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Last mile logistics: Research trends and needs

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Aspiring green agendas in conjunction with tremendous economic pressures are resulting in an increased attention to the environment and technological innovations for improving existing logistics systems. Last mile logistics, in particular, are becoming much more than a consumer convenience necessity and a transportation optimization exercise. Rather, this area presents a true opportunity to foster both financial and environmental sustainability. This paper investigates recent technological advancements and pending needs related to business and social innovations, emphasizing green logistics and city logistics concepts. We discuss various pertinent aspects, including drones, delivery robots, truck platooning, collection and pickup points, collaborative logistics, integrated transportation, decarbonization and advanced transport analytics. From a mathematical perspective, we focus on the basic features of the vehicle routing problem and some of its variants. We provide recommendations around strategies that may facilitate the adoption of new effective technologies and innovations.

Keywords: last mile logistics; freight transportation; vehicle routing problem; sustainability; operational research; literature review.

1. Introduction

In recent years, the vulnerability of supply chains and transportation networks was exposed at a time when the demand for last mile logistics services soared. While COVID-19 has been a significant threat to almost everything as part of modern life, relevant operational responses have been almost exclusively reactive than proactive. Similarly, the logistics networks connecting us to goods have been under immense pressure due to increased online shopping. The value of public and private partnerships for the environment and technology integration has never been more crucial for the transport industry. As customers ask for fast and reliable last mile delivery, bringing technological innovation into sustainable transportation systems is urgently needed. Before the pandemic, the logistics industry was under pressure to improve their operations for cost reduction and profit making in a highly competitive market while dealing with unending requirements of their customers. For example, in their research, Gevaers *et al.* (2014) investigated the cost characteristics of last mile delivery services. In order to quantify the costs, their proposed simulation model considered the level of customer service, type of delivery, geographical area, market, density, fleet and the environment. It is highlighted that the last mile-related costs can differ greatly depending on these factors.

Environmental sustainability has never attracted equal focus compared with the economic priorities of retailers and logistics service providers (LSPs). It is now time to consider both financial and environmental sustainability in an attempt to escape from the disastrous impact of the pandemic and be ready for the future. There is an excellent opportunity to make changes and improve the design and operations of freight transportation soon as discussed in Meersman & Van de Voorde (2019). Looking at the vulnerability of the logistics systems, the logistics industry needs to make the best use of available resources to ensure a sustainable future for all. Green logistics has been one of the most studied topics in the last decade, and it has brought various ideas and algorithms for tackling emissions, particularly greenhouse gases (GHGs) (Dekker *et al.*, 2012; Demir *et al.*, 2014; Marrekchi *et al.*, 2021; Moghdani *et al.*, 2021). We can extend this area of research by looking at the latest technological, social and business innovations as a remedy to last mile problem.

Freight transportation manages the complete operation of the movement of freight and related resources from a starting location to a final destination by paying particular attention to customers' requirements (Ghiani *et al.*, 2013; Toth & Vigo, 2014). In practice, traditional LSPs aim to manage these activities at the lowest possible logistics cost and risk to be a preferable option for shippers and customers. Therefore, it is essential to optimize the whole logistics network, considering the characteristics of each component used in freight transportation. As noted in the literature, there are two main areas in freight transportation based on the coverage area of distribution/collection services. These two types of transportation are called long-haul and short-haul transportation. In long-haul transportation, freight is transported over a long distance (i.e. minimum hundreds of kilometres). Short-haul transportation is referred to as a small distance delivery within a city or region. This paper focuses on short-haul transportation as it is the most crucial part of the supply networks and the most relevant one for last mile logistics.

Due to the unprecedented increase in e-commerce and accessibility of goods via the Internet, the role of LSPs has become more critical in the supply network. The Swiss Reinsurance company estimates that the population living in areas classified as urban will increase by approximately 1.4 billion to 5 billion from 2011 to 2030 (DHL, 2014). This will make the logistics systems more complicated than before. The cheapest delivery to satisfy customers' needs has been the top priority for the logistics industry. Nowadays, the commitments for on-time delivery and reduced or net-zero emission (GHGs and air pollutants) are also becoming very important targets in a competitive and cost-driven logistics market (Savelsbergh & Van Woensel, 2016).

As the most crucial part of the supply network, the road transportation mode is the most used and preferred option by the logistics industry. The whole process in road freight needs to deal with several decision-making stages. At the lowest level (operational-level) of planning, the Vehicle Routing Problem (VRP) has been extensively studied since the original work by Dantzig & Ramser (1959). The main objective in this problem is to obtain a set of routes for vehicles starting and ending at a depot to visit customers' locations. The problem also considers several practical operational constraints. These may include vehicle capacity or compartment volume, distance or duration, customers' time windows (i.e. hard or soft), and other related customer, product, resource or LSP-related specific requirements.

Traditionally, the minimization of the travelled distance was considered as the main objective in the VRP literature. With the increasing emphasis on the environment, the interaction of operational research with automotive engineering highlighted various factors to accurately estimate fuel consumption. This interaction has to lead to the development of green logistics (and green vehicle routing as a sub-category) topic in the operational research literature (Demir *et al.*, 2014; Moghdani *et al.*, 2021).

Another positive impact on freight transportation from the effects of increased e-commerce sales is the acceleration of the adoption of technological innovation for the industry. Seamless delivery and the use of new alternative resources, such as drones, delivery robots and truck platooning have led to new opportunities for the logistics industry. This paper presents a brief discussion on how the last mile logistics have evolved around green logistics (or sustainability) and technological innovations in recent years. This discussion will highlight the current achievements and the outlook of future needs on last mile logistics. We note that our focus is mostly on vehicle routing optimization and related developments in the context of last mile logistics. Other aspects of last mile logistics, such as the location problems and humanitarian logistics, are not covered in this paper.

The scientific and visionary contributions of this paper is threefold: (i) to discuss the importance of green vehicle routing and city logistics for the last mile delivery, (ii) to briefly introduce the VRP and some of its variants, (iii) to review the latest technological developments in last mile logistics. The remainder of this 'positioning' paper is organized into five sections. Section 2 presents a brief review on green vehicle routing, whereas section 3 discusses recent research in city logistics. Section 4 provides relevant VRPs along with an example of VRP mathematical formulation. In section 5, we discuss contemporary topics related to last mile logistics. Conclusions and the outlook of future research needs on last mile logistics are provided in section 6.

2. Green logistics and sustainability

This section discusses how green logistics (and sustainability) is shaping the planning of vehicle routing activities from the last mile perspective.

Green logistics is an area that focuses on manufacturing and delivering freight to avoid the depletion of scarce natural resources. We focus only on the distribution part of green logistics in this paper. From this standpoint, green vehicle routing is a specific research domain in green logistics that studies VRPs and related negative externalities. In this research domain, vehicles running on petroleum-based fuels (petrol or diesel) or alternative cleaner fuels are explicitly considered for a better and more efficient route planning.

The most studied negative externalities are GHG emissions. They are primarily generated from power stations, transportation and industrial processes. As the primary reference metric, the CO_2-equivalent (CO_2e) is used to compare emissions based on their global warming potential by translating other gases to the equivalent amount of CO_2. More specifically, all gaseous emissions from transportation can be converted to the amount of CO_2 needed to create the same effect as CO_2e. The reduction of emissions is an essential topic for obvious reasons, and governments are trying to tackle this problem. Since 2016, transportation has become the largest emitting sector in the UK. The UK's transportation sector was accountable for 27% of the total-generated emissions in 2019. Of the total emissions, a large share of emissions (91%) came from road transport vehicles in the same year (BEIS, 2021). With regards to freight transportation, heavy goods vehicles were responsible for 18% of road transport emissions (equivalent to 19.5 MtCO_2e), and delivery vans were responsible for 17% of emissions (equivalent to 19 MtCO_2e). While road transportation was one of the sectors most affected by the pandemic, emissions are likely to increase as transport demand increases. Next to the generation of GHGs, the logistics industry also generates large amounts of air pollutants. These include particulate matter, CO (carbon monoxide), ozone (O_3) and hazardous air pollutants.

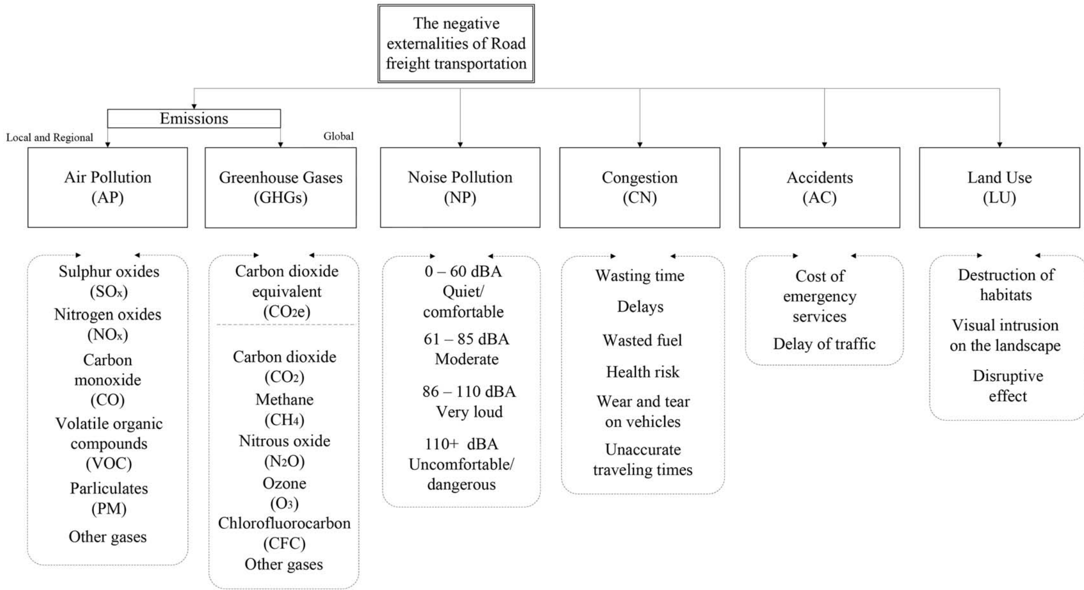

FIG. 1. The most common negative externalities of road transportation. Source: Demir *et al.* (2015).

As CO_2 or CO_2e is directly proportional to fuel consumption, the generated (on-road) emissions can be calculated by looking at the fuel consumption rate. The ultimate goal in green vehicle routing is to produce greener transportation plans (or routes) based on fuel consumption estimation. However, the methodology for calculating emissions can be in different forms than each other. For example, vehicle-generated emissions depend on various factors, including vehicle occupancy and age, fuel type, engine temperature, vehicle speed and load. However, from an operational planning perspective, vehicle payload and speed are the more relevant and controllable factors in routing. Such discussions have started the green vehicle routing domain as various factors and methodologies are available in the literature. Significantly, the interest in fuel consumption modelling within routing domain has created a great deal of research in the operational research domain.

Next to emissions, the literature has also focused on other types of negative externalities. The other negative externalities of freight transportation include noise pollution, traffic congestion, road accidents and excessive land use. We refer the interested readers to literature on (see, e.g. Brons & Christidis, 2012; McAuley, 2010) for more details. Later, Demir *et al.* (2015) has also developed a comprehensive framework for negative externalities of road freight transportation as shown in Figure 1.

Figure 1 presents the details of negative externalities of road transportation. As highlighted in the figure, the focus should be on emissions, and all other externalities of transportation should be carefully considered through better and more efficient transport planning. We note that there is good progress on GHGs-related studies in the literature, but more research is needed for other types of negative externalities. From the supply chain management perspective, there is also good progress on sustainability. For example, Luis *et al.* (2021) developed an optimization model for a sustainable closed-loop supply chain network with conflicting objectives (i.e. the minimization of the total logistic costs and the total amount of carbon emissions). The authors provided a mathematical model and matheuristic algorithm to investigate the trade-offs between conflicting objectives.

The birth of green VRPs in the operational research domain has created various analytical methods for making better decisions in last mile logistics. Various authors have proposed mathematical formulations and solution algorithms tailored specifically for the reduction of emissions. Next to distance-minimization in routing problems, authors in this domain have proposed more comprehensive objective functions and dealt with more practical constraints. For example, vehicle speed and payload have become the most important decision variables for reducing emissions. Using different type of emissions modelling for the calculation of emissions required more complex and advanced analytical techniques. In their study, Leenders *et al.* (2017) investigated the allocation of emissions to a specific shipment in routing by considering more advanced fuel consumption formulae. The authors looked at terrain, distance, payload and the fuel consumption rates of empty and loaded vehicle. Their research highlights the importance of considering more holistic approach for estimating emissions and fuel consumption. Considering the complexity of fuel consumption modelling, there is still need for in-depth research for developing advanced methodologies, including exact and approximations methods.

3. City logistics

This section briefly discusses how city logistics became an essential area of research in the logistics literature.

Logistics management is a complex but crucial activity. It includes supply, distribution, production and reverse logistics. Each of these dimensions looks at a different aspect of the supply network. The focus of our paper is the distribution of goods to customers. The e-commerce hype in the last decade has fundamentally changed the way customers purchase and consume products, and the expectations for delivery has also similarly changed over the years. Before the pandemic, 35% of industrial leasing could be attributed to the e-commerce business. In 2020, the e-commerce logistics market had grown more than 27%. To sustain profitable and environmental last mile delivery in urban areas, the topic of city logistics has gained more popularity in the transport industry. In simple terms, city logistics is considered the delivery and/or collection of parcels in cities. It also promotes cleaner transportation modes (i.e. rail, maritime), new handling and storage processes, reduced inventories and waste, reverse logistics, attended delivery, next-day, same-day and instant delivery services. From an operational perspective, the performance of city logistics requires seamless planning of vehicle routes to reduce empty miles, unnecessary driving and idling. In addition, city logistics operations require more efficient, light and modular vehicles that run on alternative or cleaner energy.

Similar to green vehicle routing, city logistics also pay attention to the environmental impact of all logistical operations in an urban environment. Savelsbergh & Van Woensel (2016) discuss the importance of city logistics for urban development. The authors also pointed out the requirements of city logistics, such as connectivity, big data and analytics, automation and automotive technology. Other aspects of city logistics are discussed by Taniguchi & Thompson (2018), who particularly look at the impacts of city logistics on the environment.

One of the main tasks in city logistics is to establish coordination and consolidation opportunities between different stakeholders and it is a crucial success factor for the city logistics. Next to finding the right location decision, there is also need for zero and low-emission zones within urban areas (see, e.g. Lurkin *et al.*, 2021). The classic approach of running smooth city logistics activities is to consolidate freight volumes outside the city without creating unnecessary trips. Normally, the term urban distribution centres is used to refer these specific locations outside the city. From these locations, the handled freight is then moved into the cities using cleaner and alternative vehicle technologies or services. This two-level problem is also known as two-echelon distribution problem in the literature. By adding more distribution centres closer the cities, the supply chain can be extended to improve efficiency of both upstream and downstream (Savelsbergh & Van Woensel, 2016). For a recent review paper we refer to Sluijk *et al.* (2022). In the next section, we define the most applicable VRP formulation for the last mile logistics.

4. Vehicle routing problems

A fundamental last mile problem is to find a set of routes to serve a set of customers located in a geographical region. As the problem has many dimensions, such as a vehicle, operation, driver and fuel type, many studies focus on various dimensions of routing.

The VRP deals with designing vehicle routes subject to various constraints. The basic assumptions of the VRP can be listed as follows: (i) vehicle(s) must start and end at the same depot; (ii) each customer must be visited only once by a vehicle and (iii) the total payload in a vehicle must not surpass the available vehicle capacity. These assumptions are the basic features of the standard VRP. Due to customers' requirements and operational challenges in last mile logistics, various VRPs and mathematical formulations have been proposed in the literature. We refer to studies on VRP and its variants for more details, see e.g. Toth & Vigo (2014); Vidal *et al.* (2020). There are also other studies that look at more several practical constraints. For example, Derigs & Pullmann (2016) studied different strategies for the solution of a variety of rich VRPs with regards to solution quality and speed. The authors proposed variable neighbourhood search algorithm by considering several modules for different types of VRP features.

The standard VRP with distance minimization is known as the capacitated VRP (CVRP) and it can be defined mathematically as follows. We assume that a complete graph $G = (N, A)$ includes node set $N = \{0, 1, 2, ..., n\}$ and arc set $\in A = \{i,j : i,j \in N, i \neq j\}$. Each node (customer) $i \in N\backslash\{0\}$ is defined with a demand q_i. The depot is considered as node 0. All homogeneous vehicles (m) are located and available at the depot. Each arc $(i,j) \in A$ is quantified with a distance d_{ij} between nodes i and j. Moreover, the vehicle capacity is denoted with Q. The objective in the CVRP is to obtain a set of vehicle routes with the lowest total travelling distance. The closest CVRP variant is the distance constrained VRP (DVRP). In the DVRP, capacity-related constraints are changed with other constraints such that the length of a route must not surpass the defined distance range.

Another practical VRP variant is known as the VRP with pickup and delivery (VRPPD). This problem is finding a set of vehicle routes for a group of requests. This can be very relevant for LSPs who wish to simultaneously or subsequently serve pickup and delivery customers in the same route. There are also other variants of the VRPPD available in the literature. In the case of real-time vehicle routing optimization, dynamic VRP formulations can be used for dispatching vehicles to serve customers. Some parts of the transport plan must be decided beforehand, and the plans may need to be revised regularly in practice. This makes the routing problem more complex but practical for the logistics industry.

Another important variant is known as the production routing problem in the literature. This problem considers a more complex but practical planning problem that jointly optimizes production, inventory, distribution and routing. In the study of Shahrabi *et al.* (2021), the authors studied the same problem with time windows, deterioration and split delivery. The authors specifically looked at the bi-objective (i.e. economic and social sustainability) model for a single product. They also proposed an interval robust approach and extensive analysis are conducted on a real-life case on a food factory.

The most relevant extension of the VRP in last mile logistics is the VRP with time windows (VRPTW). Next to customer's demand, each customer should also be served within predefined time intervals. For all locations (a set of customers and depot) $i(i \in N_0)$, a time window $[a_i, b_i]$ is defined. In this delivery problem, each customer has to be served within this interval. The delivery should begin at customer $i(i \in N_0)$ just after the lower bound of time window a_i but not later than the upper bound of time window b_i. Also, if the vehicle arrives at customer i location before the start a_i, the vehicle should wait the time a_i to commence delivery.

As an example VRP model formulation, a mixed-integer linear programming model for the VRPTW is presented below. The following decision variables are used for the model.

First, the notation x_{ij} (binary variable) gets the value of 1 if and only if arc (i, j) is chosen. Second, the notation f_{ij} (continuous variable) shows the total payload on arc $(i, j) \in A$ and the notation (continuous variable) y_j is the service start time at node $j \in N_0$. And finally, the notation (continuous variable) s_j is the total time used on a route including $j \in N_0$ as the last customer.

$$\min \sum_{i,j \in N} d_{ij} x_{ij} \tag{4.1}$$

subject to

$$\sum_{j \in N} x_{0j} = m \tag{4.2}$$

$$\sum_{j \in N} x_{ij} = 1 \qquad \forall i \in N_0 \tag{4.3}$$

$$\sum_{i \in N} x_{ij} = 1 \qquad \forall j \in N_0 \tag{4.4}$$

$$\sum_{j \in N} f_{ji} - \sum_{j \in N} f_{ij} = q_i \qquad \forall i \in N_0 \tag{4.5}$$

$$q_j x_{ij} \leq f_{ij} \leq (Q - q_i) x_{ij} \qquad \forall (i, j) \in A \tag{4.6}$$

$$y_i - y_j + t_i + t_{ij} \leq K(1 - x_{ij}) \qquad \forall i \in N, j \in N_0, i \neq j \tag{4.7}$$

$$a_i \leq y_i \leq b_i \qquad \forall i \in N_0 \tag{4.8}$$

$$y_j + t_j - s_j + t_{ij} \leq L(1 - x_{j0}) \qquad \forall j \in N_0 \tag{4.9}$$

$$x_{ij} \in \{0, 1\} \qquad \forall (i, j) \in A \tag{4.10}$$

$$f_{ij} \geq 0 \qquad \forall (i, j) \in A \tag{4.11}$$

$$y_i \geq 0 \qquad \forall i \in N_0. \tag{4.12}$$

The objective function (4.1) is the minimization of the total distance. Constraints (4.2) ensure that a vehicle must departure from the depot. Constraints (4.3) and (4.4) are the degree constraints to ensure each customer is visited one time only. Constraints (4.5) and (4.6) state the flows of payload on each arc chosen in a solution. Constraints (4.7)–(4.9), where K and L are large numbers. They also ensure the time window features of the problem. Constraints (4.10)–(4.12) define non-negativity conditions.

5. Current trends and business and social innovations

This section provides a discussion on recent trends and developments in the last mile logistics. More specifically, we discuss how these contemporary topics affect last mile logistics practices.

When considering new technological instruments for adoption, one may consider the 'Law of Disruption' model, which is proposed by Downes (2009). The author explains how digital life has changed and how technology develops exponentially while social, economic and legal systems change incrementally. This law presents a pattern of how different types of change manifest themselves. The author also points out that technological innovations are generally ahead of social and political change. As in other industries, we can also expect regulatory barriers or negative public perception to remain in effect in the next 5–10 years for the logistics sector. This is more or less the case for all technologies and innovations discussed here. Especially, there is a need for mathematical proofs and evidence before the actual implementation. Mathematical modelling and optimization can help promoting these technologies and innovations by providing quantitative justification. More research can aid policy makers and governments to take action for greener transportation, especially within populated urban areas. We will now discuss some of these latest developments to attract more attention to current technologies and environmental concerns.

5.1 *Unmanned aerial vehicles (drone)*

An unmanned aerial vehicle (UAV) is an aircraft without any pilot. It can be fully or partially autonomous. This new technology is available for use in freight transportation, and a wide range of research is available in the literature. Interested readers are referred to original review papers on UAVs by Macrina *et al.* (2020); Rojas Viloria *et al.* (2021) and Rovira-Sugranes *et al.* (2022).

In a recent study, Kundu *et al.* (2021) studied a variant of the travelling salesman problem (TSP) as denoted flying sidekick TSP. In this variant, the authors consider a single vehicle case using only one drone to serve customers. In this problem setting, drone can be launched from the vehicle at customer location. The driver and drone can simultaneously deliver packages. The authors propose a novel split algorithm and heuristic method to the studied problem. Freight transportation can benefit from UAVs as they can be used to deliver goods in the last mile (DHL, 2014). Primarily, customers are interested in receiving their orders with the use of UAVs. Even though there are several advantages, it will not be easy to replace traditional road vehicle-only transportation soon. However, we have seen various small applications or trials of UAVs used in recent years. During the pandemic, companies have successfully deployed UAVs for last mile delivery. UAV technologies can be a sustainable option in the context of the last mile. These resources are already utilized by logistics and retailer companies, such as DHL International, United Parcel Service and Amazon.

From an operational perspective, UAVs can play a vital role in last mile logistics as they are fast and capable of carrying multiple packages in different weights. However, legal challenges and public perception need to be addressed before utilizing them in urban areas.

5.2 *Unmanned ground vehicles (delivery robot)*

An unmanned ground vehicle (UGV) is a type of vehicle that is operated on the ground without an onboard human presence. They can be used for transportation in urban areas to minimize delivery times.

As a practical solution, the integration of UGVs with delivery vans can offer greener solutions than using only delivery vans. As UGVs are powered by clean electricity, they do not produce emissions themselves. As a successful trial, Starship Technologies had been experimenting with the delivery system with UGVs in London in 2020. Chen *et al.* (2021) studied an urban delivery problem using robots as assistants. In their delivery system, the traditional delivery van serves the customer and acts as a mothership for its robots in the meantime. When the van is parked, robots can be dispatched to their target customer(s) and return to the same place where they depart from to rendezvous with the mothership van. This is a very realistic example of UGVs' use in practice.

From an operational perspective, UGVs have particular advantages over UAVs. Since most UAVs are powered by small-capacity batteries that last less than half an hour (on average), their capacities and flying ranges are quite limited. However, UGVs have more loading capacity, and their range is much more than UAVs. With an integrated delivery van and UGVs, drivers can also supervise UGVs in certain areas, which is not the case for UAVs.

5.3 *Collection and delivery points*

As an alternative solution in urban areas, collection and delivery points can improve the logistics efficiency and reduce emissions. Especially, in populated city centres or in the proximity of heavy footfall areas, these points can be preferred by customers. In the study of Janjevic *et al.* (2019), the authors proposed a new method for the integration of collection and delivery points in the design of multi-echelon logistics systems based on a real-life case study. The benefits of using these systems are quantified by showing significant cost benefits for companies involved in last mile logistics.

Weltevreden (2008) studied collection and delivery points in the Netherlands and its consequences for other stakeholders. The author showed that these locations are most used for returning online orders. For retailers operating a service point may lead to additional revenues. In recent study, Kedia *et al.* (2020) looked at to identify the optimal density and locations for establishing collection and delivery points in New Zealand. The authors modelled the problem as a set covering problem by considering city demographics and travel distance between population centres and potential facility locations. New type of points such as dairies and supermarkets were found to be more accessible than traditional post shops.

5.4 *Truck platooning*

The arrival of autonomous vehicles is an opportunity to improve people's lives and protect the environment. These vehicles also contribute to advancing the sustainable development agenda. One of the application areas of autonomous vehicles is platooning, which links two or more vehicles (trucks) together to create a form of train. Generally, LSPs aim to make their operations more efficient by utilizing their resources (i.e. fleet, labour etc.) (Ghiani *et al.*, 2013). These companies are also paying close attention to their environmental footprint. Early adopters of truck platooning can bring a competitive advantage amongst LSPs. Countries are also interested in automation and, more particularly, truck platooning. Most of the autonomous vehicle projects in Europe are done by collaborating with different organizations and countries. Cooperation of actors, especially in the European Union (EU), is progressing well since EU countries have similar legislation.

Truck platooning will contribute to the transport industry, including improved traffic management, reduced operational costs and operations (Tavasszy & Janssen, 2016). Next to these advantages, truck platooning will also make the logistic operations more efficient and optimize the labour market. Platooning will also optimize the supply network from a higher perspective. This will eventually reduce CO_2e emissions and minimize congestion by improving traffic flows with reduced tailbacks. Truck platooning can be more efficient for longer distances and heavy good vehicles. The possibility to platoon with different trucks or multi-brand platooning is also needed to form vehicles in a platoon successfully.

5.5 *Collaborative logistics*

Generally, last mile delivery solutions are individually managed by retailers and LSPs. Due to competitiveness of the last mile delivery market, there is little room for joint and synchronized solutions. Collaborative logistics can address the challenges of last mile by increasing cost efficiency and utilization. The major challenge in last mile logistics is that the demand points are often located in highly congested urban areas and they are quite far from distribution centres. In the study of De Souza *et al.* (2014), the authors looked at industry alignment through a synchronized marketplace concept by using clusters of customers, suppliers and service providers in Singapore.

Park *et al.* (2016) studied the collaborative delivery problem to measure the effects of collaboration for apartment complexes in Korea. Potential benefits are also quantified in this study and the role of the public sector is considered to be essential.

5.6 *Integrated transport*

As a promising business model, integrating freight flows with public scheduled transportation can be a viable option for freight transportation. A successful synchronization of delivery vehicles with scheduled public transport is directly related to coordination, which is the critical factor for seamless movement of freight in the last mile (Ghilas *et al.*, 2016).

As public transportation systems have particular coverage, specific delivery trips of delivery vans may overlap with the scheduled line services. Using public transportation instead of delivery vans may reduce transportation cost and create environmental benefits. Due to the shorter driving time of their delivery vans, LSPs may reduce their operational costs. Less travel time also leads to reduced amount of CO_2e emissions. It is not an easy task to coordinate both delivery vans and public scheduled lines from an operational perspective. However, this system can be a viable option for the industry, especially in rural areas.

5.7 *Decarbonization*

By definition, decarbonization in road freight reduces transportation-related activities' carbon footprint (GHGs). Reducing emissions in every industry is essential to ensure global temperature standards set by the Paris Agreement and governments. As the share of last mile increases due to e-commerce sales, more research and green thinking are needed for the industry.

In 2021, the Department for Transport of the UK published a policy plan on decarbonizing transport to meet the UK's net-zero targets (Department for Transport, 2021). Some of the proposed initiatives include: phasing out the sale of all new non-zero emission HGVs; demonstrating zero emission HGV technology on UK roads; stimulating demand for zero-emission trucks with financial and other incentives; supporting efficiency improvements and emission reductions in the current fleet; and also taking new measures to transform last mile deliveries. From this perspective, two technologies look prominent for last mile logistics. These include electric vehicles and green hydrogen, and these options could help reduce the environmental impact of last mile logistics.

5.8 *Towards transport analytics: the role of data and information*

The Internet of Things is known as the network of physical objects to enable data and information exchange between different physical and virtual objects. Last mile logistics and transportation can also benefit from information sharing on inventory, supply chain, resources and people. However, although promising, it is a great challenge to change the logistics systems and its related overwhelming daily operations. It requires the involvement of various stakeholders to act together for all types of operations.

It is important to consider different analytical approaches with information sharing capability for the last mile logistics. In the study of Krushynskyi *et al.* (2021), the authors investigate two policies to improve the efficiency of the LSP by allowing more flexibility in choosing the delivery locations. The considered policies include roaming vehicle routing and the second policy allows the possibility of aggregating certain locations. The problem is modelled as TSP real-life parcel delivery data are analyzed. The authors points out that the two proposed policies can lead to significant improvements in the route length.

In order to improve the efficiency of last mile logistics, all processes during the transportation should be improved. Such improvement can be achieved by using advanced analytics, artificial intelligence (AI) and blockchain systems. Historical logistics data can be utilized to proactively reduce the vulnerability of traffic networks and improve the communication between transport users with real-time data. For example, AI-enhanced decision-making capabilities can provide real-time information and actionable suggestions for the planning of vehicle routes. In a related study, Ozarik *et al.* (2021) studied VRP in which customer presence probability data are explicitly considered in the planning of routes. As the unavailability of customers is a major problem for the logistics industry, the real-time location information of customers can improve the delivery service and reduce the unnecessarily generated emissions.

6. Conclusion and recommendations

The last mile delivery is the most complicated part of the supply network. It deals with the movement of goods from a hub to their final destination. This is normally the customer's doorstep. It is essential to make the delivery as efficient as possible while minimizing all operational costs. Due to urbanization and population growth, this final step of transportation is becoming increasingly important. Customers prefer to have on-time delivery, and this might be a challenge for the industry because of various uncertainties. Because of these challenges, there is a growing need to provide LSPs with relevant evidence, strategies and decision-making tools to help them plan better.

Academic research in last mile logistics has successfully considered new trends and technological developments in scientific investigations. However, there is a need for more research focusing on more operational and tactical issues related to routing optimization. Our short positioning paper has looked at various dimensions of last mile logistics and discussed the outlook of future research needs by the industry.

The future of last mile logistics will be shaped by technology, innovation and customer requirements. There is already good progress for using advanced technology in logistics. Digitization, automation and robotic systems will help LSPs to handle last mile operations more efficiently. The industry will also pay more attention to sustainability and decarbonization as the share of emissions from transportation must be reduced sharply in the next 10 years in many countries.

Building upon findings of our research, we can make the following recommendations for the adoption of the latest technologies and innovations in the last mile logistics.

- The unending customer requirements must be addressed by promoting greener last mile delivery services through the use of advanced mathematical optimization techniques. In particular, there is a need for developing proactive and robust algorithms specifically designed for dynamic traffic environments.

- The negative externalities of freight transportation and social indicators must also be considered within route optimization along with economic indicators. There is good progress on the environmental sustainability, but more research is needed to tackle social sustainability.
- The barriers influencing the adoption of the latest technological solutions and innovations must be dealt with using quantitative data generated with the help of operational research techniques.
- AI-enhanced decision-making approaches should be used based on the available data for creating vehicle routes and schedules. The algorithms should be suitable for processing large amounts of data within reasonable solution times.

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