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Review

Evolution, Challenges, and Opportunities of Transportation Methods in the Last-Mile Delivery Process

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Abstract: The rapid development of modern logistics and e-commerce highlights the importance of exploring various modes of transportation in the last-mile delivery (LMD) process. However, no comprehensive studies exist in the literature exploring all modes of LMD transportation, the changes in these transportation modes, and the commonalities between them. In this study, we address this gap by conducting a systematic review of 150 academic journal articles utilizing a combination of the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) content analysis and text mining analysis. Nine primary transportation methods (parcel lockers, autonomous drones, trucks, bicycles, crowd logistics, electric vehicles, tricycles, autonomous robots, and autonomous vehicles) are identified in this research. Additionally, we provide an analysis of the historical changes in these transportation modes in LMD. Using a bottom-up induction method, we identify the three major clusters of scholarly focus in the LMD literature: emphasis on value co-creation between consumers and logistics providers, practical delivery performance (path optimization or algorithms), and environmental friendliness. Further, we analyze the main themes under each cluster, leading to the identification of opportunities, challenges, and future research agendas. Our findings have implications for scholars, policymakers, and other stakeholders involved in LMD transportation modes.

Keywords: challenges and opportunities; last-mile delivery; mode of transport; PRISMA; text mining analysis

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1. Introduction

With the rapid growth of e-commerce, in which consumers increasingly prefer online shopping over retail stores, last-mile delivery (LMD) is a crucial element of the logistics supply chain [1]. From environmental and economic perspectives, practitioners, end-users, and academics consider the LMD process—the final step of the delivery process—as the most critical and least efficient element of the logistics supply chain [2]. Upstream suppliers such as retailers are attentive to delivery costs, and LMD costs constitute over 40% of the total supply chain cost [3–5]. Midstream regulatory agencies focus on carbon emissions and the environmental impact of service processes [6,7], and downstream consumers express concerns about service quality and time windows [8–11]. This has led to a surge in the research on LMD since 2018. Figure 1 illustrates the search results from the academic abstract and citation database Scopus using the keyword "last-mile delivery". The dotted line with an arrow represents 2010–2022 LMD development trends, with future development trends predicted using a simple index calculation.

The evolution of industry from the digitization, automatization, and connectivity of production processes of Industry 4.0 to the human-centered processes of Industry 5.0—in which humans work alongside robots and smart machines—and the increasing deployment of automation has led to the rapid transformation of LMD transportation modes in logistics supply chain systems. Early-stage manual door-to-door delivery evolved into the mid-stage emergence of parcel lockers and then to the recent rise in automated delivery methods such as drone delivery and delivery robots. This transformation presents opportunities and challenges for the logistics industry stakeholders, with significant implications for upstream retailers, midstream government regulatory departments, and downstream customers. The extant literature has focused on various methods of transportation (modes) in LMD, and some studies have specifically focused on certain types of transportation, such as aerial drones, crowd logistics, and electric vehicles (EVs) [12]. However, no comprehensive studies exploring all modes of LMD transportation, the changes in these transportation modes, and the commonalities between them exist in the LMD literature.

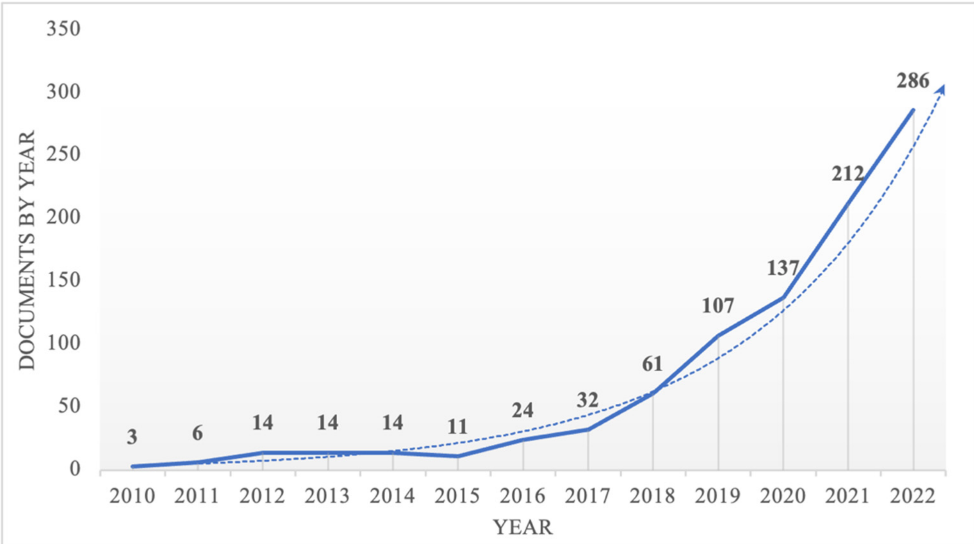

Figure 1. Research trends using "Last Mile Delivery" as keyword in Scopus in 2010–2022.

As an increasing number of researchers participate in discussions and studies concerning diverse transportation modes in the LMD, encompassing practical application requirements, efficiency, cost optimization, and environmental impact, a pressing demand arises for an article that comprehensively addresses research on all transportation modes in LMD. This study fills this gap in the literature. We identified LMD transportation methods, tracked changes in transportation methods since 2010, and explored areas of concern or commonalities among scholars regarding the application of these transportation methods to LMD. Our analysis of the opportunities and challenges encountered in the application of these transportation modes in the LMD process has implications for scholars, policymakers, and other stakeholders involved in LMD transportation modes. This study addresses the following research questions:

RQ1: How many and what LMD transportation modes have scholars focused on in the LMD literature?

RQ2: How have these LMD transportation modes evolved?

RQ3: What are the common files (clusters and themes) of these transportation modes in the LMD literature, and what opportunities and challenges do they encounter?

The remainder of this study is organized as follows. Section 2 describes our research methodology, three-step data collection process, and data analysis techniques. Section 3 discusses the main findings of our systematic review, including the three most significant clusters of transportation modes that scholars focus on in the LMD literature and a comprehensive analysis of the key themes within each cluster. Section 4 presents future opportunities, challenges, implications, and limitations.

2. Methodology

The research objective of this study was to provide a systematic review of transportation modes in the LMD literature using state-of-the-art methods. To achieve this, this review followed the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines [13,14].

2.1. Data Sources and Search Strategy

This systematic review located and evaluated research articles related to modes of transportation for LMD and analyzed the evolution of these academic journal articles to facilitate the creation of synthesized insights and a future research agenda. To ensure the comprehensive coverage of peer-reviewed journal platforms, the Scopus abstract and citation database was used as a database for reliable and updated journal articles [15]. Two-layered search keywords were prepared based on the research objective and questions. The first layer was composed of keywords related to the meaning of "last-mile delivery", such as "last mile" and "transportation or logistics". The second layer consisted of keywords relevant to "modes". Furthermore, all possible modes of transportation, such as "parcel lockers" or "crowd logistics", were manually identified. The first author of this study conducted this search on 30 April 2023.

2.2. Article Selection

Automatic and manual methods are subsequently employed to remove irrelevant sources. The specific process is outlined as follows.

2.2.1. Criteria for Automatic Elimination Process

Utilize the academic database "Scopus" to filter for relevant targets. Because only one database (Scopus) was used, there is no issue of article duplication at this stage.

Inclusion criterion included:

- Articles containing "last-mile delivery", "last-mile transportation", or "last-mile logistics" in the article title, abstract, and keywords.

Exclusion criteria included:

- Subject areas related to "medicine", "computer science", "physics and astronomy", and "earth and planetary sciences", because vocabulary such as "last mile" is often used in disciplines such as electronic communication or the Internet, in addition to transportation; therefore, the scope of this review excluded these disciplines because the research interests did not pertain to these irrelevant areas and articles written in languages other than English.
- Articles that did not fall under the category of journal publications, such as conference papers, book chapters, editorials, books, and notes, were omitted from the analysis. This decision was based on the premise that journal articles, having undergone at least one round of peer review prior to publication, were considered more suitable for inclusion in literature reviews.
- Articles that were not published between 2014 and 2023—since the primary focus was on recent scholarship, only research from the past decade was reviewed.

2.2.2. Criteria for Manual Elimination Process

This process primarily involves a manual, independent review of the aforementioned articles for inclusion eligibility. The target articles were independently assessed based on their title, keywords, and abstract to determine whether they met the criteria. When it was difficult to establish eligibility based solely on the title, keywords, and abstract, a thorough examination of the full text was undertaken. If a consensus could not be reached in such cases, the first and second authors of this study would collaborate with the third author to arrive at well-informed decisions.

Inclusion criterion included:

- Articles that qualitatively or quantitatively discussed various transportation modes in LMD.

Exclusion criteria included:

- Articles in which the research scope was not clearly aligned with the LMD domain—for instance, the term "LMD" may have only appeared in the title or introduction, and the subsequent text lacked an in-depth discussion of the topic;
- Articles that did not specifically focus on available types of transportation modes—for instance, articles that primarily explored customer satisfaction in LMD without specifying a particular mode of transportation—as the scope of our study required the presence of at least one mode of transportation in the journal article;
- Articles that were unclear, nonsensitive, or communicated inadequately.

2.3. Data Extraction and Collection

We extracted the year of publication, author country (based on the institutional address in the article), journal title, research methods, and main research content and findings for the shortlisted articles.

2.4. Data Compilation and Analysis

First, the basic characteristics of the target paper were analyzed to establish a fundamental understanding of the various transportation modes of LMD within the scope of this review. Following this, the data were classified and organized based on the research objectives and questions of this study, employing data mining analysis. Subsequently, the results obtained from this classification were manually refined until a consensus was reached. Finally, utilizing the above classification, the primary research topics and future directions were analyzed.

2.5. PRISMA Flow Diagram

Figure 2 displays the PRISMA flow diagram, which outlines the article selection process. Initially, a database search produced 2843 records. Among these, 1349 were eliminated as they did not align with the eligibility criteria for automated screening in Scopus (e.g., non-English languages). Subsequently, 372 articles underwent evaluation for eligibility based on Scopus screening outcomes. Following a manual review, 150 articles satisfied all eligibility criteria and were selected for further analysis.

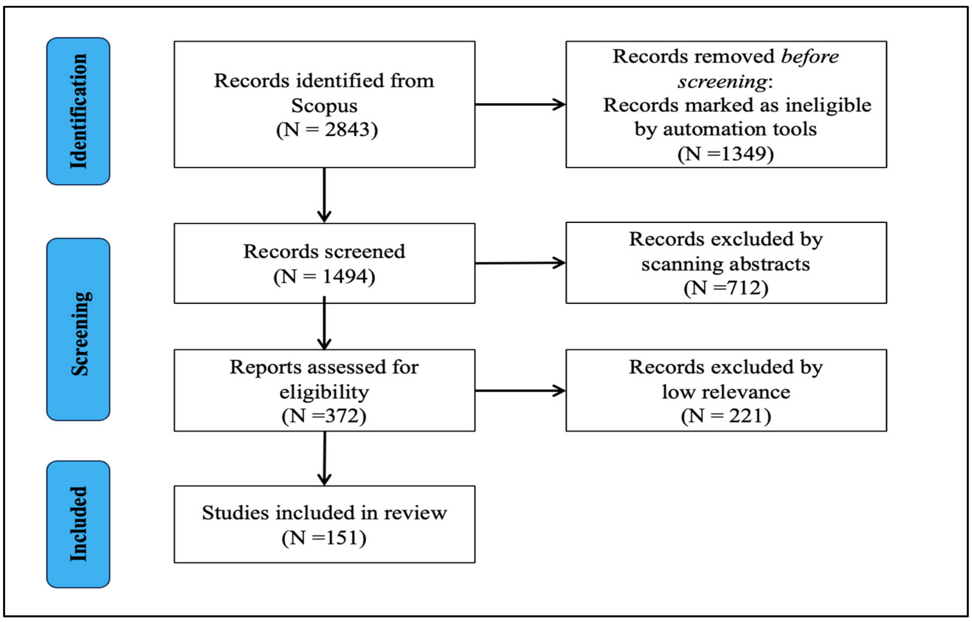

Figure 2. The PRISMA flow diagram—article selection process.

2.6. Characteristics of Included Articles

The publication year, journal, and country (according to the article authors' institutional addresses) distributions of the reviewed articles are discussed in this section. There was a noticeable growth trend in the number of articles related to various modes of transportation in LMD (Figure 3). As our data collection was conducted through April 2023, the number of articles was expected to peak in 2023. Specifically, the number of articles published between 2019 and 2023 (f = 130) was approximately 6.5 times higher than that published between 2014 and 2018 (f = 20). This demonstrated that researchers increasingly focused on various transportation methods associated with LMD over a five-year period. Given the recent rapid expansion of e-commerce and the increasing importance of LMD transportation methods, it can be anticipated that the LMD literature will correspondingly focus on these transportation methods.

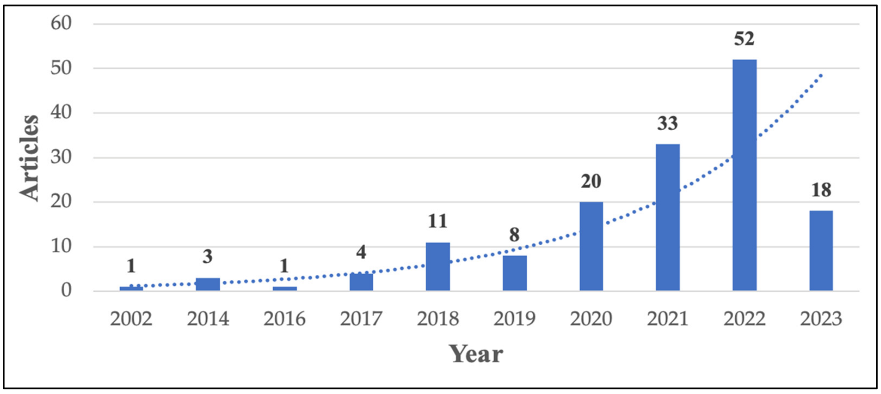

Figure 3. Distribution of LMD articles in 2014–2023.

Figure 4 shows the 2014–2023 distribution of LMD journal articles. Owing to the wide distribution, we listed 13 journals (f $\geq$ 3) with a relatively high volume of articles. ***Sustainability*** published the most relevant articles (f = 13). As a comprehensive journal that focuses on sustainability, it covers a wide range of topics related to the last mile, including systematic literature reviews and empirical investigations of various transportation modes. ***Transportation Research Part D: Transport and Environment*** ranked second (f = 8), with the majority of articles focusing on evaluating and comparing transportation modes in the last mile within the environmental and energy fields. ***Transportation Research Part C: Emerging Technologies*** and ***Transportation Research Part E: Logistics and Transportation Review*** jointly held the third position (f = 5). The former includes innovative technical articles on emerging aspects of the last mile, such as exploring low-altitude air congestion in relation to human–machine delivery efficiency.

The latter includes literature reviews and comparative analyses in this field, such as those examining the adoption of autonomous driving robots during the last mile. Three journals ranked fourth: ***European Journal of Operational Research***, ***International Journal of Logistics Research and Applications***, and ***Journal of Retailing and Consumer Services*** (f = 4). The main focus of ***European Journal of Operations Research*** is the routing optimization of various transportation modes within LMDs and the placement of distribution stations. ***International Journal of Logistics Research and Applications*** focuses on the opportunities and challenges encountered in the practical application of various modes, whereas ***Journal of Retailing and Consumer Services*** leans toward exploring consumer willingness to adopt different modes of LMD transportation and investigates the antecedents influencing such willingness. Six journals were ranked fifth (f = 3): ***IEEE Access***, ***International Journal of Physical Distribution & Logistics Management***, ***Journal of Transport Geography***, ***Mathematics***, ***Sustainable Cities and Society***, and ***Transportation Research Record***. Among these, ***Sustainable Cities and Society*** primarily focuses on the relationship between various modes of LMD and sustainability, while the other four journals primarily propose various algorithms to enhance the performance of different modes in the last mile.

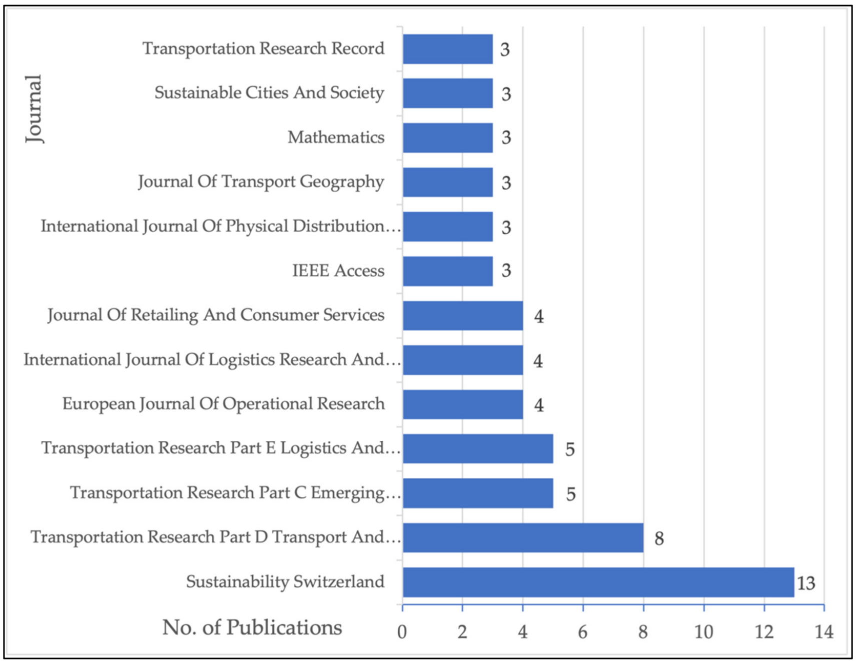

Figure 4. Distribution of LMD articles by journal in 2014–2023.

Figure 5 shows the distribution of articles on different LMD transportation modes by country (authors' institutional addresses). Considering the extensive range of options, focus was placed on the top five selections. The United States (f = 30) and China (f = 23) contributed most to the LMD transportation mode literature. Italy (f = 17), the United Kingdom (f = 12), and Germany (f = 11) closely followed in third, fourth, and fifth place, respectively. These countries are highly active in terms of last-mile deliveries. Furthermore, the United States and Italy exhibited a greater inclination toward exploring empirical research on innovative models, such as drones or autonomous delivery robots. Apart from these areas of focus, China also focused on unique modes of transportation such as tricycles. Italy showed a preference for the empirical analysis of crowd logistics in LMD, whereas bicycles and other LMD transportation modes were more common in Germany and the United States.

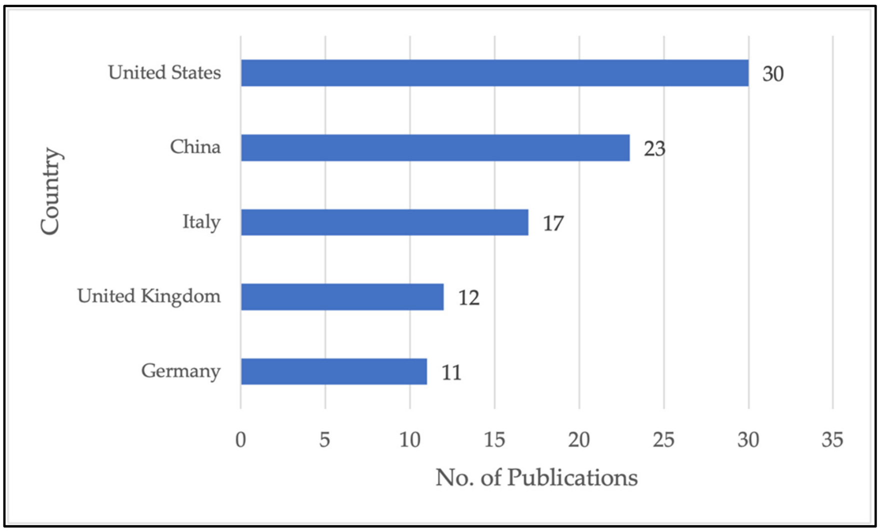

Figure 5. Distribution of articles on different LMD transportation modes by author country in 2014–2023.

3. Results

Using content analysis, we addressed this study's three research questions by quantifying and analyzing the presence and relationships of certain keywords, themes, and concepts.

3.1. Text Mining Analysis: Occurrences of Transport Modes

VOSviewer, a software package for constructing and visualizing bibliometric networks, was utilized to conduct the text mining analysis [16]. We filtered all transportation modes mentioned in the LMD literature and applied the criteria (occurrence frequency $f \geq 4$) to ensure that these transportation modes received relatively high scholarly attention in the context of LMD. Text mining analysis revealed nine transportation modes. The fractional counting method was employed to accurately identify all transportation modes mentioned in the LMD literature [17]. When issues with synonyms for a transportation method were encountered, they were categorized as the same type. The specific identification keywords are listed in Table 1. It is worth mentioning that transportation modes with a frequency of less than four, such as buses [18], taxis [19,20], or baby prams [21], are interesting transportation options. Although they are not discussed in this article, we believe that these transportation methods are also indispensable in the LMD field.

Table 1. Occurrences of transport mode keywords in LMD articles in 2014–2023.

Transportation Modes	Occurrences	Identify Keywords
Parcel lockers	44	Smart locker; modular locker; mobile parcel locker; express cabinet; pick up locker
Autonomous drones	43	Delivery drone; drone delivery service; unmanned aerial vehicles/UAVs; drone delivery system/DDs
Trucks	34	Conventional truck; diesel truck; truck
Bicycles	19	Bike; commercial bike; cargo bike; e-bike
Crowd logistics	25	Crowd; crowd shipping; crowd worker; crow shipper; crowdsourced delivery
Electric vehicles	21	Electric light commercial vehicles (eLCVs)
Tricycles	8	Freight tricycle
Autonomous robots	8	Sidewalk autonomous delivery robot; autonomous delivery robot

Figure 6 shows the distribution ratios of LMD transportation modes in the selected articles. The most extensively explored modes were parcel lockers (21%) and drones (21%). Trucks (17%) and crowd logistics (12%) followed, and EVs (10%) received considerable attention. The three modes that account for less than 10% are tricycles (4%), autonomous robots (4%), and autonomous vehicles (2%). The two fully automated transportation modes can be attributed to the potential for further development of the actual utilization rate of autonomous robots.

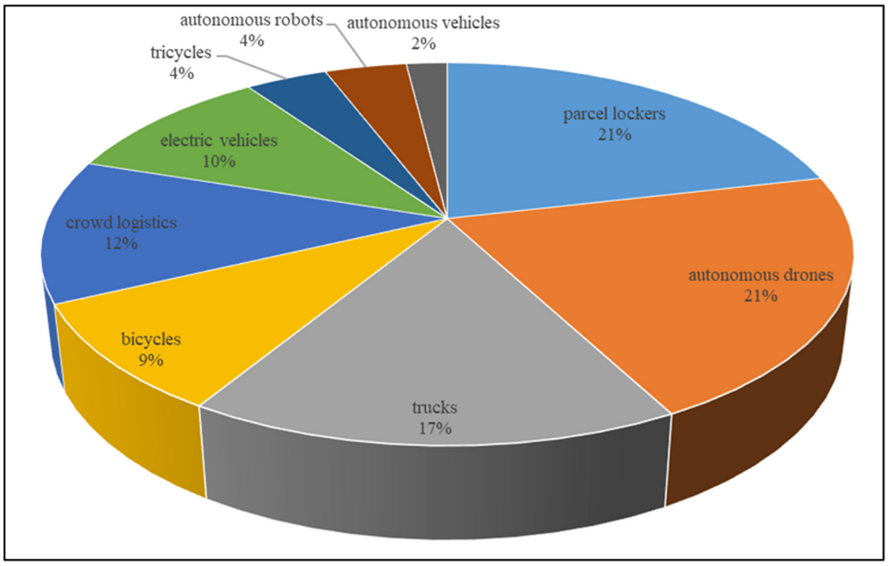

Figure 6. Transportation mode occurrence in LMD articles in 2014–2023.

3.2. Co-Occurrence Network Analysis: Overlay Visualization

In addition to text mining, 150 LMD articles were manually reviewed. Our literature review showed that prior to 2014, most articles on LMD in the logistics field primarily focused on carbon emissions resulting from transportation and the quality of logistics services. From 2014 to 2018, published articles on LMD primarily emphasized technology, operational optimization, supply chain structure, performance measurement, and policy. During this period, only 20 of 150 academic articles focused on LMD transportation modes. After 2018, there was a significant surge in scholarly LMD articles. This finding is further supported by our overlay visualization analysis (Figure 7).

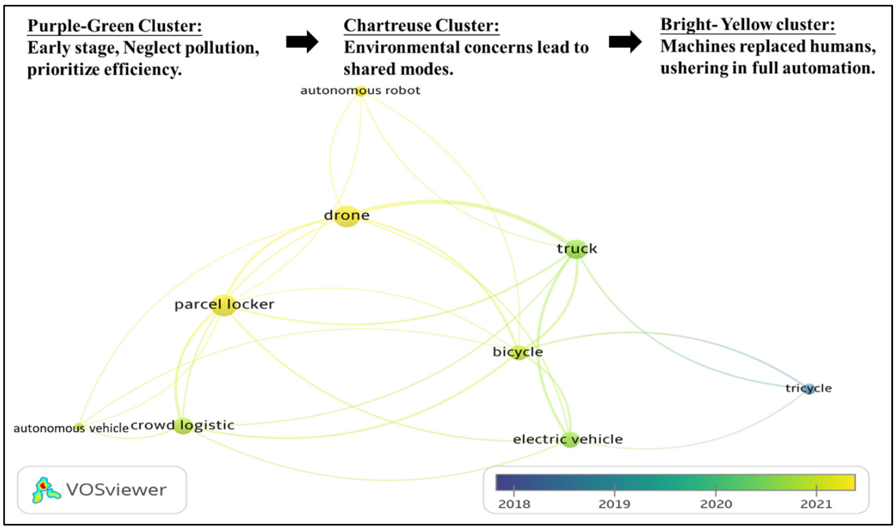

Figure 7. Visualization of transportation modes by article publication year in 2018–2021.

This research revealed that scholarly focus on transportation modes in LMD between 2018 and 2022 can be categorized into three stages: the early stage, characterized by tricycles, trucks, and electric vehicles; the mid stage, featuring crowd logistics, parcel lockers, bicycles, autonomous vehicles, and autonomous drones; and the late stage, represented by autonomous robots. A pattern emerged when examining the complete evolution of the transportation modes (Figure 8). In the early stage, scholars paid scant attention to pollution and focused solely on efficiency. In the mid stage, a growing concern about the environmental impact emerged, leading to the rise in crowd logistics and bicycles in the sharing economy. In the late stage, machines with automation capabilities gradually replaced human labor, ushering in a fully automated era—this trend, however, exists only within the scope of our literature review.

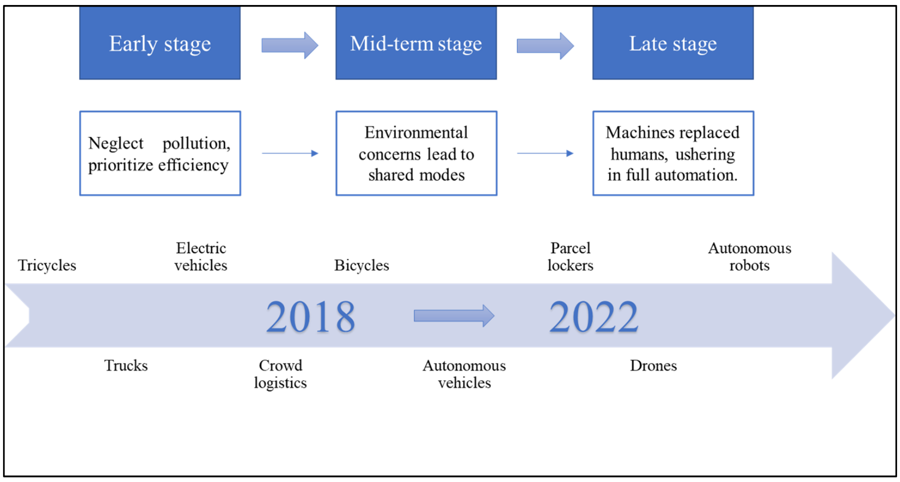

Figure 8. Three stages of transportation mode transformation in LMD articles in 2018–2021.

3.3. Formation of Clusters and Themes

After identifying the most frequently appearing transportation modes in the LMD literature, we shifted our attention toward identifying common areas of concern among scholars in the LMD field and explored the shared clusters and themes among them. Given the significant attention these modes have received in the field of LMD, curiosity has arisen to explore the shared clusters or themes among them. Classification of the shared clusters or themes related to these LMD transportation modes was conducted inductively using a bottom-up approach. First, VOSviewer software was employed to conduct a preliminary analysis, extract frequently occurring keywords, and organize them into groups based on their similar characteristics. Further, we discussed the similarities and uniqueness of the identified groups and subgroups until a consensus was reached. Then, we categorized the LMD transportation modes that appear in the literature into three main clusters and shared themes (Figure 9):

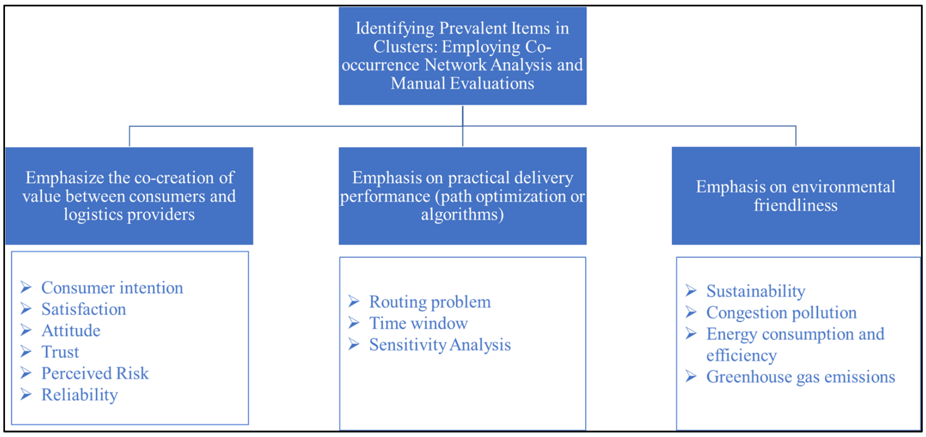

Figure 9. Key clusters and themes of transportation modes in LMD articles in 2018–2022.

Cluster 1, the co-creation of value between consumers and logistics providers;
Cluster 2, practical delivery performance (path optimization or algorithms);
Cluster 3, environmental friendliness.

3.3.1. Cluster 1: Emphasis on the Co-Creation of Value between Consumers and Logistics Providers

Cluster 1 highlights the main factors influencing value co-creation between consumers and logistics providers in various transportation models, including consumer intention, satisfaction, attitude, trust, perceived risk, and reliability.

Value co-creation refers to the collaborative process through which the key players (consumers and logistics providers) in an LMD jointly produce valuable outcomes [22]. This interactive process involves the active participation of customers as value co-creators, whereas logistics providers assume the role of facilitating value creation [23,24]. This implies that when a consumer and a logistics provider are involved in an LMD, each party can influence the logistics service itself. For example, consumers can determine the time or location of pickups based on their personal preferences, and logistics service providers may adjust their delivery times according to the associated risks or benefits. Consumers need to pay varying fees when dealing with baskets of different sizes [25], and suppliers may have to consider specialized transportation methods or means when dealing with varying product characteristics [26]. Thus, value co-creation creates numerous opportunities and challenges. To identify the most prevalent themes in Cluster 1 related to value co-creation, co-occurrence network analysis was employed, and manual evaluations were conducted.

Consumer Intention

Consumer intention is one of the most frequently examined aspects within the cluster of value co-creation, likely because consumers consider factors, such as price, time, reliability, trust, and risk, when making choices regarding LMD logistics services [27,28]. Furthermore, consumer intentions exhibit different representations of LMD across various transportation modes. For example, a study on autonomous delivery vehicles showed that price sensitivity is the strongest predictor of consumer behavioral intentions, followed by performance prediction and hedonic motivation [29].

Parcel lockers. A recent empirical study found that time pressure, perceived behavioral control, and reliability significantly influence the willingness to continue using parcel lockers. This study also discovered that younger consumers exhibited a much higher inclination to continue using parcel lockers than older consumers [30,31]. A study from Iran investigated the impact of consumers' walking distance on parcel locker intention and observed that a coverage area of approximately 250 m was most suitable for parcel locker placement [32]. Similarly, a study from Thailand examined consumers' intention to use parcel lockers and determined that perceived behavioral control and attitudes related to convenience, reliability, privacy security, and compatibility have an impact on consumers' intention to use [33]. Chen et al. (2020) developed a theoretical model with consumer engagement readiness as the underlying structure and demonstrated that for parcel lockers, technology anxiety and service convenience fully moderated the impact of consumer engagement readiness on usage intention [34]. Zhou et al. (2020) empirically examined the psychological factors that influence online consumers' behavioral intentions when adopting parcel lockers. The results indicated that performance prediction, effort expectations, social influence, and promotional conditions were positive determinants for parcel locker adoption [35].

Autonomous drones. Leon et al. (2021) examined the impact of consumers' willingness to adopt autonomous drones in LMD delivery services and found that perceived usefulness had the greatest influence on consumer adaption [36]. Another study discovered that all sub-factors in the extension of the unified theory of acceptance and use of technology (UTAUT2) model had a positive and significant impact on consumer autonomous drone adoption, with personal norms having the most positive influence on user intention [37]. A study of consumer willingness to adopt autonomous drone delivery in the Thai market found that the two antecedents of personal innovation and enthusiasm do not affect Thai users' perceived usefulness of AD delivery services [38].

Autonomous robots. Yuen et al. (2022) conducted a total-effect analysis and found that attitude had the greatest impact on consumers' willingness to use autonomous robots, followed by perceived usefulness and perceived ease of use [39]. Another study explored the factors affecting online consumers' willingness and attitude toward using sidewalk autonomous robots and discovered that attitude, innovation, and optimism have a positive impact on consumers' willingness to use them [40].

Crowd logistics. With the rise in the sharing economy, scholars have considered consumer intention and shared economic transportation modes. Upadhyay and Tiwari (2021) explored the impact of Indian consumer willingness to use crowd logistics platforms on LMD, observed an increasing focus on the potential impact of collaborating with various stakeholders, and highlighted how crowdsourcing can create employment opportunities and generate income [41].

Numerous studies on consumer intention have demonstrated its significance in the field of LMD. At the consumer level, consumer intentions can influence decision making, enhance usage and loyalty, and have a profound impact on logistics. For logistics service providers, consumer intentions can aid in predicting market demand and delivering personalized services. However, as most studies either reference or rely on existing theoretical models from other fields, and no specific consumer intention models exclusively tailored to the LMD domain exist, future research should explore this area.

Satisfaction

Satisfaction is widely recognized as a significant predictor of individuals' ongoing behavior, often reflecting their perception of performance satisfaction, which is a psychological experience [42]. Consumers' perceived satisfaction is one of the most crucial factors determining user retention rate [43]. However, scant research on consumer satisfaction with express delivery services in e-commerce exists [44]. Satisfaction has a significant and direct impact on user behavior, and the positive role of satisfaction in promoting consumption intention has been verified in numerous studies. However, few studies have demonstrated the direct and positive influence of satisfaction on consumption behavior [42]. With the growth of online and omnichannel retailing, consumer satisfaction with logistics services has become increasingly important in LMD [45].

In various LMD modes, consumer satisfaction directly and positively affects user behavior (nonconsumption behavior). The moderating effect of perceived satisfaction highlights the need to derive positive stimuli from this psychological factor to bridge the gap between intention and behavior [46], in which satisfaction acts as an intermediary variable, significantly impacting two paths in LMD (behavior intention ← risk and user behavior ← promotion condition), as risk negatively influences satisfaction, thereby altering consumers' psychological expectations and enhancing behavioral intentions. Conversely, favorable accommodation can increase satisfaction, ultimately increasing the likelihood of behavioral adoption. This finding confirms the positive impact of satisfaction on consumer trust and loyalty, ultimately influencing their behavior [47]. Hong et al. (2019) proposed that the practicality, communication, reliability, and influence of logistics services are important predictors of consumer satisfaction [48]. Similarly, Huang (2019) demonstrated that efficient delivery is a key factor for consumer satisfaction [49]. Akeb et al. (2018) supported this view by asserting that delivery services in LMD significantly affect customer satisfaction in an online shopping environment [50]. Thus, consumer satisfaction is typically determined by the discrepancy between their expectations and perceived experience of a product or service [43], further highlighting the importance of satisfaction when consumers encounter different LMD modes of service.

We found that scholars have also conducted research on the satisfaction of logistics service providers. A study from Nanjing, China, analyzed the travel satisfaction of electric two-wheeler delivery riders and found that factors such as safety and accessibility, environmental comfort, delivery convenience, policy acceptance, and perceived pressure positively impact delivery travel satisfaction, whereas delivery penalties have a negative impact [51]. Similarly, low satisfaction among service personnel has been shown to lead to excessive turnover and reduced work motivation within the LMD industry [52]. Investigating the satisfaction factors of logistics service personnel using electric tricycles for LMD under policy intervention, researchers observed that perceived convenience, sound policies, legality, and dispatcher satisfaction were significantly and positively correlated, whereas the standardization system was negatively correlated with the satisfaction of logistics service personnel [53].

Overall, in LMD, consumer satisfaction is crucial as it guarantees loyalty, retention rate, and subsequent behaviors. Similarly, for logistics service providers, satisfaction is essential for ensuring employee retention and motivation.

Attitude

Attitude is a primary concept in social psychology. Its original meaning refers to behavioral beliefs that can be favorable or unfavorable towards behavioral intentions. Attitude influences information processing, represents an evaluative judgment of an object of thought, and reflects an individual's assessment of the desirability of the behavior in question [54–56].

Based on the understanding that attitudes involve evaluations of behavior and are influenced by beliefs about the outcomes of that behavior [57], attitude plays a significant role in shaping people's inclinations toward selecting modes of LMD. For instance, individuals may exhibit more favorable attitudes toward environmentally friendly modes of LMD [58]. Scholars have emphasized the significant positive correlation between attitude and behavioral intention, according to the theory of planned behavior. This suggests that attitude influences individual behavioral intention [59,60]. Furthermore, consumers' favorable attitudes toward objects or technologies directly influence their acceptance and usage [61]. Consequently, consumer attitude plays a pivotal role as a prerequisite for adopting specific modes of transportation in the context of LMD, and numerous studies in this field have investigated the significance of attitude toward consumers' behavioral intention and their subsequent impacts [40].

Autonomous vehicles. Yuen et al. (2017) proposed that attitudes toward autonomous vehicles involve individuals' evaluations of autonomous vehicles, which can be positive or negative [62].

Parcel lockers. Wang et al. (2018) revealed that only perceived relative advantage directly affects intention, whereas compatibility and complexity have an indirect effect through attitude [61]. In contrast, a survey on parcel lockers in Thailand found that perceived relative advantage, compatibility, and complexity could directly or indirectly influence Thai consumers' intentions without involving attitudes [33]. Exploring consumers' attitudes toward new delivery services such as home delivery or parcel lockers, de Oliveira et al. (2017) evaluated Brazilian consumers using contingent valuation, and the results showed that although home delivery remains consumers' primary choice, the parcel locker pickup method has a considerable potential customer base [63].

Overall, in the LMD field, consumer attitude plays a crucial role in selecting the appropriate means of transportation. A positive attitude typically leads to consumers becoming more inclined toward choosing and adopting a specific mode of transportation. However, our review of the extant literature on LMD emphasized that research on attitudes has focused primarily on fully automatic delivery methods or parcel lockers. This indicates the urgency of scholarly focus on attitude in LMD.

Trust

Trust has been studied in various social sciences including psychology, political science, and economics. Each discipline offers a different perspective on the role of trust in social processes. The literature identifies different categories of trust, such as characteristic, rational, and institutional trust [64]. Considered essential for organizational success, trust requires time and effort to establish [65]. Building customer trust in an organization can lead to efficient business operations and continuity. Consequently, the development of trust is expected to increase consumer willingness to use a service, highlighting the equal importance of trust in their choice of transportation mode in LMD [66].

Scholars have used various approaches to measure the impact of trust, including multiple regression models [67] and structural equation modeling [68]. Most of these studies treat trust as an independent or latent variable with a mediating effect [69]. Upadhaay et al. (2021) evaluated the mediating role of trust in crowdsourcing sharing economic platforms, revealing a positive correlation between the willingness to participate in the sharing platform and trust in crowd logistics carriers (travelers, movers, authorized drivers) [41]. Trust is also considered a fundamental aspect of the sharing economy, particularly when discussing shared transportation modes such as crowd logistics. Numerous studies have explored the relationship between trust, reputation, and perceived risk and have found that trust partially or fully mediates these factors [19,70,71]. Trust is also closely related to various service attributes such as delivery time, delivery cost, and the professionalism and experience of couriers [28]. Furthermore, trust has been found to influence consumer willingness to use autonomous delivery services [36]. Overall, the topic of trust in service provider capabilities is an emerging topic in the LMD literature, as trust is recognized as a significant factor driving the adoption of transportation modes in LMD.

Perceived Risk

Perceived risk refers to the emotional impact experienced during decision making. Emotional responses to hazardous situations often differ from cognitive assessments of risks—in such cases, emotions tend to drive behavior [72]. Perceived risk can be categorized into five dimensions: financial, security and privacy, performance, social, and time risks [73]. Security and privacy risk is a common concern in online businesses, particularly related to potential losses associated with the improper use of personal information, especially in the context of big data [74]. Performance risk refers to the possibility that a product or service may not meet an expected performance level, which is particularly relevant for the promotion of new technologies [75]. Social risk pertains to the fear of losing one's position in a social group, whereas time risk refers to the potential waste of time or making wrong purchases [76].

The literature on perceived risk in the LMD mainly focusing on the aspects of privacy risk and performance risk was discovered. Security and privacy risk is a common concern in the online environment, and logistics service providers must address the risk of privacy breaches to influence consumer behavioral intentions. Some scholars noted that perceived privacy risks have a significant impact on the willingness to use drone delivery services, with no significant moderating effect observed [77]. Performance risk relates to products or services that do not meet expectations, such as the loss of items by service providers. Ganjipour and Edrisi (2022) found that the need for human–computer interaction and perceived risk negatively impact consumer adoption of autonomous drone delivery services [37]. Another study demonstrated that increasing the perceived privacy risk leads to a decrease in the willingness to adopt autonomous drone delivery services [36]. A study in Thailand revealed that users' perceived privacy risk negatively moderates the perceived ease of use and adoption of autonomous drone delivery services [78]. Other scholars have explored the structural differences in risk belief systems among individuals with varying attitudes toward autonomous delivery. The results showed that targeting risk beliefs at the structural center rather than at the periphery with autonomous delivery risk-reduction information led to greater changes in the public's risk belief system and risk perception [79].

Similar risk studies have been conducted for other modes of transportation. For example, Ganjipour (2022) found that performance and delivery risks negatively affect consumer adoption of autonomous robots [40]. A study on autonomous vehicles in Germany demonstrated that perceived risk is a significant predictor of consumers' behavioral intentions [29]. Another study discovered that perceived risk is a negative factor that influences behavioral intentions in the context of parcel locker services [79]. These findings indicate that perceived risk is a common consideration for various transportation methods within LMD. However, our review found that more attention seems to be paid to the perceived risk associated with emerging transportation modes, such as the various fully automated modes of transportation in LMD.

Reliability

Reliability refers to a service provider's ability to perform promised services independently and accurately [80]. It is considered a fundamental dimension of service quality and is crucial for self-service technologies. Any lack of reliability can waste time for consumers [81]. Consequently, reliability is generally considered as one of the most important factors when selecting a service [82]. Numerous studies have demonstrated the significant impact of reliability on the willingness to continue using a service. For instance, Shao et al. (2020) found that location reliability significantly influences the intention to continue using bike-sharing services [83]. As reliability is associated with the direct benefits consumers receive, Yuen et al. (2019) discovered that consumers generally perceive parcel lockers as more reliable than home delivery services due to reduced chances of delivery delays and the avoidance of delivery failures when no one is available to accept a package at home [84]. Furthermore, empirical studies have confirmed the positive effect of reliability on Thai consumers' willingness to use parcel lockers [33]. Another empirical study conducted in Tianjin, China, revealed that the reliability of parcel lockers significantly influences Chinese consumers' intentions to continue using them [31]. In summary, our review of transport modes in LMD indicated that most research on reliability has focused on parcel lockers modes.

3.3.2. Cluster 2: Emphasis on Practical Delivery Performance (Path Optimization or Algorithms)

Cluster 2 focuses on optimizing the delivery performance in various LMD transportation modes, including time window management, routing problems, and sensitivity analysis. Delivery performance is an inherent challenge in the last mile, whether it pertains to the value co-creation between buyers and logistics providers in Cluster 1, or the actual delivery efficiency in Cluster 2. The ultimate goal is to meet the expectations of both parties, enabling the maximization of efficiency and benefits for consumers and logistics service providers. Therefore, in the last mile, logistics service providers must prioritize and continuously improve delivery performance across all transportation modes.

Routing Problems

Dantzig and Ramser (1959) are credited with pioneering the formulation of the vehicle routing problem (VRP) [85]. The Vehicle Routing Problem (VRP) represents a combinatorial optimization and integer programming challenge, which revolves around identifying the most efficient collection of routes for a fleet to distribute goods to a specified group of customers. Typically, the cost is computed based on either the overall distance covered by the vehicles or the cumulative travel time, all with the goal of minimizing the total routing expenses [86]. Over the years, researchers have made numerous refinements, such as Clarke and Wright (1964), who introduced an efficient greedy algorithm known as the saving algorithm, which improved upon [87].

Owing to the non-deterministic polynomial-time hardness nature of the problem, solving VRP instances using mathematical programming or combinatorial optimization may have limitations in terms of scalability. However, researchers continue to persevere in finding optimal solutions for the VRP in various LMD modes.

In relation to EVs, Lijun and Zhang (2023) carried out an investigation into the semi-open time-dependent multisite EV routing problem, taking into account battery charging and swapping within the context of LMD [88]. A mixed-integer programming model was developed, considering factors such as EV energy consumption, travel time, and carbon emissions. Given the intricate nature of the problem, they introduced a multi-objective simulated annealing algorithm to assess the economic and environmental advantages of the semi-open collaborative distribution approach. The findings indicated that the algorithm exhibited strong performance and yielded high-quality solutions, effectively reducing the overall cost and carbon emissions of logistics firms through collaborative distribution. In a separate investigation, Wang et al. (2022) concentrated on formulating a location-routing problem that incorporated pickup stations, optimizing both the placement of pickup stations and the scheduling of EV deliveries simultaneously [89]. The primary aim was to meet the overall demand while simultaneously reducing the total cost, comprising the opening and processing expenses of the pickup station, along with the fixed and routing costs associated with EVs. To tackle this challenge, they introduced an effective branch-and-price algorithm. It is worth noting that despite advancements in battery technology, concerns about the limited driving range of EVs still pose a significant obstacle to their widespread use in logistics [90]. Qi et al. (2018) met this demand by presenting fresh logistics planning models and offering valuable management insights [91].

Regarding crowd logistics, scholars generally believe that crowd logistics has a significant impact on regional travel behavior [92]. Contrary to conventional truck-only systems that incur higher operational costs, transitioning to this approach holds the promise of generating economic advantages. These include downsizing the truck fleet; capitalizing on increased operational adaptability, such as steering clear of high-demand zones and peak hours; and adapting vehicle load capacities. Additionally, researchers like Arslan et al. have devised an accurate technique to address the information matching challenge inherent in crowdsourced logistics. Their findings suggest that, compared to the traditional delivery method employing dedicated vehicles, employing temporary drivers may render the last-mile segment more cost-efficient [93,94].

Regarding autonomous robots, their inefficiency limits their application in LMD owing to the low number of orders delivered per trip. Liu et al. (2022) extended the two-level vehicle transportation costs and emissions and proposed a mixed-integer programming model, efficiently solving it using a cluster-based artificial immune algorithm [95]. The results showed that compared to existing methods in the LMD literature, this solution provided a better outcome. Nguyen et al. (2022) investigated the parallel drone scheduling vehicle routing problem, which addressed the minimum-cost parallel autonomous drone scheduling vehicle routing problem [96]. This study proposes a mixed-integer linear program and ruin-and-recreate algorithm, which outperformed the other algorithms in terms of solution quality.

In the context of integrating autonomous drones with trucks, Rave et al. (2023) formulated a tactical planning model. This model aimed to pinpoint the most cost-effective positions for dedicated drone stations within fleets and logistics service providers, all with the goal of minimizing overall expenses. Additionally, they presented a transportation study focused on Last-Mile Delivery (LMD) methods in rural regions [97].

Zhen et al. (2023) investigated a variation of the VRP within an innovative cooperative delivery framework involving both trucks and autonomous drones [98]. A mixed-integer programming model was developed to address this issue, and an optimal solution approach was crafted using a branch-and-price-and-cut algorithm to solve the proposed model. Moshref-Javadi et al. (2021) conducted an assessment and comparison of three distinct delivery models involving trucks and autonomous drones [99]. The routing problem in question was mathematically defined, and theoretical limits were established to showcase the maximum potential cost savings achievable when compared to truck-only routes. Their research revealed that increased coordination between trucks and autonomous drones can lead to substantial reductions in customer waiting times.

Our review revealed that numerous cases of autonomous delivery associated with trucks have been reported in the LMD field. Scholars generally believe that trucks combined with autonomous delivery are more competitive than pure autonomous delivery, which may provide new ideas for autonomous delivery in LMD [100,101].

Time Windows

Early formulations of the VRP typically overlooked time windows. Zachariadis et al. (2015) expanded the scope of the VRP to encompass simultaneous pickup and delivery services, though they did not consider the inclusion of time windows for these services [102]. However, with the development of the electronic logistics industry, vehicle routing problems with time windows have emerged as an inevitable trend. In this situation, multiple vehicles depart from a central depot and attend to customers located at various geographic points. Each customer has distinct item requirements and specified service time windows. The aim is to reduce the combined travel and waiting times of vehicles to a minimum, all while guaranteeing that customers receive service within their allocated time frames [103]. With the evolving requirements of LMD, the open VRP—a distinct variant of the VRP characterized by the open nature of vehicle routes—has emerged. Unlike the closed VRP, in which vehicles are required to return to their original starting points after completing delivery tasks, the open VRP allows for open-ended routes [104]. After 2000, with the rapid growth of the logistics distribution industry, the significance of the open VRP has increased, as it has the potential to lower travel costs, particularly in the domain of LMD distribution [104]. The open VRP is further classified into two categories based on the strictness of the time constraints: the open VRP soft time open window and the open VRP hard time window. In an open VRP soft time window, the objective is to reach each visit within the time window as much as possible, with penalties for early or late arrivals. In contrast, an open VRP hard time window requires visits to occur strictly within a specified time window, with service being denied otherwise. Currently, metaheuristic algorithms primarily focus on solving the open VRP hard time window [105]. Nowadays, the issue of time windows in LMD extends beyond the vehicle routing problem and encompasses other transportation modes such as parcel lockers or autonomous drones.

In the field of autonomous delivery, Chen et al. (2021) presented an innovative variation of the VRP that incorporated time windows and included the use of delivery robots, which provided a mathematical model that saved significant operating time, and then introduced a two-stage mathematical algorithm to solve medium-scale instances, thereby addressing the challenges encountered by autonomous robots [38]. Lin et al. (2022) devised a model aimed at maximizing revenue, which took into account time windows and customer satisfaction. Their results demonstrated that this model provides effective solutions applicable in real-time delivery settings [106].

In the domains of autonomous delivery. Ostermeier et al. (2022) proposed a cost-optimal routing method for trucks and robotic systems in LMDs with time windows [107]. Their approach focused on minimizing the number of delivery trips while considering the available robots. The results indicated that the truck and robot concept can reduce last-mile costs by up to 68% compared with truck-only deliveries. Similarly, Di et al. (2021) addressed the problem of arranging autonomous robot-equipped truck fleets for last-mile deliveries. The issue was defined as a mixed-integer linear program, and a heuristic program was created to deliver services to customers using either trucks or autonomous drones, all within a predefined time frame [108].

The introduction of self-collection parcel lockers brought about the time window problem, not only in discussions on vehicle routing but also in the context of parcel locker self-collection. Punakivi and Saranen (2001) explored delivery time windows for human reception in Finland, which typically ranged from one to three hours [109]. Considering such time window constraints, the parcel locker service has transitioned from manned to unattended services, allowing customers to select delivery time windows. Punakivi and Tanskanen (2002) subsequently showed that, in contrast to the traditional model of human-operated reception with a two-hour delivery time frame, the shared reception box concept led to a substantial reduction in transportation expenses, ranging from 55% to 66% [110]. Merkert et al. (2022) examined competition priority and willingness to pay for time window attributes in parcel locker services in Australia [9]. This study found that people prefer parcel locker mail services over autonomous delivery when the same time window attributes are ensured.

Some scholars considered the time window problem in the context of combining parcel lockers and vehicle operations. For example, Vincent et al. (2022) proposed a new variant of the time window VRP that incorporated locker delivery as a delivery option [111]. A combination of the parcel locker and VRP was used to formulate a new mathematical programming model. To address the VRPPL, a simulated annealing (SA) algorithm was developed. Similarly, Giovanni and Novellani (2022) focused on the routing problem of using one or more cars for direct package delivery to customers or lockers [112]. The effect of introducing lockers was investigated by considering the time windows of these problems. A set of novel formulations was proposed by researchers, and the differences between routing problems with lockers and classical routing problems were examined.

In the realm of Evs, Rastani and Çatay (2021) reexamined the established EV routing problem involving time windows. They incorporated the load weight carried by the EV and introduced two distinct mathematical formulations for the problem. These formulations were then subjected to testing using commercial solvers to assess their performance, particularly in scenarios involving small load instances [90].

Sensitivity Analysis

As a mathematical modeling technique, sensitivity analysis has a high occurrence rate in research related to LMD modes. It is primarily used to identify influential factors among various uncertain variables and analyze their impact on target indicators, including the degree of impact and sensitivity. Our review found that sensitivity analysis appears to be the preferred method for exploring model robustness in LMD.

As an illustration, Kahr (2022) illustrated how various problem parameters influence the planning and design of outdoor parcel locations through sensitivity analysis. The findings underscored that the implementation of parcel lockers can serve as an effective support mechanism for LMD, offering substantial returns on relatively modest investment costs [113]. In terms of the parcel locker compartment design, Kahr recommended a preference for small and medium compartments over large and extra-large compartments. In a Turkish study, a unique approach, which combined the Bayesian best-worst method with Pythagorean fuzzy weighted aggregated sum product assessment, was chosen for determining the optimal placement of parcel lockers. Following that, a sensitivity analysis was utilized to assess the model's resilience and pinpoint the most suitable placement for parcel locker storage units within Istanbul [114].

Koshta et al. (2022) conducted tests and evaluations using gray decision-making tests and evaluation laboratory technology to assess the application of autonomous drone delivery in rural healthcare supply chains [115]. They utilized a simulated annealing algorithm to test the stability of the model and concluded that a "lack of government regulation" was the most critical obstacle. The findings revealed seven causal barriers and six affective barriers, with "limited load capacity", "low range", and "difficulty flying in bad weather" being the most prominent reasons for obstacles. Additionally, barriers such as "lack of skilled manpower", "limited precision of navigation systems", and "lack of leadership commitment" were identified as significant obstacles to effectiveness. Wangsa et al. (2022) devised algorithms that take into account cost and environmental considerations to pinpoint effective LMD choices. These algorithms enable the determination of the most favorable values for order quantity, safety factor, delivery time, total emissions, and delivery quantity [116]. A sensitivity analysis was used to illustrate the proposed model. Through a comparative analysis, it was found that in LMD, apart from being environmentally friendly, the overall cost of using autonomous delivery is lower than that of motorcycles, resulting in potential savings of approximately 3–4%. In another study, Cokyasar et al. (2021) proposed an autonomous drone delivery network that utilized automated battery-swapping machines to extend its range [117]. They designed and introduced three related solutions that were validated through a sensitivity analysis. The results indicate that the service time and cost are key parameters for long-term autonomous drone delivery.

As evidenced by the frequent use of sensitivity analysis, path planning in LMD continues to pose challenges and uncertainties. Therefore, further quantitative studies are required to comprehensively understand this problem, which involves numerous uncertainties, and gain deeper insight into this topic.

3.3.3. Cluster 3: Emphasis on Environmental Friendliness

In recent years, the rapid expansion of e-commerce has significantly reshaped the transportation landscape, primarily due to the surging need for LMD services in urban regions.

The proliferation of e-commerce is widely recognized as the primary driver behind the surge in urban truck traffic, consequently leading to a substantial environmental concern [118–120]. According to our review, the primary focus of scholarly attention in the LMD literature is Cluster 3, environmental friendliness, and the themes of sustainability, congestion pollution, energy consumption and efficiency, and greenhouse gas emissions. This can be divided into externality and sustainability types. Within the realm of LMD transportation, negative externalities primarily encompass air pollution and greenhouse gas emissions, which contribute to climate change, as well as noise pollution and traffic congestion [121,122]. Sustainability covers a broad range, and in this context, all "change processes that align resource development, investment direction, technology development direction, and institutional change with future and current needs" except those related to externalities are listed as the category of sustainability [123,124]. As per this definition, the initial step toward guaranteeing an improved quality of human life and sustainable resource management is the efficient mitigation of adverse external impacts [122].

Sustainability

The United Nations has proposed 17 sustainable development goals, 169 specific goals, and more than 200 indicators to achieve its 2030 agenda. In contemporary society, sustainability is assuming a growing significance and can be defined as "fulfilling the current needs while safeguarding the future generations' capacity to fulfill their own requirements".

The scope of our literature review shows that in the exploration of various modes of LMD, scholars mainly discuss sustainability from three aspects: economic, environmental, and social sustainability.

Malik et al. (2023) pointed out that electric cargo bicycles offer the prospect of enhancing the sustainability of urban logistics activities, particularly for LMD, as viable substitutes for traditional electric cars and vans. In warmer and drier weather, small businesses exhibit a preference for utilizing electric cargo bikes for transporting goods over longer distances [125]. Gonzalez et al. (2022) contended that cargo bikes and trikes have surfaced as profitable choices for enhancing the effectiveness of LMD within Latin American cities, where issues like underdeveloped infrastructure and inadequate investment in innovative technologies pose challenges to freight transportation [124].

In their 2018 study, Buldeo et al. examined which crowd logistics strategies garnered the highest level of endorsement from stakeholders engaged in sustainable development initiatives, aiming to ensure quicker and more adaptable delivery solutions [126]. Frehe and Teuteberg (2017) introduced a novel idea for the sustainable integration of crowd logistics, founded on the inherent qualities and attributes of the crowd logistics business model [127]. Crowd logistics is a collaborative strategy that assigns delivery tasks to many participants who act as ordinary couriers to reduce delivery costs and support sustainability.

Regarding autonomous drones, Bányai (2022) focused on the impact of integrated autonomous drone services based on trucks in LMD and analyzed the solution's impact on environmental impact and sustainability [128]. Baldisseri et al. (2022) assessed the sustainability, both from an environmental and economic perspective, of delivery methods in Last-Mile Delivery (LMD) that incorporated autonomous drone-equipped electric trucks. Their evaluation involved a comparison with conventional logistics systems [129]. The findings indicated that the option combining trucks and drones had the potential to substantially lower emissions, with cost efficiency primarily hinging on the degree of drone automation. Nevertheless, it is crucial to take into account possible shortcomings in social sustainability, particularly concerning safety and equity [130]. In addition to delivery speed and cost, environmental and social sustainability factors play increasingly important roles in LMD. From this perspective, the autonomous drone distribution of autonomous deliveries may be a good choice in terms of transportation speed and sustainability, as UAVs are powered by electricity, thereby reducing their impact on the environment [131]. Scholars have suggested that electric vehicles (EVs) could serve as a viable replacement for internal combustion engine vehicles (ICEVs) to alleviate their detrimental effects on environmental sustainability [120].

Despite significant progress, sustainability in LMD still encounters significant challenges, particularly in urban areas. The central concern revolves around meeting the demands of urban consumers within the parameters of the transportation system's functions and requirements, all while making consistent strides in sustainability. This subject holds paramount significance for the sustainable progression of urban areas across diverse LMD transportation modes, calling for sustained, long-term investigation [132].

Congestion Pollution

Many research inquiries have delved into the societal and environmental consequences of LMD in urban regions, particularly in the context of e-commerce, primarily focusing on traffic congestion and air pollution, which are discussed in the pollution part in detail in a later section. Congestion has always been a significant challenge for urban last-mile transportation systems. Generally, the longer the congestion time during transportation, the more severe the corresponding negative issues [133]. Ranieri et al. (2018) found that congestion in urban areas leads to increased travel times, higher fuel consumption, reduced public transport efficiency, and delays [122]. Therefore, effectively addressing congestion is crucial for ensuring environmental sustainability. In the literature, scholars have proposed two solutions to alleviate congestion in LMD. Cargo bicycles present an alternative to motorized freight vehicles, providing versatility and efficient goods delivery in densely populated European urban settings, all while producing zero emissions [134].

Autonomous delivery is a promising alternative to LMD because it can reduce road congestion without interfering with land infrastructure. Nevertheless, the adoption of autonomous delivery faces constraints, including limited battery capacity and a restricted delivery range, necessitating the deployment of large fleets in commercial-scale operations. Low-altitude air congestion may occur in such cases. To address this, in 2021, She and Ouyang introduced a finite element method as a numerical solution to address flow balance and compute system performance. This approach provides an improved means of alleviating congestion in low-altitude airspace [135].

Additionally, enhancing the utilization of shared transportation, pedestrian and cycling pathways, automation, integration, and multimodal transport will markedly diminish congestion in the transportation sector, ultimately fostering enhanced health and well-being. Recognizing the vital role of addressing congestion issues in various modes of LMD, the Commission emphasizes the importance of prioritizing sustainable transitions in the transportation of people and goods.

Energy Consumption

In light of global initiatives aimed at diminishing the reliance on fossil fuels, such as the UK government's intention to cease the sale of new gasoline and diesel vehicles by 2035, it becomes imperative to investigate alternative fuel sources [136]. Based on our literature review, scholars in the field of LMD models have proposed replacing petroleum energy with electric energy. The research findings indicated that a numerical examination of various scenarios revealed a potential reduction in energy consumption by approximately 87% through the incorporation of autonomous delivery applications and the integration of first- and last-mile delivery operations. Furthermore, a study introduced a novel approach to assess the influence of diverse truck–drone collaborative delivery solutions on energy efficiency, lending support to the concept of autonomous delivery as an effective means to curtail energy consumption [128].

However, Kirschstein (2020) holds the opposite opinion. His proposition suggested that, across all stages of autonomous drone flight (including takeoff, level flight, hovering, and landing), the application of autonomous drones within static warehouses typically lacks an energy consumption advantage over conventional truck-based distribution systems, particularly in densely populated areas [137]. Autonomous drones exhibited an energy consumption range of 440 to 1300 g of carbon dioxide equivalent per delivery (g CO_2e/delivery), while delivery vans and EVs displayed ranges of 89 to 600 g CO_2e/delivery and 66 to 530 g CO_2e/delivery, respectively. These findings imply that conventional vans might represent a more favorable option.

Furthermore, Ramroth et al. (2013) demonstrated that EV freight transportation can yield substantial fuel savings. However, the ultimate economic feasibility relies on variables like battery costs and the distance driven on a daily basis [138]. High utilization has been identified as the key to cost-effective EV adoption. However, as previously mentioned, high utilization increases the risk of battery degradation [139]. In EV, effectively solving the battery degradation risk problem remains a topic worth exploring.

Greenhouse Gas Emissions

The primary driver of climate change is the release of greenhouse gases into the atmosphere. The significance of greenhouse gas emissions comes to the forefront in transportation planning because the worldwide transportation industry contributes to around 20–25% of the total global greenhouse gas emissions. This places it in second position, following only the electricity and heating sectors [140]. The transportation sector, including road, air, and sea transport, is responsible for a significant share of global CO_2 emissions, with 74%, 12%, and 12%, respectively. These emissions have more than doubled over the past 45 years, causing severe consequences for the environment and human society. Thus, the implementation of decarbonization measures within the transportation industry is imperative. Such policies are essential to substantially mitigate the adverse climate and environmental effects while simultaneously safeguarding the economic and social sustainability of transportation [141].

Efforts to tackle this concern have seen a rise in both national and local initiatives. These encompass the formulation and implementation of regulatory frameworks spanning the transportation, energy, and economic development domains. Notably, the European Council has established ambitious objectives for the European Union, with a primary aim of slashing greenhouse gas emissions by a minimum of 55% by 2030. This directive aligns with the overarching goal of achieving climate neutrality by the year 2050 [142]. In the context of LMD transportation, one solution for reducing greenhouse gas emissions is to gradually transition urban freight to transportation methods that generate less air pollution, such as EVs, autonomous delivery, or cargo bicycles. These alternatives have proven to be effective in reducing greenhouse gas emissions [132].

Research conducted earlier has revealed that autonomous drone aircraft release 3.5 g of CO_2 equivalent per 0.8 km when flown within urban settings and 40 g of CO_2 equivalent per 8.83 km when operated in rural regions [143]. Bányai (2022) posited that utilizing autonomous drones for integrated services from the first to the last mile can significantly reduce energy consumption and virtual greenhouse gas emissions, thereby establishing a more sustainable logistics system [128]. On the contrary, Stolaroff and colleagues (2018) conducted an assessment of the overall environmental impact across the lifecycle of an autonomous drone delivery system that incorporates various intermediate fixed local warehouses to link regional distribution centers with end consumers. In this particular scenario, the deployment of small autonomous drones for deliveries (0.5 kg) generally results in a reduction in CO_2 emissions per delivered package (around 600 g CO_2e/delivery for drones compared to 1000 g CO_2e/delivery for electric trucks) [144]. However, a large autonomous drone with an 8 kg payload would result in higher emissions (approximately 1300 g CO_2e/delivery) compared to an EV or a small delivery van.

Although some studies have suggested that autonomous delivery can effectively reduce greenhouse gas emissions, other scholars have different opinions. As an illustration, Figliozzi (2017) conducted a comparison between autonomous drones and trucks, ultimately determining that, in terms of emissions per kilogram and per unit distance, trucks emerge as the most environmentally sustainable mode of transportation [145]. This means that drones can only reduce emissions compared to trucks if each truck completes fewer than 10 deliveries on a single route.

Apart from autonomous drone transportation, several other studies have underscored the carbon emission benefits of cargo bicycles and tricycles when compared to conventional vehicles like vans and trucks. Bicycles and tricycles have demonstrated noteworthy enhancements in reducing both CO_2 emissions and PM2.5 particulate matter, achieving reductions of approximately 50% and 59%, respectively [146].

Allen et al. (2018) delved into the utilization of light goods vehicles for parcel deliveries within central London. Their study revealed that limited vehicle usage in LMD operations results in extended delivery times and increased emissions of CO_2 and other greenhouse gases [146]. Certain researchers have examined the implementation of electric vehicles (EVs) in Milan, Italy, and their findings indicate that adopting EVs can lead to a decrease in greenhouse gas emissions. Specifically, a reduction of 17% (20 km per day) to 54% (120 km per day) in greenhouse gas emissions was observed. Furthermore, the reduction is even more significant with a higher daily mileage [120].

To sum up, while innovative transportation methods like autonomous driving hold promise in potentially lowering greenhouse gas emissions by utilizing electricity, this outcome is not guaranteed. In situations where the LMD delivery process involves excessively long distances or requires high transportation frequency, traditional truck transportation may be a more effective solution than autonomous delivery transportation for reducing greenhouse gas emissions. Therefore, future research should explore alternative transportation modes to replace existing ones, ensure transport efficiency, and minimize greenhouse gas emissions during the LMD process.

4. Conclusions

In this section, we discuss our findings of the general research trends in LMD transportation modes, commonly adopted data collection and analysis methodologies, and recommendations for future research.

4.1. General Research Trends in LMD Transportation Modes

Our systematic review of the LMD literature identified nine LMD transportation modes of scholarly focus: parcel lockers, autonomous drones, trucks, bicycles, crowd logistics, EVs, tricycles, autonomous robots, and autonomous vehicles. We found that with the expansion of e-commerce, there has been a significant increase in the number of articles exploring various modes of transportation in the LMD field since 2018. As the general trend in LMD is toward full automation and minimal environmental impact, academic research in this area is expected to continue to grow in the coming years.

In terms of transportation modes, we found that the three key areas in LMD were parcel lockers, autonomous drones, and trucks. However, with the progression of Industry 4.0 to Industry 5.0 and the further development of artificial intelligence technology, we expect that autonomous drones, autonomous robots, and autonomous vehicles will gradually become more important. Additionally, we posit that the EV market should not be underestimated. In conclusion, we suggest that future scholars should focus on practical research on autonomous delivery, autonomous drones, autonomous vehicles, and EVs in LMD to provide further insights for managers, policymakers, and other stakeholders.

4.2. Opportunities, Challenges, Implications, and Limitations

LMD transportation modes face various opportunities and challenges. Based on our systematic review of the LMD literature, we identified three main clusters, each with specific themes. The first cluster highlights the main factors influencing value co-creation between consumers and logistics providers in various transportation models, including the themes of consumer intention, satisfaction, attitude, trust, perceived risk, and reliability. In terms of the value co-creation between consumers and logistics providers, younger consumers are generally more inclined to use fully automated transportation methods than older consumers. Perceived usefulness has the greatest impact on consumer willingness to adopt autonomous delivery and transportation. Additionally, price sensitivity is the strongest predictor of consumer behavioral intention. This implies that logistics providers should pay more attention to younger consumer attitudes, perceived usefulness, and price sensitivity when offering autonomous delivery transportation modes. We found that the theme of satisfaction plays a crucial role before actual usage because it directly influences user behavior and subsequently affects consumer trust and loyalty. Therefore, logistics service providers should actively improve important factors that predict satisfaction such as the practicality, communication, and reliability of their services [49]. Apart from these two critical themes, other themes such as attitude, trust, perceived risk, and reliability also hold varying degrees of importance in co-creating value, and management should give this adequate attention. Despite numerous proposals of measurement schemes for value co-creation (including measuring its antecedents), academics still lack a dedicated model that comprehensively explains the various modes of transportation in LMD. Hence, future researchers should conduct more in-depth studies on this topic.

The second cluster focuses on optimizing the delivery performance in various LMD transportation modes, and the themes of time window management, routing problems, and sensitivity in terms of practical delivery performance (path optimization or algorithms). Although emerging transportation methods such as autonomous drone delivery, crowd logistics, and EVs are gradually replacing traditional methods such as trucks, many significant issues remain to be resolved [93]. These include EV battery life and range anxiety problems, crowd logistics scalability, and autonomous robot efficiency challenges in LMD [90,91,95]. Moreover, although scholars have proposed combining traditional transportation methods with autonomous delivery to overcome these obstacles, the research is still mainly limited to simulation experiments and has not been implemented in real-life scenarios. With the emergence of intelligent transportation methods, future researchers are encouraged to provide more practical empirical research for industry professionals.

According to our review, the primary focus of scholarly attention in the LMD literature is the third cluster of environmental friendliness, and the themes of sustainability, energy consumption, and greenhouse gas emissions. Increased attention to the environment and ecology is crucial to ensure a better quality of life for humans, and sustainable resource management is of paramount importance in this process. Although scholars have suggested that electric cargo bicycles can replace traditional EVs or trucks, and such delivery methods have begun to spread to many cities worldwide, this approach reduces freight efficiency. Therefore, environmental friendliness and high efficiency are important research topics that should be pursued. The combination of trucks and drones appears to have a more significant impact on reducing CO_2 emissions and congestion than traditional logistics [129]. However, in addition to safety concerns, there may be potential social sustainability flaws regarding fairness [130]. It is also important to recognize that this so-called comparative advantage has certain limitations and cannot be universally applied. For example, in densely populated areas, the energy consumption of autonomous robots is greater than that of traditional trucks [137], suggesting that choosing a traditional mode of transportation might be a better option in such areas. As another alternative mode of transportation, EVs have many advantages over traditional transportation modes, such as low pollution, fuel efficiency, and economic feasibility [147]. However, while realizing these advantages, the increased risk of battery degradation owing to the high utilization rate of EVs remains a challenge for future applications of EVs in LMD.

4.3. Contribution of This Study

With the vigorous development of e-commerce, scholars have generally reached a consensus that LMD is both an expensive and a challenging link in the overall logistics process. This is primarily because of diverse delivery environments, such as urban areas and rural villages, each with unique complexities. Furthermore, with the gradual progression of Industry 4.0 processes to those of Industry 5.0, and full automation technology, our systematic review revealed the flourishing of an increasing number of emergent transportation methods in LMD.

No comprehensive studies exploring all modes of LMD transportation, the changes in these transportation modes, and the commonalities between them exist in the scholarly LMD literature. In this study, we addressed this gap by conducting a systematic review of 150 academic journal articles using a combination of PRISMA content analysis and text mining analysis methods. Manual analysis revealed three clusters and related themes with which scholars were mainly concerned. Each cluster and its important themes were examined, ultimately revealing answers to our three research questions.

4.4. Limitations

The current study is not without some limitations. First, the concept of last-mile delivery can be investigated in a variety of fields. Therefore, despite the best efforts of the authors, some papers may not be included in the examination. Second, some researchers might not utilize "LMD" as a keyword, despite their research being relevant to the same concept as "LMD". The authors of this paper encourage future researchers to expand the search criteria and include keywords like "urban delivery" to undertake more comprehensive investigations. Third, although we have tried our best to explore all the current mainstream LMD modes in this literature review, choosing between these modes remains a complex and challenging problem in this field. Some scholars in the industry are attempting to address these issues using methods like weighted aggregated sum product assessment (WASPAS) or multi-criteria decision making (MCDM) [130,148,149]. Additionally, there are more basic methods, such as the analytic hierarchy process (AHP), related to mode choice. We suggest that future researchers further investigate the trade-off issues between these modes. For instance, conducting a literature review specifically focusing on LMD mode choice could help fill the gaps in this field. Finally, due to limitations in the research methods employed, we may have overlooked some intriguing and vital clusters within the field of LMD modes. These aspects encompass factors such as the size of the basket of goods and various product characteristics that are of concern to both consumers and suppliers. We recommend that future researchers endeavor to incorporate these elements to facilitate more comprehensive research and exploration in the future.

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