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Characterization and Design for Last Mile Logistics: A Review of the State of the Art and Future Directions

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Abstract: One of the most challenging problems in last mile logistics (LML) has been the strategic delivery due to various market risks and opportunities. This paper provides a systematic review of LML-related studies to find current issues and future opportunities for the LML service industry. To that end, 169 works were selected as target studies for in-depth analysis of recent LML advances. First, text mining analysis was performed to effectively understand the underlying LML themes in the target studies. Then, the novel definition and typology of LML delivery services were suggested. Finally, this paper proposed the next generation of LML research through advanced delivery technique-based LML services, environmentally sustainable LML systems, improvement of LML operations in real industries, effective management of uncertainties in LML, and LML delivery services for decentralized manufacturing services. We believe that this systematic literature review can serve as a useful tool for LML decision makers and stakeholders.

Keywords: last mile logistics; systematic literature review; last mile logistics innovation; logistics system design; logistics service characterization

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1. Introduction

The evolution of e-commerce markets has drawn great attention to various delivery service issues [1,2] which are intrinsically related to last mile problems. As last mile delivery services require various logistics elements to satisfy faster and more reliable delivery conditions [3], last mile problems have been treated as more inefficient, more expensive, and less environmentally-friendly issues than any other problems in supply chain networks [4]. Indeed, the last segment of supply chains has been increasingly fragmented and has caused additional delivery costs due to the distributed collection/destination locations of customers using e-commerce services [5]. The route from the shop to the courier or shipping agency that will handle the delivery is known as the first mile. In contrast, the transit of products from the shipping agency or transportation hub to the intended final destination is referred to as the last mile. The final delivery between the local parcel depot and the customer who has purchased goods traditionally accounts for up to 28% of the total shipping cost but the lack of economies of scale that makes the last mile costly and ineffective necessitates new last mile strategies and solutions [4,6]. In particular, over the last few years, the stakeholders of last mile deliveries have faced many challenges in providing strategic deliveries due to a wide variety of market risks (e.g., COVID-19 pandemic, urban population growth, densification, traffic congestion and safety, customers' behavior change, and greenhouse gas emissions) and opportunities (e.g., globalization, advanced transport systems, innovative information and communication technologies, Internet of Things, and Industry 4.0) [1,4,7–12]. Accordingly, last mile logistics (LML) that inevitably involve complex operations of last mile deliveries have been more critical in the modern logistics industry.

Issues in LML can be viewed from various geographical dimensions of logistics. Many consumers in urban areas require same-day and on-demand delivery services that involve LML for groceries, prepared meals, and retail purchases as LML can provide customers with convenience and flexibility [13]. Furthermore, LML suppliers in urban areas have experienced many challenges such as traffic congestion, limited delivery time, service regulations, inefficient delivery vehicle routing, and inappropriate supply chain network design [4,14,15]. Consequently, urban logistics should be addressed to enhance the economic, environmental, and social sustainability of LML [11].

Many reports have presented that economic growth, improvement of environmental sustainability, resolution of urban unemployment, safe urban freight transport, and regional economy development are particularly related to LML [10]. As such, an appropriate design for city logistics is considered essential to improve welfare in society [16]. For instance, the first mile in a city and the last mile to the final consignee can be operated by conventional trucks and environmentally friendly city freighters or technology-advanced delivery cars, respectively [17]. Furthermore, the high demand of LML delivery services has increased complexity in design of urban logistics [14,18]. In 2014, 54% of the world population already lived in cities or urban areas, and by 2050 a projected two thirds will be urban [19]. This means that more than six billion people globally will live in urban areas, which leads to great pressure on all aspects of urban planning, including LML [20]. The necessity of LML clearly shows that the overarching objective of LML efforts is to elevate the prosperity of city logistics while alleviating their emerging negative consequences [10,12]. In this regard, existing LML-related studies have provided a wide variety of approaches to solve last mile problems in urban areas.

This paper aims to provide a comprehensive and structured review of recent studies relevant to LML and focuses on operational as well as technological aspects. Our state-of-the-art review identifies various potentials and opportunities associated with LML-related research. Although individual studies have successively achieved the ultimate goal of LML, they tend to provide redundant and ambiguous concepts across critical LML terminology defined by different contexts and properties in supply chain management. In other words, there has been no widely agreed upon framework to characterize LML and its innovations in a supply chain, and only a few studies have investigated the conceptualization of LML to contemplate a comprehensive framework for practical LML services. In order to improve the operational efficiency of last mile applications and offer practical guidelines for future research, it is necessary to first develop consensus on the underlying characteristics and design for LML. Along with previous LML issues and approaches that have been primarily addressed in existing studies, major opportunities for more innovative design and development are suggested to motivate various future applications in this paper.

The rest of this paper is organized as follows. In Section 2, we introduce the methodology behind our systematic literature review. We employ a text mining of an extensive set of existing LML-related studies to effectively understand major themes in the literature as a basis for a comprehensive literature review. In Section 3, existing definitions and concepts of LML in the literature are examined to provide a standard definition of LML. Section 4 discusses four main issues (i.e., sharing economy, proximity stations/points and hubs, environmentally sustainable LML, and delivery technology innovation), which are identified from LML themes through text mining, are further reviewed in order to characterize current issues and approaches for LML. New opportunities for design and development of innovative LML are proposed in Section 5. Finally, Section 6 offers guidelines for practice and offers opportunities for future research.

2. Systematic Literature Review Methodology and Analysis

A literature review for LML was performed based on a systematic literature review procedure widely adopted in other domains [10,21]. First, the objective and scope of the literature review on LML were established. In this study, the main objective was to provide a systematic review of recent LML-related studies to investigate the definition and typology of LML, main issues and concerns in LML, and new opportunities for the next generation of LML. Based on a preliminary search of highly cited LML studies, significant keywords that include "last mile logistics", "urban logistics", "city logistics", "typology of last mile logistics", "last mile logistics innovation", "collaborative last mile logistics", "cooperative last mile logistics", "sustainable last mile logistics", and "robust last mile logistics" were identified to better search target research articles. Different combinations of these keywords using Boolean AND and OR operators were used to retrieve initial articles published between 2001 and the end of August 2021 in scientific platforms—EBSCO, Elsevier, Google Scholar, JSTOR, Science Direct, Springer, Web of Science, and Wiley Online Library. Examples of the keyword combinations for the literature search are ("last mile" AND "logistics"), ("last mile logistics" AND "urban logistics"), ("last mile logistics" AND city logistics"), ("last mile logistics" AND "innovation"), and ("collaborative last mile logistics" OR "cooperative last mile logistics"). Various research works including these keywords or their combination in the title, keyword list, or abstract were disclosed. Consequently, more than 400 research works written in English were collected as the initial article set for review. Next, the following search criteria were applied to refine the initial article set: (i) inclusion of research areas related to LML, and (ii) inclusion of peer-reviewed journal articles having meaningful keywords in their abstract. Then, 169 research articles from 84 unique journals were identified as LML studies that contributed to recent LML advances, but 15 journals were associated with more than three articles each (Figure 1). This indicates that a small number of journals dominate LML studies over most other journals. Finally, the 96 research articles which had more than 10 citations were selected as target articles. The literature demonstrates that LML is an emerging research area with rapid growth (Figure 2a). The black solid line and the green dashed line represent the total number of and the average number of publications, respectively, while the red line means the number of publications for each year. Moreover, Figure 2b shows the top eight countries producing the most LML research based on the affiliation of the first author. Furthermore, the top five articles in terms of the number of citations are [22] (476), Ref. [23] (331), Ref. [24] (243), Ref. [25] (236), and [26] (233). An overview of the literature review method used for this study is presented in Figure 3.

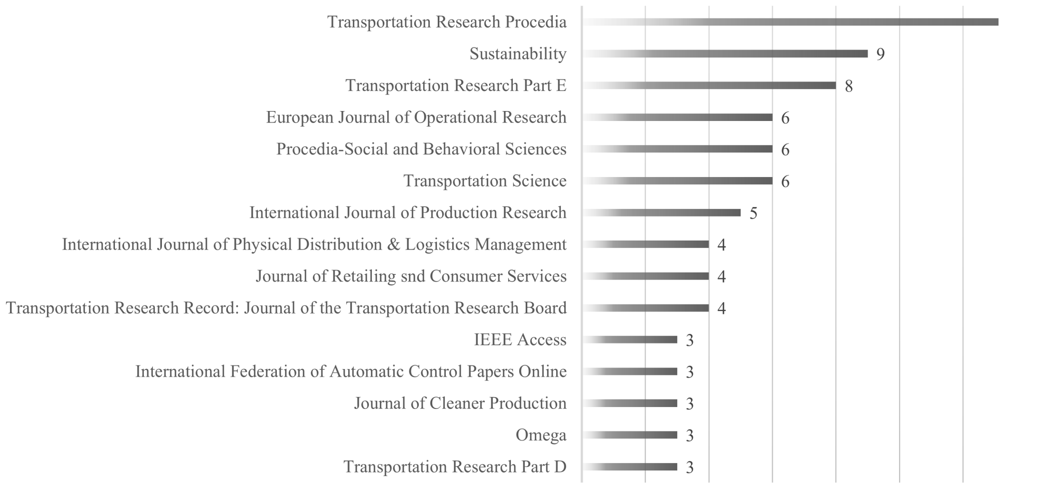
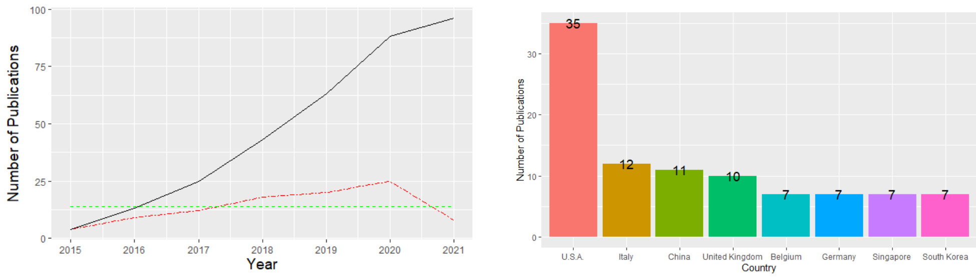


Figure 1. Top 15 journals according to the number of papers.

To better understand the underlying themes addressed in the target research article set, text mining analysis was performed using the following procedure. First, text data were collected from the title, abstract, and keywords of each article and separately saved to a text file. The set of text data was processed by the *tm* package for the *R* statistical program language [27] to standardize the text data; stop-words, whitespaces, numbers, and punctuation were removed from the original text dataset, and all letters were transformed to lower case. In addition, each word in the set of text data was stemmed by the *SnowballC* package [28] to regard word variants originated from the same root as the same term (e.g., "destin" for "destination" and "destinations"). As a result of the above pre-processing, an initial document-term matrix (F) was produced consisting of 96 target articles and 2616 terms in Equation (1). The individual frequency of 2616 terms observed from the target research articles was represented by the following ($m \times n$) sparse matrix:

$$F = \begin{bmatrix} f(a_1, t_1) & f(a_2, t_2) & \cdots & f(a_1, t_n) \\ f(a_2, t_1) & f(a_2, t_2) & \cdots & f(a_2, t_n) \\ \vdots & \vdots & \vdots & \vdots \\ f(a_m, t_1) & f(a_m, t_2) & \cdots & f(a_m, t_n) \end{bmatrix}, \quad (1)$$

where a_m refers to the mth target research article for all $m \in M = \{1, 2, \cdots, 96\}$, t_n is the nth term appearing in the set of articles a_m for all $n \in N = \{1, 2, \cdots, 2616\}$ and for all $m \in M$, and $f(a_m, t_n)$ is the frequency of term t_n in article a_m for all $n \in N$ and for all $m \in M$. The above procedure was performed by the application provided in [29].



(**a**) Publication year (**b**) Regional profile

Figure 2. Systematic review analysis of target research articles.

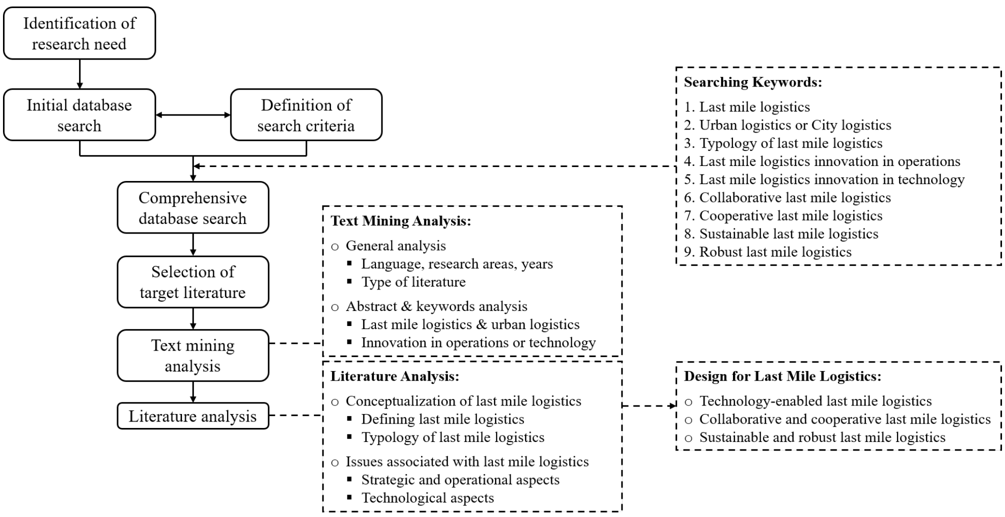


Figure 3. Framework for systematic literature review.

As common terms (e.g., last mile and logistics) that frequently appeared across the target research articles did not help explain specific features of the different works, the frequency $f(a_m, t_n)$ for all $m \in M$ and for all $n \in N$ was transformed into the Term Frequency-Inverse Document Frequency (TF-IDF) [30]. The TF-IDF transformation for a document-term matrix treats common terms frequently appearing in a specific set of articles as more important than common terms widely observed in most articles. First, TF-IDF values of each term for all the articles are calculated using Equation (2) and then averaged. Herein, the relative term frequency ($= t_n / \sum t_n$ of each article) was used to avoid a situation where a lengthy article has a high TF-IDF. Next, terms having a mean TF-IDF average were sorted to finalize the document-term matrix (F) using the equation in Equation (2):

$$f^*(a_m, t_{n^*}) = f(a_m, t_{n^*}) \times \log(|M|/|M_{t_n}|), \tag{2}$$

where t_{n^*} is the relative term frequency, $|M|$ is the cardinality of the target research article set M (i.e., $|M| = 96$), and $|M_{t_n}|$ is the cardinality of the set of articles, including the specific term t_n for all $n \in N = \{1, 2, \cdots, 2616\}$. The term selection based on TF-IDF was performed based on the R-codes provided by [31]. As a result, a new document-term matrix consisting of 96 target articles and 827 terms was generated for the term-frequency analysis of the target articles.

Figure 4 shows the 50 most frequent terms that describe significant features of the target research articles. Overall, the frequently appearing terms across the LML studies indicate that the 169 target research articles have focused on strategic and operational improvements in LML; for example, "hub", "omnichannel", "crowdsourc (e.g., crowdsource)", "platform", "collabor (e.g., collaborative)", "crowdship (e.g., crowdshipping)", "consolid (e.g., consolidation)", "alloc (e.g., allocation)", "energi (e.g., energy)", "stochast (e.g., stochastic)", "price", "global", and "profit". Furthermore, the frequency of terms shows that technological advances in LML are another main focus in the literature; for example, "smart", "autonom (e.g., autonomous)", "intellig (e.g., intelligent)", "electr (e.g., electric)", "drone", and "bike". This paper thus focuses on (i) strategic and operational aspects and (ii) technological aspects of LML to highlight research issues and identify future opportunities.

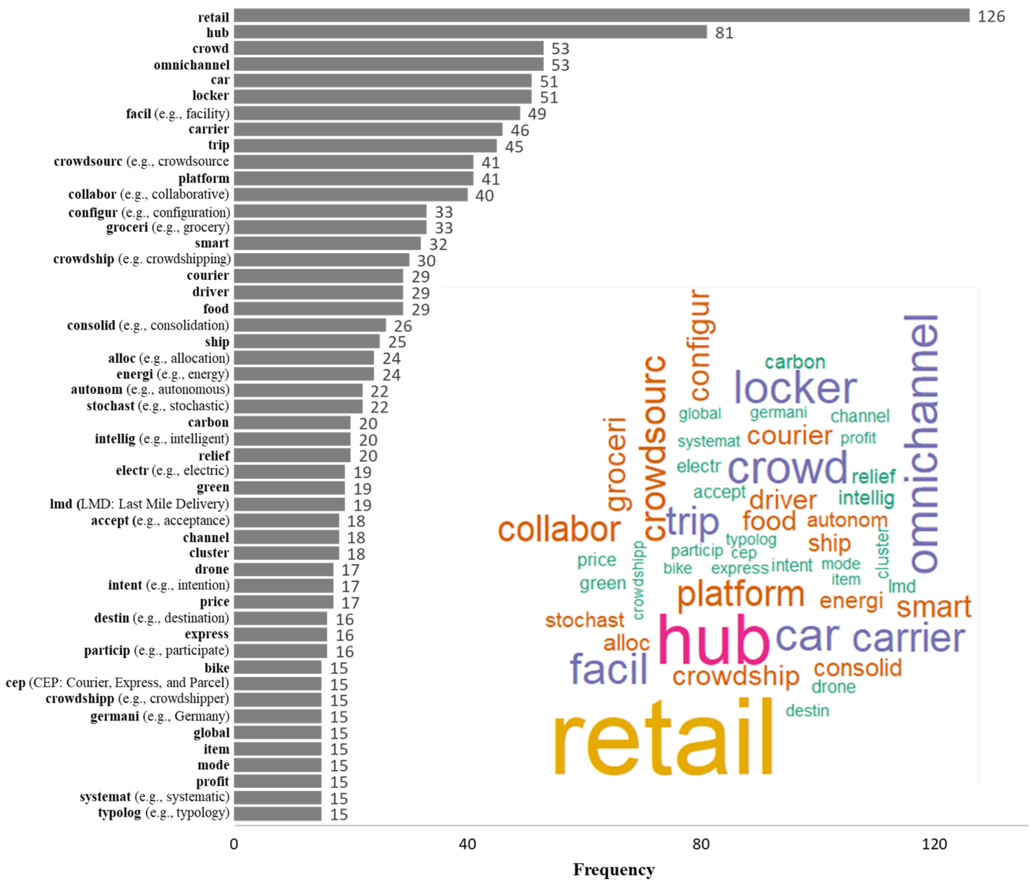


Figure 4. The 50 most frequent terms identified from the target research articles.

3. Conceptualization of Last Mile Logistics

The term last mile was first coined in the telecommunications industry [14] and was originally used to indicate the final leg of a delivery system for traditional deliveries from brick-and-mortar retailers [32]. Early applications of LML in the literature narrowly extended supply chains directly to the end consumer, which simply represented a home delivery service for consumers [33,34] and the last part of a delivery process [13]. In this regard, traditional LML was conceived of as deliveries for the last mile supply chain, last mile, final mile, home delivery, B2C distribution, or grocery delivery.

However, the traditional definitions have not been sufficient to describe newly emerging LML features driven by recent e-commerce changes that inherently involve new uncertainties [35,36], exclusion of in-store order fulfilment processes [23], and non-specific final locations [33,37]. Despite a steady increase in the number of contributions to LML research, LML has been conceptualized inconsistently across studies without consensus around a single definition of LML [11]. As various LML approaches have been available, a consistent and robust definition of LML is necessary to be a basis for LML design frameworks. Table 1 shows the various LML-related definitions used in our target research articles.

Table 1. Definitions of LML-related terminologies.

Terminology	Reference	Definition
Last mile	[32]	Final leg in a B2C delivery process in which the parcels are delivered to the destination, either at the recipient's place or at a collection point
	[38]	Last part of a delivery process of physical goods from a last transit point to a final drop point
	[39]	Distance from the main traffic station, such as rail transit, to the destination
	[40]	Last segment of distribution for a delivery with the specific distance
	[41]	Transport of goods from a local contact place to a point of consumption
Last mile delivery	[14]	Final leg of transport of goods in the supply chain to their consumption point
	[42]	Delivery of purchased items to the doors of customers
	[43]	Delivery of goods to the home in the last link of the supply chain
	[44]	Delivery of parcels to their destination in a city
	[45]	Last segment of a delivery process that involves all required activities and processes of the delivery chain
	[46]	Delivery from the last upstream transit point to the last recipient
	[47]	Transport from the retailer's local point to the final recipient's place
	[48]	Delivery of items to their final recipient's point within a city
Last mile distribution	[49]	Last part of the supply chain delivery process, including necessary activities from the last transit point to
Last mile parcel distribution	[50]	Delivery of parcels from distribution centers or substations to individual addresses
Last mile logistics	[51]	Movement of goods from a distribution center to the last recipient's doorstep
	[13]	Last stretch of a B2C consignment delivery process
	[11]	Last stretch of the logistics system from the last distribution point to the recipient's preferred final drop point
	[1]	Last stage of a delivery from a distribution center to a customer's place
	[52]	Last stretch of a B2C parcel delivery process of goods from a penetration point to the final consignee's point

An important insight from the target research articles is the functional scope of three different logistics domains: city logistics, urban logistics, and LML. The three logistics domains can be clarified with different perspectives [14]. City logistics is a critical field in urban areas and mainly focuses on stakeholders' interrelationships from the perspective of macro-level logistics. However, urban logistics refers to how parcels can be effectively transported in urban areas at a meso level. On the other hand, LML is related to delivery processes at a micro level. Considering these three different functional scopes, in this paper, a working definition for LML is proposed to synthesize all the above LML-related definitions as follows:

LML is the final branch of parcel delivery services that involves a point of delivery to a final consignee's preferred, predefined collection point or destination location after order placement.

Based on the above LML definition, the scope of interest in this paper covers a research stream from leaving warehouses of the supplier or logistics provider to arriving at the collection point designated by a final consignee. The underlying characteristics of LML concepts under the LML definition have been presented in various types of LML-related research. The operational and technological aspects of LML identified in Section 2 show that the nature of LML-related research can be categorized into four LML main research areas in Section 4 (see Table 2).

Table 2. Typology of LML-related research.

Research Area	Main Issue
Sharing economy	Impact of sharing economy in LML to employment market Operations of sharing economy in LML Environmental impact of sharing economy in LML
Proximity stations/points and hubs	Integrating proximity stations/points into the existing LML seamlessly Searching for potential locations for these stations/points Location-routing problem for LML Vehicle routing problem for LML Assessment of distributed network strategies for LML
Environmentally sustainable LML	Multi-criteria decision making for sustainable LML Environmental impact assessment and sustainable strategies for e-commerce LML Integration of environmental sustainability into new LML approaches
Delivery technology innovation	Limitations of traditional truck-or van-based last mile delivery services Transition to innovative and environment-friendly last mile delivery services using advanced vehicle technologies

4. Current Issues of Last Mile Logistics

The keywords frequently appearing in existing LML studies address that the main issues of LML in the literature are associated with sharing economy, proximity stations/points and hubs, environmental sustainability, and delivery technology innovation. The following subsections show extant LML studies that discussed each issue through various approaches.

4.1. Sharing Economy

The advancement of information and communications technologies has accelerated the introduction of sharing economy in LML. Sharing economy in LML involves a way of parcel deliveries by individual, self-contracted contractors joined at a crowdsourcing platform. New technologies that help find optimal routing and parking spots in real time have been lowering the entry barriers of crowdsourcing so that more logistics service providers can join a crowdsourcing platform for last mile parcel deliveries. Crowdsourcing for last mile deliveries is likely to spread further as the digital economy grows, which may be one of the viable options for tackling rising unemployment [53]. Using a crowdsourcing platform, passenger cars in urban areas can be utilized for home delivery services. Crowd workers in LML can be characterized by open-loop car routes, drivers' wage-response behavior, interplay with the ride-share market, and service zone sizes for fulfilling last mile deliveries from shared logistics. Although sharing economy in LML is not as scalable as a traditional truck-only system, this transition to the sharing economy paradigm for LML has a potential to create economic benefits by reducing original truck fleet sizes and exploiting additional operational flexibilities [54]. Specifically, from the logistics company's perspective, using a personal car to carry delivery parcels by an individual contractor can keep costs low, as it does not require additional fleet capability even if more parcels need to be carried. Instead, the company apply surge pricing to resolve a demand-supply imbalance for the last mile parcel deliveries. This allows the logistics company to be more flexible to the logistics-related market. From the self-contracted worker's perspective, their idle capacity can be utilized for carrying parcels. Many people have idle capacity in the course of their day, and using small slivers of time to carry parcels can be one of the ways to effectively use such an idle capacity. Furthermore, this provides an avenue toward the gig economy and shows options for resolving unemployment issues. From the final customer's perspective, the reduction in high overhead business intermediaries with a low-cost technology platform can reduce the delivery cost to the customer's site.

Table 3 summarizes the major issues and findings of LML studies related to sharing economy. Ref. [55] presented a mixed integer programming (MIP) model that solves a vehicle routing problem (VRP) in which vehicles are operated by crowdsourced occasional drivers. Ref. [56] extended the work of [55] to an MIP model considering multiple parcel deliveries for each crowdsourced driver. Ref. [42] performed a simulation analysis based on logistic regression and an agent-based transportation simulator to identify the benefits of LML for retail store order pickups using a social network of customers. The results showed that employing friends in a social network for LML can decrease transportation emissions and delivery costs while maintaining delivery speed and reliability. Ref. [18] performed a discrete event simulation analysis based on a conceptual framework with five principles to facilitate the integration of crowdsourced delivery into a conventional delivery network. Ref. [57] identified the effectiveness of crowdsourcing last mile delivery through a simulation model for same-day delivery using crowdsourced vehicles. They found that crowdsourced fleets can be effective to maximize the total number of deliveries when late delivery penalties are not severe. Ref. [25] proposed a route planning problem to model a dynamic crowdsourced delivery platform that automatically matches delivery tasks, ad-hoc drivers, and dedicated backup vehicles for deliveries uncovered by ad-hoc drivers. They found a total cost reduction through ad-hoc drivers, along with backup vehicles and an increase in the cost-efficiency of the system depending on the drivers' stop willingness. Ref. [58] presented a model to identify factors that affect the acceptability and preferences of crowdshipping attributes between consignors and consignees for package deliveries. They found that preferences can be described distinctively depending on shipment distance. Ref. [50] proposed a last mile parcel delivery system that employs ridesharing strategy based on internet of vehicles intelligence for deliveries in a smart city.

Table 3. LML-related issues and research findings: Sharing economy.

LML-Related Issue	Research Finding	Reference
Social impact	Crowdsourcing delivery to decrease unemployment	[53]
Economic impact	MIP model to address the VRP for crowdsourced drivers	[55]
	Total cost reduction by ad-hoc drivers with backup vehicles	[25]
	Effectiveness of crowdsourcing last mile delivery	[57]
	Delivery cost reduction by a dual-channel logistics system	[18]
	Multiple parcel deliveries for each crowdsourced driver	[56]
	Acceptability and preferences of crowdshipping attributes characterized depending on shipment distance	[58]
	Potential of crowdsourcing last mile delivery	[54]
Environmental impact	Negative impacts of crowdsourcing deliveries on overall	[59]
	environmental performance	[54]
	Reduced transportation emissions and delivery costs due to the use of social network	[42]
	Positive effect of shared mobility on greenhouse gas emissions	[60]
	Reduced carbon emissions and delivery distance in urban and suburban areas by a social network-enabled package pickup	[61]

4.2. Proximity Stations/Points and Hubs

Using proximity stations or proximity points is a new way to improve the efficiency of LML. This is useful for small- to medium-sized delivery parcels when customers are not at home. Deliverers store parcels at a depot station near a customer's address when home deliveries fail, and customers pick up their products later. In addition, delivery time can be reduced by visiting a proximity point during the night when traffic volume is low [62].

The applications of proximity stations and/or proximity points to LML are aimed, not only to integrate proximity points into existing LML, but also to identify locations for proximity points (see Table 4). Ref. [63] proposed a modular bento-box system to store delivery parcels until customers pick up their deliveries. Shopping malls, central squares, and residential districts were suggested as examples for the possible location of proximity points. Ref. [64] proposed an effective mobile crowd-tasking model that handles many citizens as crowd workers to perform LML. They formulated a proximity station problem in LML as a minimal-cost network flow problem, which minimizes the additional cost to assign all delivery parcels in pick-own-parcel stations to the most convenient crowd workers. Similarly, Ref. [26] investigated the utilization of parcel locker pickups for LML in the Polish InPost Company system and found that the proper location of parcel lockers was one of the most important factors for delivery efficiency.

Table 4. LML-related issues and research findings: Proximity stations/points and hubs.

LML-Related Issue	Research Finding Integrating Proximity Stations/Points	Reference
Integrating proximity stations/points into the existing LML	Improvement of delivery time, increase in average travel speed, and reduction in greenhouse gas emissions by using proximity stations/points	[62]
	Modular bento-box system for customer pickup	[63]
Identifying potential locations for proximity stations/points	Network min-cost flow problem with pick-own-parcel stations to maximize resources using a collaborative approach	[64]
	Evaluation of using parcel lockers in the Polish InPost Company system	[26]
Routing problem for last mile delivery hubs	Location-routing model to determine the placement of last mile delivery hubs	[65,66]
	Development of a hybrid genetic algorithm to efficiently solve the computational complexity issue of the location-routing problem with large-size instances for LML hubs	[67]
	Development of a two-stage stochastic travel time model to solve a delivery VRP to the set of final customer's homes and the set of hub locations for pickup stores	[68]

Hub location problems can be also applied to properly address the location of proximity stations and/or points and to consolidate last mile deliveries across urban areas that can reduce traffic and cut greenhouse gas emissions (see Table 4). Depending on the type of demand allocation for final customers, a last mile hub location problem can be partitioned into single and multiple allocation problems. The single allocation problem assigns every final customer to a single last mile delivery hub, while the multiple allocation problem assigns every final customer to more than one last mile delivery hub. Setting up efficient hub locations for LML can lead to great economic/temporal benefits for both consignors and consignees in delivery costs, quality of delivery services, and environmental impacts [69].

The location of last mile delivery hubs affects both the fixed cost of hub placement and the variable cost of delivery parcels to final customers. Refs. [65,66] respectively proposed a location-routing model to determine multiple last mile delivery hubs based on the total location and delivery vehicle routing costs for each customer's pickup and delivery needs. Ref. [67] further proposed a hybrid genetic algorithm that efficiently handles the computational complexity issue of existing LML location-routing models. Ref. [68] proposed a two-stage stochastic travel time model to solve a delivery VRP for the sets of both final customers and hub locations of pickup stores.

With a number of studies focusing on the potential locations for last mile delivery hubs, last mile delivery hubs have been established in practice. For instance, the City of London Corporation determined its first last mile delivery hub for the purpose of removing large numbers of delivery vehicles from city streets. This last mile delivery hub is expected to accelerate the use of e-cargo bikes and people on foot for the final leg of parcel deliveries and to take up to 23,000 fewer vehicle journeys in central London every year [70].

4.3. Environmentally Sustainable LML

As the environmental impact of operational activities in industries has become an urgent global issue, environmental sustainability is now essential in the management and operations of the entire supply chain [71]. In particular, LML involves various externalities such as gas emissions, air pollution, noise, and congestion [11]. The significant role of LML in the environmental sustainability of a supply chain has urged the transformation of the conventional LML into a more environmentally sustainable system. Accordingly, various studies have adopted environmental factors in modeling LML problems along with traditional time and cost factors through proposed LML approaches (Table 5).

Table 5. LML-related issues and research findings: Environmental impact.

LML-Related Issue	Research Finding	Reference
Multi-criteria decision making for sustainable LML	Conceptual framework to evaluate LML from economic, social, and environmental aspects	[72]
	Bi-criteria auction process of last mile delivery orders that maximizes both economic and environmental sustainability	[73]
	A distributed network based on crowd logistics as the most sustainable LML strategy	[74]
Environmental impact assessment and sustainable strategies for e-commerce LML	Lower carbon footprints in last mile deliveries through e-commerce than conventional brick-and-mortar stores	[43]
	Effective reduction in greenhouse gas emissions through local collection and delivery points for failed home deliveries	[75]
	Stochastic last mile model to calculate probabilistic estimates of traveling distances and break-even point at which last mile delivery causes less carbon emissions than customer pickup	[76]
	Reduction in light goods vehicle traffic and associated environmental impacts through LML	[77]
	A framework to reduce CO_2 emissions in e-commerce LML	[78]
	Principles for sustainable LML	[79]
Integration of environmental sustainability into new LML approaches	Reduction in carbon emissions and delivery distances through a social network enabled package pickup	[61]
	Importance of local authorities to promote cargo cycles	[24]
	Reduction in CO_2 emissions per person through shared mobility	[60]
	Emissions and cost savings by using a social network in LML for retail store order pickups	[42]
	Slightly more emissions in minimizing operating costs for the last mile delivery system than minimizing emissions for the system	[54]
	Negative impact of crowdsourcing in LML on the environment of the road	[59]
	Crowd logistics that can be environmentally-friendly only if it is optimized for existing delivery trips	[80]
	Both environmental and economic benefits obtained by crowd-shipping through public transportation in urban areas	[81]

The importance of environmental sustainability in LML led to multi-criteria decisions to simultaneously consider both economic and environmental factors that have trade-offs in LML. Ref. [72] provided a conceptual framework to evaluate last mile options from economic, social, and environmental aspects that involve design criteria and performance attributes for industrial, institutional, and consumer group stakeholders. Ref. [73] proposed a bi-criteria auction process to assign last mile delivery orders to trucks that maximizes both the economic and environmental sustainability of LML. Ref. [74] evaluated three LML strategies (i.e., centralized distribution network, decentralized distribution network through home-delivery, and decentralized distribution network based on crowd logistics) through a system dynamics simulation and its multi-criteria decision analysis using the Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE) on economic, technological, environmental, and societal criteria. Their case study of local food LML showed that a distributed network based on crowd logistics is the most sustainable LML strategy.

The sustainability role of LML in e-commerce was also widely discussed to suggest new sustainable LML strategies in the literature. Ref. [43] addressed that last mile deliveries through e-commerce resulted in lower carbon footprints than conventional brick-and-mortar stores. Ref. [75] addressed that local collection and delivery points for failed home deliveries of e-commerce can effectively reduce greenhouse gas emissions against traditional shipping methods. Ref. [76] developed a stochastic LML model to calculate probabilistic estimates of traveling distances, and they compared carbon emissions generated by conventional customer pickup and last mile delivery through e-commerce. Ref. [77]

examined LML for light goods from e-commerce retailers in London, and they concluded that last mile deliveries for e-commerce can reduce light-goods vehicle traffic and associated environmental impacts. Ref. [78] developed a framework to reduce carbon dioxide (CO_2) emissions in e-commerce LML and suggested potential solutions (e.g., re-allocation of vehicles, use of electric vehicles (EVs), reduction in delivery failures, proper vehicle planning, alternative fuels, and urban consolidation centers) to reduce CO_2 emissions in LML. Ref. [79] examined the urban delivery performance of LML for business-to-consumer and business-to-business cases in the United Kingdom.

Recent studies have paid more attention to environmental sustainability of new LML operations and approaches that are expected to provide both economic and environmental benefits in urban logistics. Ref. [61] compared last mile delivery distances and greenhouse gas emissions in last mile delivery systems (i.e., door-to-door delivery, designated package pickup, and socially networked package pickup) for online purchases, which were modeled through a genetic algorithm. Their results showed that a social-network-enabled package pickup can significantly reduce carbon emissions, as well as delivery distances in both urban and suburban scenarios. Ref. [24] proposed a sustainable urban logistics framework to boost the potential use of cargo cycles based on empirical case studies in the United Kingdom. They claimed that local authorities play a critical role in promoting cargo cycles to make them major urban freight transport. Ref. [54] proposed a novel logistics planning model for last mile deliveries based on shared movability, which can characterize open-loop car routes, wage-response properties, and competition in the ride share and delivery services. Refs. [54,59] found that last mile delivery through shared mobility may increase greenhouse gas emissions due to an increase in vehicle traveling distance. Ref. [60] conducted a survey from 363 car sharing respondents in the Netherlands to analyze the effect of shared mobility on car use and CO_2 emissions, and they concluded that shared mobility positively affected the environment in Belgium. Ref. [42] claimed that LML for retail store order pickups using a social network of customers can reduce emissions from ground logistics as well as delivery costs while maintaining delivery speed and reliability. Ref. [80] suggested crowd logistics platforms, and compared the performance their proposed platform with traditional logistics counterparts in terms of the unit delivery cost and the environmental impact of crowd logistics. Their multi-actor multi-criteria analysis to evaluate the delivery scenarios showed that crowd logistics can be environmentally-friendly only if they are optimized for existing delivery trips. Ref. [81] evaluated the environmental and economic impacts of crowdshipping through public transportation in the city of Rome. The scenario analysis based on a discrete choice model in [81] showed that the crowdshipping platform can have both environmental and economic benefits.

4.4. Delivery Technology Innovation

Along with the studies addressing operational challenges, LML studies related to overcoming technical issues were also abundant in the literature. Newly emerging delivery technologies such as unmanned aerial vehicles (UAVs) or drones, connected autonomous vehicles (CAVs), EVs, automated lockers, real-time data transmission systems, dynamic route planning systems, fleet management solutions, tracking devices, and identification means and devices [4,12,82] were discussed to improve LML performance (see Table 6).

Table 6. LML-related issues and research findings: Delivery technology innovation.

LML-Related Issue	Research Finding	Reference
Limitations of traditional truck- or van-based last mile delivery services	Service transition from truck- or van-based goods delivery to drone-assisted delivery in urban areas	[82]
	Social costs of home delivery due to increased delivery traffic flows in residential areas	[83]
Transition to innovative and environment-friendly last mile delivery services using advanced vehicle technologies	Possibility that UAVs or drones can carry heavier goods while hovering	[22]
	Challenges of drones used for LML services in urban areas	[1]
	Importance of using CAVs for future LML delivery services in urban areas	[84]

An innovative transition of delivery services from truck- or van-based parcels deliveries to drone-assisted deliveries in urban areas has received attention in logistics [4,82]. According to the 2016 Material Handling Industry (MHI) Annual Industry Report [85], 59% of survey respondents recognized that emerging technologies, including UAVs or drones, CAVs, EVs, or robots, were having influence on logistics. The report also claimed that adoption rates for such technologies are expected to grow to higher than 50% over the next decade. Indeed, drones have been extensively utilized in the logistics field, deployed for delivery services in LML [86,87]. However, challenges in the legal restrictions and restricted service areas, labor and logistics costs, battery safety, and cost efficiency of drone applications for LML prevented drones from being prevalently used for urban LML deliveries [1]. For more reliable deliveries by drones in LML, operational challenges for drone-assisted delivery or truck–drone hybrid delivery will need to be tackled [88–91]. With improved adoption processes, drones can be an essential strategic delivery method to innovate conventional LML delivery services if they can carry heavier goods while hovering [22].

Traffic flows in urban areas have frequently fluctuated by uncertain traffic factors on the road. Accordingly, home delivery services impose many social costs due to a sudden increase in delivery service vehicles in residential areas [83]. The use of CAVs for future LML delivery services in urban areas has been the kernel of recent studies as traditional logistics delivery services have caused intrinsic drawbacks [84]. Furthermore, autonomous trucks or vans can be integrated with drones or robots, which may significantly improve LML delivery services in urban areas [92]. EVs have also received attention in LML as an alternative to internal combustion engine vehicles, with increasing interest in new forms of delivery vehicles which are more economically and environmentally sustainable.

5. New Opportunities for Design and Development of Innovative Last Mile Logistics

The current interests and focuses of LML delivery service studies should be more closely scrutinized to find new potentials in innovative LML fields. The following subsections show new opportunities for design and development of innovative LML delivery services to improve the current LML-related issues.

5.1. Advanced LML Services with New Delivery Techniques

As we discussed in Section 4.4, LML delivery services in urban areas will accelerate technological innovation due to the extensive use of unmanned vehicles, CAVs, UAVs or drones, EVs, automated lockers, real-time data transmission systems, dynamic route planning systems, tracking devices, and identification means or devices. These can provide more opportunities for application of new delivery techniques in LML including the following areas:

- Smart scheduling and urban consolidation through new delivery technologies: The innovative and advanced delivery technologies will lead to new methods of boosting effective LML delivery services. Several Industry 4.0 solutions for LML delivery services can be actualized from advanced techniques for enabling smart scheduling and developing real-time stochastic optimization models [1]. Furthermore, the construction of consolidation centers in urban areas can improve urban LML delivery services with micro consolidation and distribution centers [84]. These overarching trends are expected to continue into the future of urban LML delivery systems.
- Improvement in operations of new delivery techniques: UAVs or drones will dominate LML delivery services in a few years. For instance, many global logistics powerhouses have already initiated drone-assisted delivery services for food and industrial products. Consumer goods represent finished products that are sold to and consumed by people, in general, whereas industrial products are materials used in the production of other commodities. Industrial products are purchased and used for both industrial and commercial purposes. They consist of machinery, manufacturing plants, raw materials, and any other commodity or component that is used by industries or businesses. Similarly, the surge in adoption of new delivery techniques, including drone taxis and small/large drones, will prominently attract a lot of attention in LML-related markets in the near future. Another promising opportunity to enhance urban LML delivery services will be realized by diversifying LML delivery channels with EVs, which is also an environmentally-friendly delivery service. However, potential issues associated with using EVs are their short drive distance, which is generally less than 150–200 miles per charge, and long recharging time of batteries compared to their internal combustion engine counterparts. Along with these issues, the LML industry also needs to improve the performance of solid-state batteries (e.g., lithium-ion and sodium-ion solid-state batteries) and recharging technologies with lower installation costs [93].
- Development of optimization models for last mile delivery operations using new advanced techniques: Owing to the commercialization of new advanced techniques and the need for innovative last mile delivery services, there are many delivery routing problems which require resolution within a short time period [94], e.g., modified VRPs or extended traveling salesman problems in LML using drones [91,95–98], autonomous vehicles [99], robots [9,92], and drone-robot integration [100]. Ref. [95] proposed a truck–drone delivery optimization model using mixed integer linear programming (MILP) and its solution approach that reflects drone energy consumption and restricted flying zones. Ref. [97] developed an MILP model to minimize the total completion time of LML delivery services using autonomous drones and delivery trucks. Ref. [91] presented an MILP to minimize the customer waiting time when using a single truck and multiple drones for delivery. Yu (2018) proposed a mixed integer, non-linear programming model to decide optimal delivery schedules (i.e., allocation, routing and battery charging) of autonomous vehicles, not only to minimize driving distance, but also to maximize renewable energy utilization. Furthermore, the delivery scheduling problems in LML need to be addressed for adopting autonomous robots [9,101]. This significant stream of research for last mile delivery operations using advanced technologies can stimulate the LML markets' innovation, as well as create steady demand for LML in the future.

5.2. Innovative LML Applications Using New Technologies and Systems for Environmental Sustainability

Although many extant studies addressed the significant effects of new LML delivery technologies on environmental sustainability (see Section 4.3), adverse effects of new technologies on the environment should be also investigated. For example, using crowdsourcing may have a negative impact on the environment in the road owing to an increase in traffic flow [59]. In particular, greenhouse gas emissions may increase due to open-loop routes of delivery vehicles, and a resultant low per-kilometer emission rate of crowdsourced vehicles can be offset in that the aggregated car trip distance is over 35% longer than that of trucks due to cars' much smaller capacity [54]. In this regard, the role of future LML delivery services in terms of environmental sustainability should be investigated in more detail to facilitate a transition to environmentally sustainable LML as follows:

- Management of negative impacts on the environment through technology enabled LML services: From the perspective of environmental sustainability in LML systems, a major challenge is to significantly decrease greenhouse gas emissions that affect climate changes. Replacing existing light delivery vehicles that are powered by an internal combustion engine to EVs for LML services can be more sustainable than traditional delivery trucks or vans [1,12,102]. New technologies to achieve sustainable LML can be performed with innovative management strategies for LML deliveries such as LML delivery services during the night avoiding high traffic congestion [103] and using EVs [78] for CO_2 emission reduction with fuel saving.
- Sustainable LML system design in urban areas: Collaborative urban logistics services should be considered for better consolidation of existing infrastructure and resources to leverage the environmental sustainability of LML deliveries in urban areas. An environmentally-friendly LML system can be operated by fewer delivery vehicles and light-weight vehicles to lessen emissions [104]. Moreover, the innovative digitalization of LML systems is required for the successful development of a sustainable smart city. Future LML delivery services are expected to integrate automation technologies and digitization into operational strategies to facilitate real-time decisions [88,105]. Thus, an intelligent system that can monitor and analyze environmental impacts of deliveries in LML in real-time will be necessary to enhance environmental sustainability in urban areas. Similarly, integrating drone- and/or robot-assisted last mile deliveries should be evaluated from both cost and environmental perspectives to suggest sustainable LML operations. For LML innovations through new technologies, policies and regulations for different stakeholders can affect successful implementation of LML [10]. Development of novel methodologies from different perspectives and that of tools to assess the viability of sustainable LML should be also addressed in future LML studies.

5.3. Effective Management of Uncertainties in LML

Supply chain systems inevitably involve structural and operational complexity as there are a wide variety of stakeholders, information, and materials that should be managed with their associated uncertainties [106,107]. Supply chain complexity becomes more critical in LML in which highly distributed supply channels and end-user locations exist with multiple delivery methods; more uncertain elements should be carefully controlled to achieve the effectiveness of LML in practice. For this, the following issues should be discussed more in depth to properly handle an increase in uncertainties while operating LML:

- Conceptualization and measurement of LML complexity: Complexity in supply chains has been variously defined depending on aspects and domains in the existing literature relevant to traditional supply chains [108]. However, the concepts and measures of complexity in LML have not been widely addressed in LML studies to date. Uncertainties that are caused by the variety, size, and dynamic operations of LML may be distinct from those in conventional logistics. Therefore, complexity in LML needs changes in definitions and measures that were originally used for conventional logistics, although basic concepts for supply chain complexity may be partially applicable to LML cases. Along with efforts to define and develop complexity measures for LML, the impact of complexity on LML performance should be investigated to understand underlying complexity dynamics in an LML system.

- Modeling LML with dynamic factors: The dynamic nature of a city's logistics system should be reflected on LML models with new indicators and aspects that properly describe uncertainties in LML. Multiple indicators to comprehensively represent traffic congestion conditions and parking space availability, which can affect delivery productivity, should be considered as sources of complexity in LML [109]. In addition, various types of uncertainty such as demand volatility, infrastructure accessibility, conflicting objectives among stakeholders [10] are required to be incorporated into LML models. Indeed, real-time data, fleet management and dynamic route planning, and tracking devices will be important resources to develop algorithms and optimization techniques in LML to reflect real-world problems.
- Mitigation of uncertainties in LML: The complexity of LML would exponentially increase as crowd-sourcing and new delivery technologies such as drones and UAVs are actively employed in logistics operations. In this regard, studies that discuss how the impact of new uncertainties in advanced LML approaches is effectively controlled are needed. For example, operational strategies that enable a highly distributed delivery network to be simplified are required to avoid complex routes [18]. Autonomous robots that assist truck-based LML can be effective in making deliveries in relatively small areas with multiple delivery stops [92].
- Developing solution approaches: Addressing VRP or location routing problems for LML generally makes associated mathematical models more complicated. This leads to high computational complexity due to its combinatorial structure in searching for optimality. As integrating new LML concepts and approaches into existing LML operations usually increases computational complexity, well-designed algorithms and/or heuristics should be developed to solve a large-scaled problem in a polynomial time. Refs. [110,111] classified multiple VRP variants for urban freight transportation and the associated algorithms solving the various LML problem.

5.4. LML for Decentralized Manufacturing Services

The growth of 3D printing technologies and services has accelerated a new paradigm of manufacturing. 3D printing provides a new opportunity that can decentralize manufacturing by producing parts near consumption, which can lead to shortened supply chains and reduced inventory [112]. Under decentralized manufacturing, LML would be more important as a large set of low-volume and lightweight final products made by decentralized manufacturing may need to be effectively delivered to highly distributed consumer locations through local transports [113]. The 3D printing industry can provide new opportunities in logistics operations, and more insights into the effects of 3D printing on LML should be scrutinized to prepare for the transition to this new paradigm of LML. In this regard, the following topics should be further discussed:

- LML for local fabshop-based 3D printing: Local 3D printing fabshops can provide a new business opportunity for logistics companies if they are able to offer 3D printing services as well as delivery services at the same time through their local 3D printing shops [114]. This type of local 3D printing is effective for orders that are required to fabricate customized design shapes and high-quality products [113]. As customers simply need to order what they want to manufacture through an online system, the role of LML for the deliveries of 3D printed products to individual customers will become more important. A dynamic local logistics network that is assisted by new mobility options (e.g., drones or UAVs) will be helpful to achieve operational efficiency if a few local fabshops should handle individual low-volume orders requested from highly distributed end-customers.

- LML for consumer-based (home) 3D printing: Consumer-based (home) 3D printing is more suitable for low-end and common products [113]. The acceleration of 3D printing at home would make material flows from material suppliers to end-users more critical [82,112], and conventional last mile delivery for final products may need a significant transition to last-mile delivery for raw materials. Therefore, rapid replenishment of a wide variety of low-volume materials for customers would be an important decision-making problem in LML. In addition, reverse logistics to reproduce raw materials from disused 3D printed products will emerge as a new competitive edge in LML.
- Concurrent manufacturing logistics (mobile manufacturing): Amazon Technologies, Inc. recently filed patents for mobile manufacturing that enables carriers equipped with 3D printers to take and produce orders at the same time during delivery [115,116]. This new form of logistics will eliminate the current strict separation between manufacturing and logistics and will provide a great deal of flexibility and competitiveness for offering final products to customers [117]. Mobile manufacturing is expected to open a new way to optimize order lead-time by valuably using delivery time, which has traditionally been considered as cost addition for final delivery. This new approach will be applicable not only to mobile manufacturing of low-variety products within small-sized vehicles (e.g., cars and small trucks) but also to mobile manufacturing of high-variety products within large-sized vehicles (e.g., large trucks and aircraft). For both cases, product quality and autonomous manufacturing in a moving vehicle should be technically and operationally supported for successful LML operations of mobile manufacturing.

6. Conclusions

LML delivery services have been a critical part of the supply chain management. Our findings in this study further indicate that additional research is required to enhance environmental, operational, and technical sustainability of LML delivery services. In this paper, we identified four new opportunities for LML: (i) Advanced LML services with new delivery techniques, (ii) innovative LML applications using new technologies and systems for environmental sustainability, (iii) effective management of uncertainties in LML, and (iv) LML for decentralized manufacturing services. The identified opportunities indicate that additional efforts in the LML research field should be given to enhance the operational, technological, and environmental sustainability of LML services.

This paper presents a literature review of LML. The main goal of this review study was to provide a systematic review of LML-related studies by investigating the definition and the typology of LML, exploring issues and concerns in LML, and discussing new opportunities and future directions for the next generations of LML. In this literature review, more than 400 works written in English were initially identified, and 169 target research articles were eventually found to meet the study criteria and identified as complete LML studies that contributed to recent LML advances. Furthermore, to better understand the underlying themes addressed in the target research, text mining analysis was performed.

Considering all reference papers comprehensively, a novel definition of LML and a typology of LML-related research are proposed in this paper. The challenges constraining the innovation of LML services are discussed with various current issues: (i) the development of information and communications technology has recently accelerated the introduction of the sharing economy era; (ii) using proximity stations or proximity points is a new way to improve the efficiency of LML, and the hub location problem has also has attention re-paid to consolidate last mile deliveries across urban areas to reduce traffic and cut greenhouse gas emissions; (iii) the innovation of techniques in LML services may be helpful to design environmentally sustainable LML; and (iv) various advanced delivery technologies can be contemplated (e.g., UAVs or drones, robots, CAVs, and EVs) to improve performance in LML services.

To improve LML services, more efforts and suggestions should be addressed for various applications that are associated with new transportation modes for LML operations and their environmental sustainability, digital transformation, and novel methodology to improve LML operations of real industries, managing uncertainties in LML, and LML for decentralized manufacturing services. In this paper, such major opportunities for design and development of innovative LML services were discussed from technological and operational perspectives.

We believe that this systematic literature review can serve as a useful tool for LML decision makers and stakeholders to model an efficient delivery system. In addition, the future directions and suggestions proposed in this paper can be leveraged for smart city designs with smart logistics systems considering sudden increases in last mile deliveries. Our study would leverage interdisciplinary collaboration with various logistics researchers and urban planners to develop a system to meet their needs.

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