010)	Linz, Austria	Synthetic	Observation, Others
Aschauer and Starkl (2014)	Linz, Austria	Synthetic	Others
Barceló et al. (2008)	Barcelona, Spain	Not specified	Not specified
Bashir and Zlatkovic (2021)	Rock Springs, Evanston, and Rawlins, United States	Real-world	Observation
Bean and Joubert (2020)	Cape Town, South Africa	Synthetic	Not specified
Bean and Joubert (2021)	Cape Town, South Africa	Synthetic	Not specified
Beliaev et al. (2022)	Sioux Falls, United States	Synthetic	Others
Bell et al. (2023)	Berlin, Germany	Synthetic	Others
Ben Rajesh and John Rajan (2020)	Bangalore, India	Real-world	Survey, Observation
Bhuiyan et al. (2015)	Montreal, Canada	Real-world	Others
Bienzeisler et al. (2022)	Hanover, Germany	Synthetic	Others
Billhardt et al. (2022)	N/A (artificial network)	Artificial	Artificial
Boussier et al. (2011)	La Rochelle, France	Synthetic	Survey, Others
Choubassi et al. (2016)	Austin, United States	Synthetic	Others
Chowdhury et al. (2023)	Toronto, Canada	Synthetic	Others
Cokyasar et al. (2021)	Chicago, United States	Real-world	Interview
Deflorio and Castello (2017)	Turin, Italy	Not specified	Not specified
Deflorio et al. (2015)	N/A (artificial network)	Artificial	Artificial
Ewert et al. (2021)	Berlin, Germany	Synthetic	Others
Gopalakrishnan et al. (2020)	Singapore, Singapore	Real-world	Others
Haas and Friedrich (2021)	N/A (artificial network)	Artificial	Artificial
Hammami (2020)	Grenoble, France	Synthetic	Survey, Interview
Hao et al. (2021)	Carson, United States	Real-world	Others
Jahn et al. (2021)	Berlin, Germany	Not specified	Not specified
Jiang and Mahmassani (2014)	Chicago and Fort Worth, United States	Not specified	Not specified
Joubert (2019)	N/A (artificial network)	Artificial	Artificial
Karakikes and Nathanail (2022)	Volos, Greece	Synthetic	Observation, Others
Karakikes et al. (2018)	Volos, Greece	Synthetic	Observation, Others
Karatsoli et al. (2019)	Volos, Greece	Synthetic	Observation, Others
Kari et al. (2014)	N/A (artificial network)	Artificial	Artificial
Kickhöfer and Nagel (2016)	Munich, Germany	Synthetic	Others
Kiouis et al. (2019)	Athens, Greece	Synthetic	Others
Krendeleva et al. (2023)	Bari, Italy	Artificial	Artificial
Kwon and Jeong (2022)	N/A (artificial network)	Artificial	Artificial
Liedtke et al. (2015)	Tokyo, Japan	Synthetic	Survey, Others
Liu and Kim (2019)	N/A (artificial network)	Real-world	Others
Llorca and Moeckel (2021)	Munich, Germany	Synthetic	Others
Lopez et al. (2019)	Lyon, France	Synthetic	Survey, Others
Maciejewski and Nagel (2012)	N/A (artificial network)	Artificial	Artificial
Martins-Turner and Nagel (2019)	Berlin, Germany	Synthetic	Others
Martins-Turner et al. (2019)	Berlin, Germany	Synthetic	Not specified
Martins-Turner et al. (2020)	Berlin, Germany	Synthetic	Others
Maxner et al. (2023)	Seattle, United States	Synthetic	Others
McLeod and Cherrett (2011)	Winchester, United Kingdom	Real-world	Observation, Others
Melo (2011)	Porto, Portugal	Real-world	Survey
Melo and Baptista (2017)	Porto, Portugal	Real-world	Survey, Observation
Melo et al. (2013)	Porto, Portugal	Real-world	Observation
Melo et al. (2017)	Lisbon, Portugal	Real-world	Observation, Others
Melo et al. (2019)	Porto, Portugal	Real-world	Observation, Others
Mepparambath et al. (2023)	Singapore, Singapore	Synthetic	Survey
Mommens et al. (2018)	Flanders, Brussels and Wallonia, Belgium	Real-world	Others
Mommens et al. (2021)	Belgium	Synthetic	Survey, Others
Naeem et al. (2023)	Islamabad, Pakistan	Synthetic	Others
Nourinejad et al. (2014)	Toronto, Canada	Real-world	Survey, Observation
Ochoa-Olán et al. (2021)	Queretaro, Mexico	Real-world	Survey, Observation, Others
Orozco and Barcelo (2011)	Barcelona, Spain	Synthetic	Not specified
Qureshi et al. (2011)	N/A (artificial network)	Artificial	Artificial
Rifki et al. (2020)	Lyon, France	Synthetic	Observation, Others

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(continued)

Papers	Context of case study	Data input to simulation	Method of data collection for simulation input
Rossolov et al. (2019)	Brovary, Ukraine	Not specified	Not specified
Sakai et al. (2020)	Singapore, Singapore	Synthetic	Survey, Interview, Observation, Others
Sakai et al. (2023)	N/A (artificial network)	Synthetic	Others
Samudio Lezcano et al. (2023)	Seattle, United States	Synthetic	Others
Sasaninejad et al. (2023)	N/A (artificial network)	Synthetic	Not specified
Savado and Beziat (2021)	Lyon, France	Synthetic	Others
Schlenker et al. (2020)	Berlin, Germany	Synthetic	Others
Simoni and Claudel (2018)	Austin, United States	Synthetic	Others
Simoni et al. (2020)	Rome, Italy	Real-world	Interview, Others
Stolfi et al. (2018)	Malaga, Spain	Synthetic	Others
Ukkusuri et al. (2016)	New York City, United States	Synthetic	Observation, Others
Validi et al. (2020)	Linz, Austria	Synthetic	Others
Walker and Manson (2014)	Aviemore, Dalkeith, Glasgow, and Livingston, United Kingdom	Synthetic	Observation
Wang et al. (2004)	Singapore, Singapore	Artificial	Artificial
Winkler et al. (2022)	Berlin, Germany	Synthetic	Others
Xie et al. (2022)	Melbourne, Australia	Synthetic	Observation, Others
Zhang et al. (2018)	Berlin, Germany	Real-world	Others
Zhao and Ioannou (2016)	Long Beach, United States	Real-world	Not specified
Zhao et al. (2019)	Beijing, China	Synthetic	Survey

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