Drones in last-mile delivery: a systematic literature review from a logistics management perspective

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Abstract

Purpose – This study presents a systematic literature review (SLR) of the interdisciplinary literature on drones in last-mile delivery (LMD) to extrapolate pertinent insights from and into the logistics management field.

Design/methodology/approach – Rooting their analytical categories in the LMD literature, the authors performed a deductive, theory refinement SLR on 307 interdisciplinary journal articles published during 2015–2022 to integrate this emergent phenomenon into the field.

Findings – The authors derived the potentials, challenges and solutions of drone deliveries in relation to 12 LMD criteria dispersed across four stakeholder groups: senders, receivers, regulators and societies. Relationships between these criteria were also identified.

Research limitations/implications – This review contributes to logistics management by offering a current, nuanced and multifaceted discussion of drones' potential to improve the LMD process together with the challenges and solutions involved.

Practical implications – The authors provide logistics managers with a holistic roadmap to help them make informed decisions about adopting drones in their delivery systems. Regulators and society members also gain insights into the prospects, requirements and repercussions of drone deliveries.

Originality/value – This is one of the first SLRs on drone applications in LMD from a logistics management perspective.

Keywords Unmanned aerial vehicle, Freight, Distribution, Parcel delivery, E-commerce

Paper type Literature review

1. Introduction

As the trend of online shopping is surging, the need of faster, more reliable and greener parcel delivery process has preoccupied almost every e-retailer. One of the most challenging transport

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legs along the parcel delivery process is the last-mile delivery (LMD) (Lim *et al.*, 2018), referred to as the delivery from a terminal to end receivers. Using conventional vehicles (e.g. trucks, vans), e-retailers and their carriers are struggling to provide the needed capacities to deliver vast amounts of goods to end receivers immaculately and within the specified time windows while remaining profitable (Allen *et al.*, 2018). Continuing to fulfill mounting LMD volumes through conventional vehicles is expected to create more road congestions, air pollution, safety hazards and other social and environmental concerns (Ignat and Chankov, 2020) – urging the industry to find an alternative.

Drones – or unmanned aerial vehicles (UAV) – represent one of the most promising technologies to enhance the LMD process, with some predicting them to change the future of supply chains (Merkert and Bushell, 2020). The global drone market is expected to reach $61.95bn USD by 2027, growing at a compound annual growth rate of 26.73% (Research and Markets, 2022). Industry giants, such as Amazon and UPS, have already begun experimenting with drones to improve their LMD process. Amazon's "Prime Air" made successful trials to deliver packages up to five pounds in 30 min or less right at the doorstep, or lawn, of the customer using drones (Amazon, 2016). Each of Amazon, UPS and Wing received their Part 135 Air Carrier Certificate from the US Federal Aviation Administration (Dallas News, 2021), indicating their determination to turn drone deliveries into a widespread reality.

Unlike conventional vehicles, drones ignore traffic congestion due to their flying capability (Liu *et al.*, 2022a), which in turn shortens delivery time and fosters customer satisfaction (Lin *et al.*, 2022). Drones can also minimize transport-related emissions through their reliance on electric batteries (Figliozzi, 2020) and substitution to conventional vehicles on the road (Kellermann *et al.*, 2020). Moreover, drones can reduce transport costs due to their low investment and operating costs (Murray and Chu, 2015) and tendency to relieve accumulating inventory volumes (McKinnon, 2016). To no surprise, these benefits have attracted supply chains in sectors beyond e-commerce, including healthcare and humanitarian relief (Rejeb *et al.*, 2023). Indeed, drones make it possible to deliver medicine and other time-critical items from hospitals, pharmacies and disaster-relief hubs to those in need under short time intervals while avoiding physical obstacles (Banik *et al.*, 2022; Holzmann *et al.*, 2021). However, despite the technology's positive prospects, some drone delivery projects led by industry leaders are still struggling to take off due to legislative, infrastructural, technical, safety and social acceptance barriers (Rathore *et al.*, 2022). DHL cancelled its "Parcelcopter" program – which was eight years in the making – in 2021, whilst Amazon shut down its "Prime Air" operations in the UK (Tech.co, 2021).

Given drones' promising (yet uncertain) potential, research on their applications has grown significantly over the past years, with several literature reviews published parallel with this growth. Some of these reviews address drones amidst other emergent technologies (e.g. Dong *et al.*, 2021), not devoting ample depth to this rapidly evolving field, whilst others focus on drones without systematic sampling of the literature (e.g. Mohamed *et al.*, 2020), not depicting the state-of-the-art on the topic. The remaining reviews, compiled in Table 1, utilize systematic sampling to examine drone use across various topics, noting that only three of them are dedicated to the LMD segment.

These three LMD-focused reviews primarily examine the modeling aspects of drone deliveries and the technical intricacies of different routing problems. Consequently, a gap is formed in the logistics management field for addressing non-modeling issues surrounding drone deliveries to inform logistics scholars, practitioners and policymakers about the potentials and challenges associated with the technology. Rejeb *et al.* (2023) shed light upon this matter in their review. However, their sample of 55 articles was "limited to the field of business and management" (p. 710), overlooking extensive drone-related literature from non-managerial fields such as engineering and computer science – which, in fact, dominate drone research (Jouhet *et al.*, 2020). What seems necessary at this point is another systematic review that derives knowledge from such

Table 1. Summary of systematic reviews on drones

Article	Systematic sampling of literature	Covered articles	Scope	Dedicated focus on drones	Dedicated focus on LMD	Logistics management perspective
Luppicini and So (2016)	✓	36	Techno-ethical review of commercial drones	✓	–	–
Kellermann *et al.* (2020)	✓	111	Drones for parcel and passenger transport	✓	–	–
Macrina *et al.* (2020)	✓	63	Drone-aided routing	✓	✓	–
Moshref-Javadi and Winkenbach (2021)	✓	100	Drone-based models in logistics	✓	✓	–
Rejeb *et al.* (2023)	✓	55	Drones for supply chain management and logistics	✓	–	✓
Comtet and Johannessen (2022)	✓	25	Drones in healthcare	✓	–	–
Pasha *et al.* (2022)	✓	145	Drone scheduling problem	✓	✓	–
This study	✓	*307*	*Drones in LMD from a logistics management perspective*	✓	✓	✓

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interdisciplinary fields to inform the logistics management field, based on criteria established within that field. Moreover, Rejeb *et al.*'s review surpassed the LMD segment to include topics such as land surveying and energy monitoring, inviting further reviews to focus exclusively on drones in LMD due to their challenging nature, substantial growth and the myriad of factors involved for their facilitation. Hence, this research aims to present a systematic literature review (SLR) of the interdisciplinary literature on drones in LMD to extrapolate pertinent insights from and into the logistics management field. We posit four research questions for this inquiry:

RQ1. From a logistics management viewpoint, what are the key criteria for adopting drones in LMD?

RQ2. What are the potentials, challenges and solutions associated with each criterion for adopting drones in LMD?

RQ3. What relationships can be identified among the criteria for adopting drones in LMD?

RQ4. What further research directions for the logistics management field can be identified for adopting drones in LMD?

To answer these RQs, we applied a deductive, theory refinement SLR of 307 interdisciplinary, peer-reviewed journal articles on drone applications in LMD during 2015–2022. This SLR contributes to logistics management by offering a current, nuanced and multifaceted discussion of drones' potentials to improve the LMD process, the challenges involved and the solutions proposed. It also offers a holistic roadmap for logistics managers to support them make informed decisions about adopting drones in their delivery systems.

The remainder of this article is structured as follows: Section 2 derives the key criteria for LMD from the logistics management literature, concluding with an analytical framework to guide the SLR process. Section 3 covers the methodological steps; Section 4 presents descriptive analysis of the sample; Section 5 provides a thematic analysis of the LMD criteria for drone applications; Section 6 presents a cross-thematic analysis; Section 7 identifies further research directions; while Section 8 covers the conclusions.

2. Identifying LMD criteria

2.1 Defining LMD

Rooted in the telecommunication industry, "last-mile" is a term used to describe the last leg of a delivery process. Contingent on the context and scope of the process, terms such as last-mile "logistics", "delivery", "distribution" and "transport" have emerged in the literature – used distinctively in some cases and interchangeably in others. Distinguishing between these terms, Olsson *et al.* (2019) argued that LMD is the step that lies at the front-end of the delivery process, encompassing "the activities necessary for physical delivery to the final destination chosen by the receiver" (p. 13). The LMD literature generally agrees that the receiver is the one who chooses the final destination, which can be a home, office, parcel locker, or others (Wang *et al.*, 2021). In turn, the sender is often the one who decides on the means of transport, which includes light goods vehicles, electric vans, bicycles, drones, or others (Olsson *et al.*, 2019). The starting point of a delivery is referred to as the "order penetration point" (Sharman, 1984), defined by Lim *et al.* (2018, p. 310) as "an inventory location (e.g. fulfillment center, manufacturer site, or retail store) where a fulfillment process is activated by a consumer order". As for who receives the order, the terms "consumer" and "customer" are commonly used among scholars, possibly due to the predominance of business-to-consumer sectors (e.g. retail) within logistics management. However, the field has expanded to encompass non-business sectors, bringing along other terms to describe the receiver. Kovács and Spens (2007) used "affected persons" to describe receivers within humanitarian relief, whereas Pohjosenperä *et al.* (2018) used "nursing staff" and "doctors" for receivers within healthcare. Since we don't wish to limit LMD to a specific sector, we apply the term "receiver", given its simplicity and inclusiveness. As for the object being delivered, "parcel", "package", "spare parts", and "samples" are terms used across the LMD literature, with the choice of term often varying by sector as well (Olsson *et al.*, 2019). We apply "item" in this research, also for its simplicity and inclusiveness. Building on the above, we define LMD as:

> The last stretch of an item delivery process that takes place from the order penetration point to the receiver's preferred destination point.

2.2 Key LMD criteria

Different delivery configurations have evolved to adapt receivers' time and location preferences while considering the available resources and infrastructure for senders (Wang *et al.*, 2021). Lim *et al.* (2018) identify three of these configurations: push-centric (the item is *sent* to the receiver), pull-centric (the item is *fetched* by the receiver) and hybrid (the item is *sent* to an intermediate site, from which it is *fetched* by the receiver). Assessing last-mile logistics varies with the configuration at hand. For instance, timely delivery is crucial in push-centric and hybrid configurations, but less so in pull-centric setups where receivers determine the pickup time. Given our focus on LMD, we consider criteria related to push-centric configurations only.

One way to look at LMD criteria is through separating criteria related to the transport mode from those related to LMD overall. For example, "transport cost" and "delivery time" depend on whether a van or a bicycle is chosen for delivery, whereas "product availability" (Esper *et al.*, 2003) and "order-picking time" (Kämäräinen *et al.*, 2001) remain independent of the transport mode. Given the emphasis on transport modes in this research, we exclusively consider LMD criteria pertinent to them.

Another way to look at LMD criteria – in relation to transport modes – is through separating the sender's viewpoint from the receiver's (Kämäräinen *et al.*, 2001). This is grounded in the idea that each stakeholder prioritizes certain criteria to be met in a given delivery event (Kiba-Janiak *et al.*, 2021). Cost of transport, for instance, is a major concern for senders (Mangiaracina *et al.*, 2019), accounting for almost half of total logistics costs for some firms (Vanelslander *et al.*, 2013). Senders are also very attentive to the applicability of the transport mode (Dong *et al.*, 2021) and its capacity (Castillo *et al.*, 2018), while receivers are usually not concerned about – or willing to pay for – such operative criteria (Ignat and Chankov, 2020). Instead, receivers can be very demanding of LMD's service levels (Mangiaracina *et al.*, 2019), which mainly relate to time, reach and item condition (Castillo *et al.*, 2018; Nogueira *et al.*, 2021).

Regulators and societies represent other stakeholder groups who influence – and are influenced by – the LMD process (Kiba-Janiak *et al.*, 2021), though both are not directly involved in it. Regulators are often responsible for providing the needed policies and infrastructures to enable operative and sustainable LMD operations (Ewedairo *et al.*, 2018) – while keeping an eye on public's acceptance (Peppel *et al.*, 2022). Societies, in turn, signify the broadest stakeholder group, concerned about the overall LMD's impact on safety, privacy and the environment (Ignat and Chankov, 2020). Table 2 [1] unpacks each LMD criterion based on the priorities of senders, receivers, regulators and societies. Note that these priorities are not mutually exclusive; e.g. delivering items within receives' preferred time window is also critical for senders to maintain customer satisfaction and avoid failed delivery cost. Safety, privacy and environmental criteria are important to all stakeholders, yet they have been placed under societies since they represent the most inclusive group.

LMD criteria	Description/examples	References
Senders' priorities		
Cost	Includes cost of transport (e.g. cost of buying/leasing vehicles, fuel cost, maintenance cost), driver cost (e.g. hourly fees, cost of problem solving) and opportunity cost (e.g. failed delivery cost)	Mangiaracina *et al.* (2019), Peppel *et al.* (2022), Siragusa *et al.* (2022)
Applicability	Includes route planning, load assignment, delivery setup, and number and location of warehouse facilities	Dong *et al.* (2021), Hagberg and Hulthén (2022), Peppel *et al.* (2022)
Capacity	Includes payload, speed, range, refueling/recharging frequency, extreme weather resistance and maintenance requirements	Castillo *et al.* (2018), Ranieri *et al.* (2018), Wang and Odoni (2016)
Receivers' priorities		
Time	Includes punctuality (i.e. receiving items within specified delivery windows) and reduced delivery time (i.e. minimizing the time between order placement and arrival)	Castillo *et al.* (2018), Mangiaracina *et al.* (2019), Rutner and Langley (2000)
Reach	Reaching receivers at their preferred destinations	Lim *et al.* (2018), Mangiaracina *et al.* (2019)
Item condition	Receiving the right item in the right quantity and condition (e.g. free from physical damage, before expiration period)	Rutner and Langley (2000), Shapiro and Heskett (1985)

(*continued*)

Table 2.
Key LMD criteria

LMD criteria	Description/examples	References
Regulators' priorities		
Policies	Includes creating/applying legal frameworks, licensing guidelines and training programs for operative and sustainable LMD	Ewedairo *et al.* (2018), Siragusa *et al.* (2022)
Infrastructure	Facilitating the necessary infrastructure for the transport mode to operate. Includes road networks, facilities to park/stop and amenities for maintenance and maneuvering	Ewedairo *et al.* (2018), Ignat and Chankov (2020)
Public acceptance	Maintaining the public's contentment with delivery systems and preserving their privacy and safety rights	Peppel *et al.* (2022), Siragusa *et al.* (2022), Wang *et al.* (2021)
Societies' priorities		
Safety	Ensuring safety of traffic users, pedestrians, residents and animals as well as properties, landmarks and buildings	Ignat and Chankov (2020), Naclerio and De Giovanni (2022), Wang *et al.* (2021)
Privacy	Includes protecting people's identities and personal space and not collecting or using their identifiable data without their permission	Peppel *et al.* (2022), Wang *et al.* (2021)
Environment	Minimizing environmental externalities related to the LMD process (e.g. air pollution, greenhouse gas emissions, energy consumption, noise pollution, congestion, visual intrusion, etc.)	Ignat and Chankov (2020), Siragusa *et al.* (2022)

Table 2.

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2.3 Analytical framework

Rooted in Table 2, Figure 1 presents the analytical framework for this study that shows the key stakeholder groups alongside their LMD priorities – setting the stage to analyze the potentials, challenges and solutions associated with drone deliveries across these priorities.

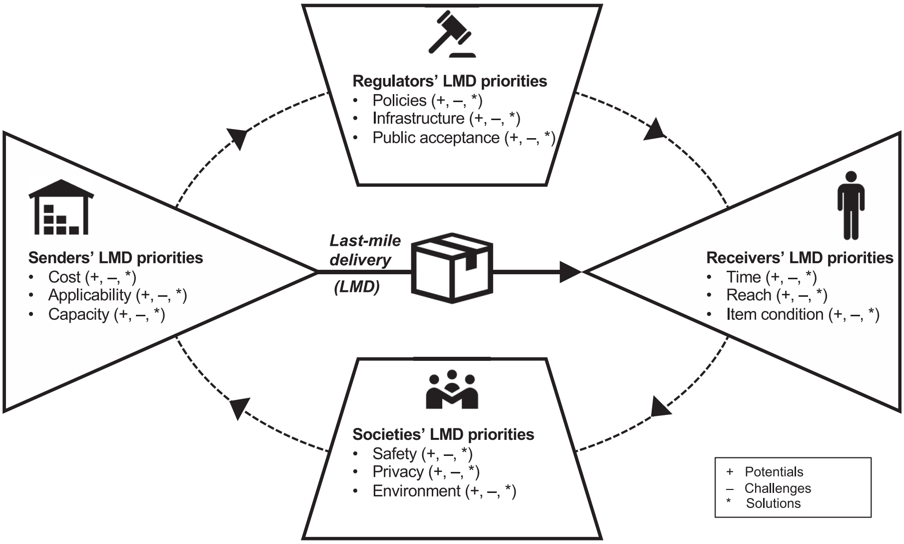

Figure 1.
Analytical framework

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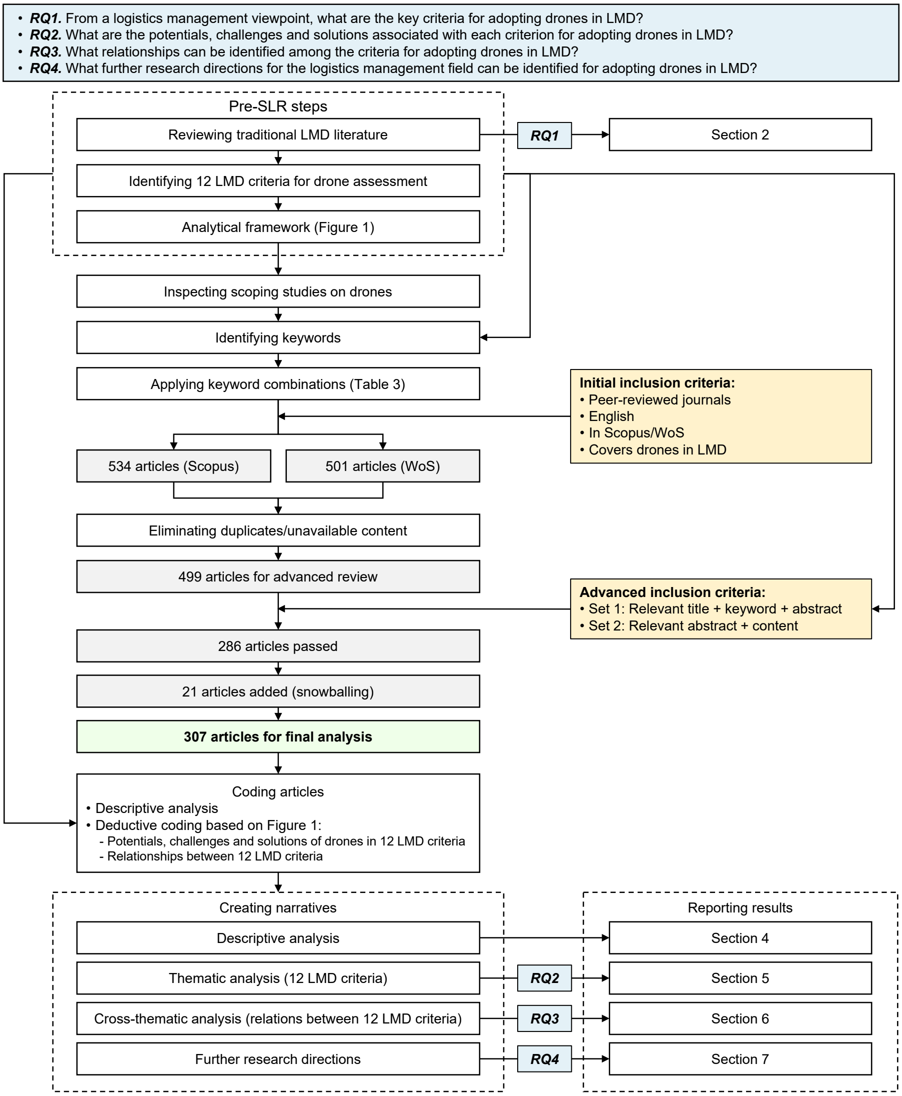
3. Methods

An SLR enables managing diversified knowledge for a specific inquiry (Tranfield *et al.*, 2003), suiting our attempt to synthesize the interdisciplinary literature on drones in LMD for the logistics management field. Among different types of SLRs, we applied a deductive, theory refinement SLR (Seuring *et al.*, 2021), because these are useful when the SLR's analytical constructs are derived *from* the field (i.e. the 12 LMD criteria), allowing the inclusion of a pertinent phenomenon emerging *outside* the field (i.e. drones in LMD, dominated by engineering and computer science). To obtain and synthesize the SLR's sample, we followed the six-step guidelines by Durach *et al.* (2017), discussed below and summarized in Figure 2.



- ***RQ1.*** From a logistics management viewpoint, what are the key criteria for adopting drones in LMD?
- ***RQ2.*** What are the potentials, challenges and solutions associated with each criterion for adopting drones in LMD?
- ***RQ3.*** What relationships can be identified among the criteria for adopting drones in LMD?
- ***RQ4.*** What further research directions for the logistics management field can be identified for adopting drones in LMD?

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Figure 2.
Adopted SLR steps

Step (1) Defining research questions – The four RQs of this study were guided by its purpose. These were, at first, not overly specified to avoid restricting subsequent steps.

Step (2) Determining required characteristics of primary studies – One initial inclusion criterion for all articles was publication in English-speaking, peer-reviewed journals – ensuring quality standards (Durach *et al.*, 2017). Two databases were selected for searching the literature: Scopus (by Elsevier) and Web of Science (WoS; by Clarivate) – chosen due to their wide-ranging repositories that span across diverse fields and their trustworthiness among scholars (Archambault *et al.*, 2009). As for the content, the articles must cover drone deliveries to align with our scope, but not necessarily in dedication. That is, several drone-related articles compared drones with other emergent freight technologies, while others focused on drone deliveries alongside other applications (e.g. monitoring, sensing). We included both types of articles to ensure capturing the state-of-the-art on drones in LMD. Also, to that end, we did not limit our search to certain research fields or methods.

Step (3) Retrieving a sample of potential relevance – Following Tranfield *et al.* (2003), three researchers identified the search keywords after examining scoping studies with high citation counts from different disciplines. Table 3 lists the derived keywords after considering cognates for “drone”, “delivery” and “logistics”. To obtain results that are neither too broad (with unrelated content) nor too narrow (with missed related content), different keyword combinations were iteratively tested and verified through discussions between the authors. Table 3 shows the final keyword combination, yielding 534 articles in Scopus and 501 articles in WoS. The similar hit count across both databases indicates the consistency of our search strings, though differences might have surfaced due to the unique handling of duplicates within each database. Merging the sample was achieved through (1) eliminating within and cross-database duplicates/unavailable content and (2) omitting articles with irrelevant abstract and/or keywords – yielding an initial sample of 499 articles. This search was conducted in January 2023.

Step (4) Selecting pertinent literature – An advanced set of inclusion criteria was applied to the remaining 499 articles. This entailed closely inspecting the abstract of each article and matching it against our analytical framework (Figure 1). To exemplify, Eun *et al.*’s (2019) abstract stressed comparing the environmental impact of drone deliveries with traditional ground vehicles while considering the drone’s capacity and applicability. Thus, the article was included as it met our initial criteria by addressing drones in LMD and advanced criteria through its focus on *environment*, *capacity* and *applicability*. Some articles needed

Table 3.
Search strings

Keywords (base)	*Cognates*
Drone	UAV; unmanned aerial vehicle; micro-aerial vehicle
Delivery	Freight; parcel; last mile; terminal to customer
Logistics	Supply chain; transport; distribution

Database	*Search strings*
Scopus	TITLE-ABS-KEY = ((“drone*” OR “UAV” OR “unmanned aerial vehicle*” OR “micro-aerial vehicle”) AND (“delivery” OR “freight” OR “parcel” OR “last mile” OR “terminal to customer”) AND (“logistic*” OR “supply chain” OR “transport”* OR “distribution”))
Web of Science	TS = ((“drone*” OR “UAV” OR “unmanned aerial vehicle*” OR “micro-aerial vehicle”) AND (“delivery” OR “freight” OR “parcel” OR “last mile” OR “terminal to customer”) AND (“logistic*” OR “supply chain” OR “transport*” OR “distribution”))

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closer examination to assess their relevance, as their abstracts offered unclear purposes despite relevant titles and keywords. To reduce bias in this step, three authors examined the articles independently. After applying initial and advanced inclusion criteria, the sample was reduced from 499 to 286 articles. This reduction was loomed with utmost caution; although most excluded articles discussed drones, their content did not mention the last-mile (or parcel) delivery segment, despite passing initial inclusion criteria. The excluded articles, instead, handled drone applications in topics entirely surpassing our scope, such as spraying fertilizers and land surveying.

Bearing in mind the need to include as many articles as possible (Pawson, 2006), criteria such as pertaining to certain journals or passing citation thresholds were not considered. This decision was backed by (1) the interdisciplinarity of the drone literature, thus not favoring journal selection and (2) the emergence of drone technologies, thus not favoring citation counting. We employed a snowballing technique by reviewing the reference lists of included articles, adding 21 more articles to the sample – each screened by two authors. Consequently, our final sample comprises 307 articles.

Step (5) Synthesizing literature – Following Braun and Clarke (2006), we applied a deductive (i.e. theory-driven) thematic analysis to synthesize the articles and code their content. The themes represent the 12 LMD criteria already established in Figure 1, whilst the articles' content was coded through extracting the potentials, challenges and solutions associated with drone use under each criterion. This was followed by a cross-thematic analysis to identify relationships between the 12 LMD criteria.

Step (6) Reporting results – Reporting was done by providing a descriptive analysis of the bibliometrics, a thematic and cross-thematic analysis of the content and derived directions for further research.

4. Descriptive analysis

4.1 Publications over time

Figure 3 presents the distribution of the 307 articles through time, indicating a rapidly growing academic interest in the topic of drone deliveries. This trend is in line with the technology's projected market growth to reach $61.95bn USD by 2027 (Research and Markets, 2022). Consequently, we expect the number of publications on this topic to grow further in 2023 and beyond [2].

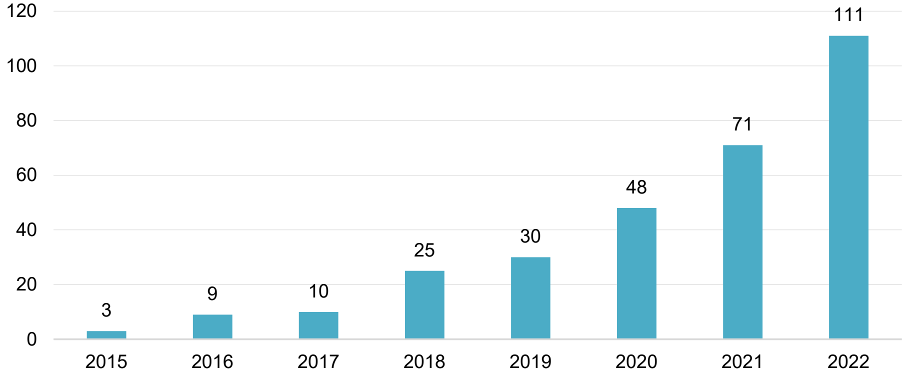

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Figure 3.
Distribution of articles by publishing years

4.2 Publications by countries

Figure 4 shows the authors' affiliations by country. The US dominated the list by contributing 30% of the sample, followed by China with 17%. European nations dominated regionally with 42% of contributions. The figure signals a need for more research to represent African countries, Latin America, the Middle East and Asian countries beyond China.

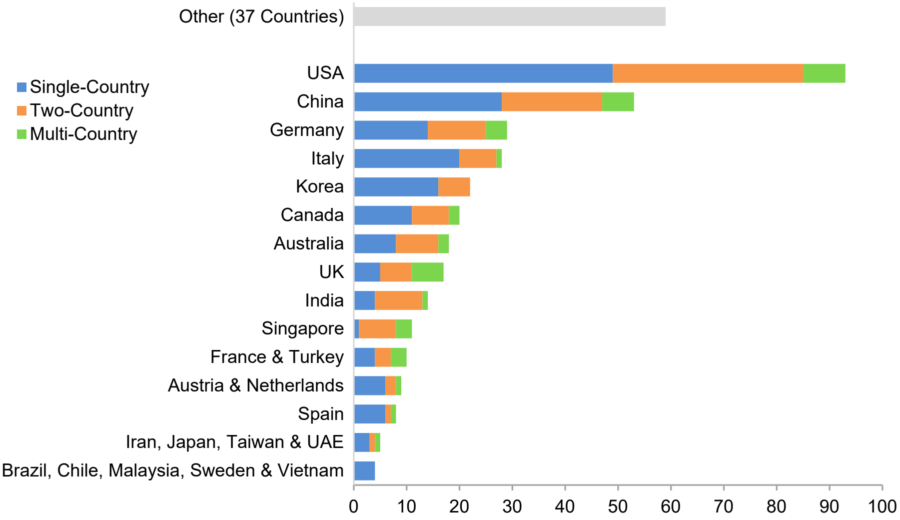

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Figure 4.
Distribution of articles by countries

4.3 Publications by methods

Figure 5 displays the distribution of articles by methods. Notably, 53% of the sample utilized a modeling approach, primarily applying multi-objective functions or routing validation methods such as the Vehicle Routing Problem or the Traveling Salesman Problem. Mixed-method articles (26%) often combined modeling with numerical cases or experiments, while

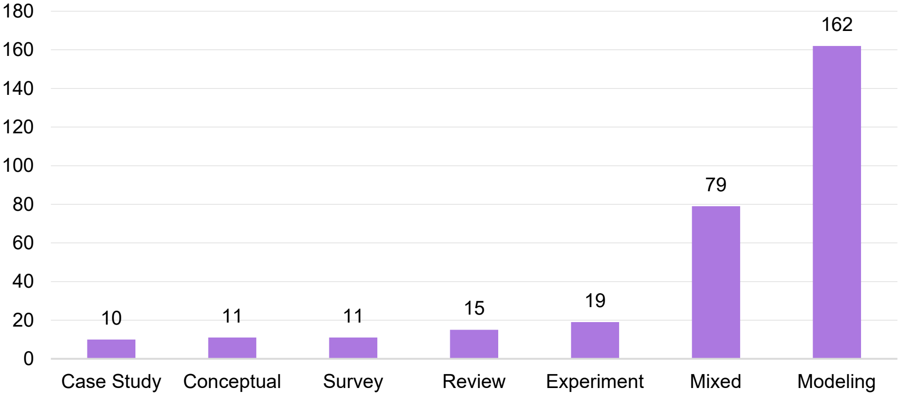

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Figure 5.
Distribution of articles by research methods

pure experiments (6%) focused on drone applications using real-world data. Review articles (5%) synthesized the academic contributions on topics comprising drones' routing, social impact and integration in healthcare. Surveys (6%) explored behavioral preferences for drone use, whilst conceptual studies (6%) delved into drone implications across different disciplines. As for case studies (3%), seven quantitatively analyzed real drone applications in healthcare and three qualitatively assessed public/expert views on drone deliveries across general and medical contexts.

4.4 Publications across journals

Figure 6 depicts the sample distribution across journals, revealing that 47% of articles were published in just 17 journals. The remaining 53% spread across 130 journals, with three or fewer articles in each. Notably, the journal "Drones" has emerged in dedication to this topic. One can also observe the dominance of journals within transport science, engineering and computer science – which may explain the prevalence of the modeling approach and the limited coverage of drones in prominent logistics management journals. This presents an opportunity for logistics management scholars to investigate the managerial aspects of this promising field.

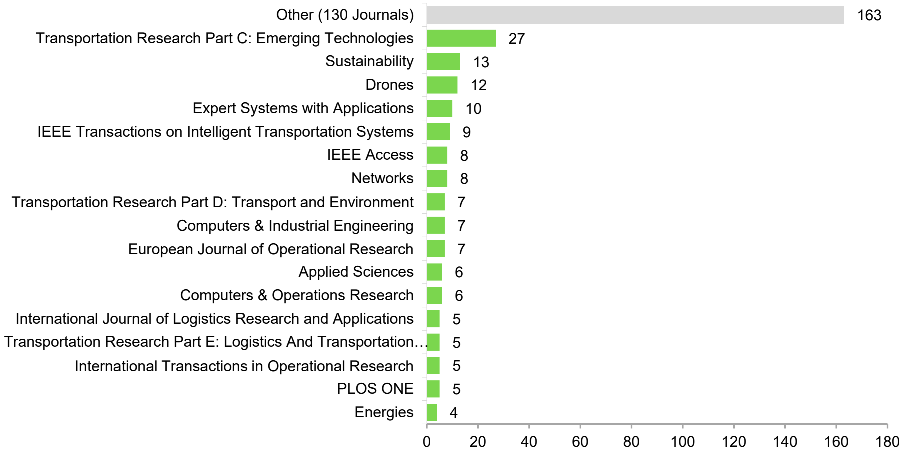

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Figure 6.
Distribution of articles by journals

4.5 Sectors adopting drone in LMD

Figure 7 shows the primary sectors adopting drones in LMD as found in the sample, noting that 22% of articles addressed drones miscellaneously without specifying a sector.

5. Thematic analysis

This section presents the SLR's findings on the potentials, challenges and solutions associated with the 12 LMD criteria for adopting drones with respect to the priorities of senders, receivers, regulators and societies – summarized in Table A2 (Appendix).

5.1 Senders' priorities

5.1.1 Cost. Reducing cost is seen as a key motive for senders to adopt drones in LMD, with trials revealing their potentials to save 28% (Karak and Abdelghany, 2019), 30% (Dukkanci

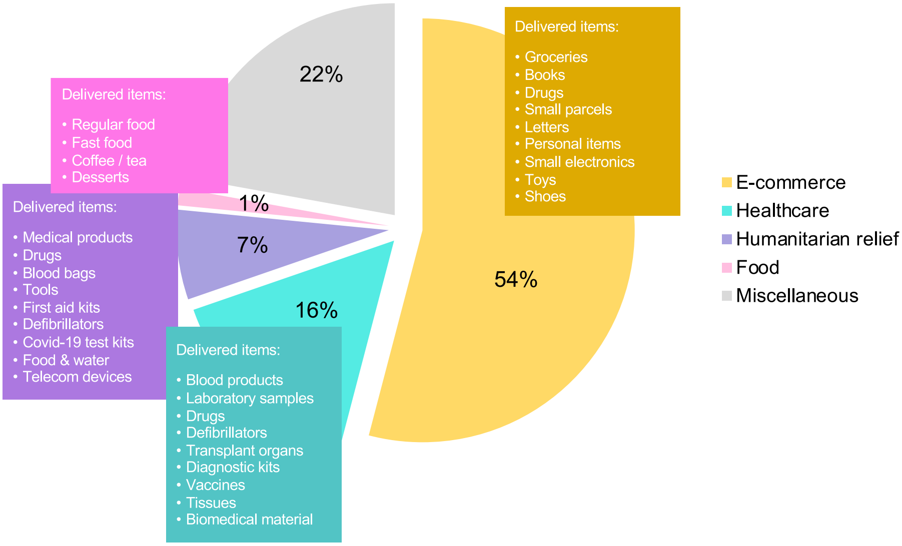

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Figure 7.
Sectors adopting drones in LMD

et al., 2021), 39% (Li *et al.*, 2022b), 80% (Lemardalé *et al.*, 2021), to even 93% (Kostrzewski *et al.*, 2022) of total LMD costs compared to conventional delivery methods. Such cost savings can be attained through drones' low investment and operating costs (Murray and Chu, 2015) alongside their ability to improve transport efficiency (McKinnon, 2016) – emphasized by drones' capacity to shorten travel time and distance (Dukkanci *et al.*, 2021) and lower reliance on fueled vehicles like trucks and vans (She and Ouyang, 2021). Drone-based deliveries may also reduce driver cost by shortening their working shifts (Dorling *et al.*, 2017) and storage cost by relieving amassed inventory volumes (McKinnon, 2016). Drones' ability to deliver quickly and on-time can also lower cost of delayed/failed deliveries (Kim and Hwang, 2020), which may, in turn, increase profitability due to improved customer satisfaction (Lin *et al.*, 2022). To achieve cost savings via drones, attention should be paid to the different cost elements involved across their utility cycle, compiled in Table 4.

Instead of treating each cost element in isolation, the literature strongly advocates applying a "system-thinking" approach to assess the overall cost savings from drone-based deliveries. Factors such as drones' scale economies (Baloch and Gzara, 2020), maintenance and deprecation rates (Shavarani *et al.*, 2019b), payload-to-energy-consumption ratio (Dorling *et al.*, 2017), drone-truck configuration (Aurambout *et al.*, 2019), allocated delivery windows/penalties (Li *et al.*, 2022b), geographical distribution of served customers (Shavarani *et al.*, 2019a) and population density of served areas (Lemardelé *et al.*, 2021) are viewed as key determinants of the overall economic viability of drone delivery systems. Highlighting the need for considering multiple cost elements, Lemardelé *et al.*'s (2021) comparison of drones with autonomous ground vehicles indicate that truck-launched drone deliveries are more viable in less dense and larger service areas (e.g. suburbs), while autonomous ground vehicles are more viable in denser neighborhoods (e.g. city centers). In another example, Aurambout *et al.* (2022) find that under current conditions drone deliveries are financially viable for serving 32–60% of the US population compared to only 16–43% in Europe.

Despite the low investment and operating costs of single drones compared to conventional vehicles (Murray and Chu, 2015), the aggregate investments in drone fleets,

Cost element	Explanation/examples	References
Drone hardware	Cost of the drone device (including its battery, motor, rotors, etc.) and its attachments (e.g. smart capsules, sensors, cameras, etc.)	Cheng *et al.* (2020), Ghelichi *et al.* (2021), Oakey *et al.* (2022)
Battery replacement	Cost of replacing old batteries with new ones – depends on battery lifetime, type (e.g. lithium-ion) and time needed for replacement	Asadi *et al.* (2022), Huang *et al.* (2022b), Li *et al.* (2022b), Oakey *et al.* (2022)
Battery charging	Cost of battery charging per hour – depends on the energy source, battery capacity and time needed for full charges	Asadi *et al.* (2022), Ghelichi *et al.* (2021), Oakey *et al.* (2022)
Maintenance and depreciation	Covers the warranty, maintenance and depreciation costs of the drone and its attachments	Dorling *et al.* (2017), Mohamad *et al.* (2020), Shavarani *et al.* (2019b)
Software and data usage	Cost of purchasing/subscribing to software for drone operations and navigation. Includes data usage cost	De Silvestri *et al.* (2022), Oakey *et al.* (2022), Shao *et al.* (2020)
Labor charges	Compensating laborers who operate drones, monitor them, resolve technical issues, fulfill orders and ensure safe operations. Covers recruitment, training and benefit costs	De Silvestri *et al.* (2022), Dhote and Limbourg (2020), Gunaratne *et al.* (2022), Oakey *et al.* (2022)
Regulatory compliance	Expenses to comply with operational, safety, privacy, ethical and environmental regulations. Covers cost of obtaining necessary licenses, registration cost, airspace charges, taxation, lobbying, etc.	Li *et al.* (2022a), Ben Dor and Hoffman (2022), De Silvestri *et al.* (2022), Oakey *et al.* (2022)
Insurance coverage	Charges paid to insurance firms to compensate for injuries caused by drones to people, damages (to drones, payloads, property, flying objects, etc.) and delivery delays	Lemardele *et al.* (2021), Oakey *et al.* (2022), Rao *et al.* (2016)
Supportive means of transport	For multi-modal delivery setups, such as operating drones with trucks. Covers cost of acquiring and operating trucks, drivers' wages, operating software, etc.	Gunaratne *et al.* (2022), Dukkanci *et al.* (2021), Sawadsitang *et al.* (2018)
Facility charges	Cost of constructing, renting and operating operational facilities, charging stations and warehouses in conjunction with drone service coverage	Ghelichi *et al.* (2021), Lamb *et al.* (2022), Shavarani *et al.* (2019a)

Source(s): Created by authors

Table 4.
Cost elements of drones in LMD

depots and recharging stations are likely to be large, especially since drones can only deliver modest loads to a small number of receivers per trip (McKinnon, 2016). This makes achieving scale economies for adopting drone in LMD a challenging task. Solutions to address this include adopting a "sharing economy" model for drones across multiple warehouses (Bruni and Khodaparasti, 2022), pairing drones with ground autonomous vehicles (Lemardelé *et al.*, 2021) and coordinating drones with trucks along delivery routes (Canca *et al.*, 2022).

5.1.2 Applicability. The reviewed literature specifies two primary approaches regarding how drones can be applied in LMD: (1) trucks and drones performing the delivery and (2) only drones performing the delivery (Figure 8). We unpack each approach below while referring the reader to Macrina *et al.* (2020) to learn about them from a modeling viewpoint.

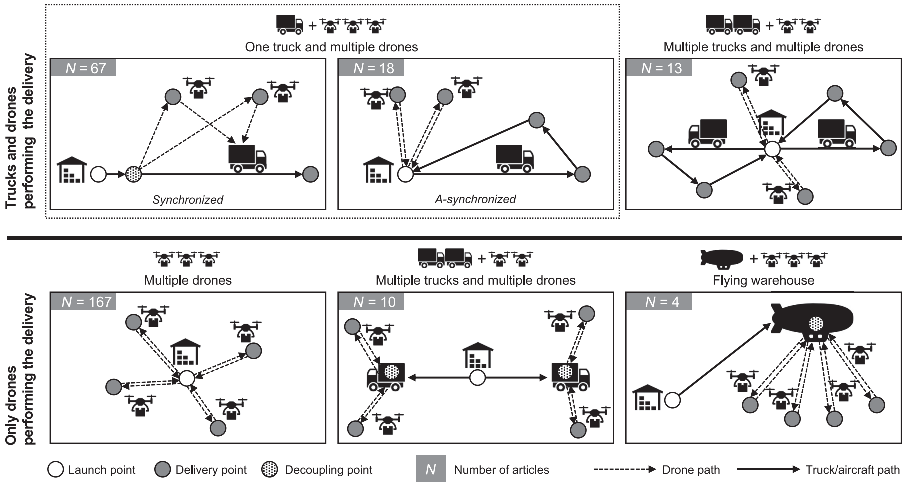


Figure 8.
Drone applications in LMD

Source(s): Created by authors

(1) *Trucks and drones performing the delivery*: can be divided into two segments. First, one truck and multiple drones, which can be further split into: (1) synchronized truck and drones, where drones are launched from a truck at one or more locations along the truck's delivery route to perform their assigned deliveries and then return to meet the truck (Bruni *et al.*, 2022; Zang *et al.*, 2022) and (2) a-synchronized truck and drones, where drones are launched from a depot to deliver to receivers close by, while a truck carries out deliveries far from the depot and beyond the drones' range (Murray and Chu, 2015; Nguyen *et al.*, 2022). Second, multiple trucks and multiple drones, by which a fleet of trucks and drones perform deliveries simultaneously – each based on their carrying capacity and travel range (Dorling *et al.*, 2017; Liu *et al.*, 2021). The key aim of both approaches is to achieve faster deliveries and assign only the heavy cargo to trucks (Eun *et al.*, 2019), which may, in turn, lower traffic congestion, transport cost and emissions (Raj and Sah, 2019; Wang *et al.*, 2022b).

(2) *Only drones performing the delivery*: can be divided into three segments. First, multiple drones (also called "drone-beehives"), by which a fleet of drones are launched from strategically located depots (e.g. city centers) to perform deliveries to several receivers (Aurambout *et al.*, 2019; Thida San and Chang, 2022). Factors such as drones' energy consumption, flying range, number of receivers and battery capacity are critical in determining the applicability of this approach (Bruni and Khodaparasti, 2022; Macrina *et al.*, 2020). Second, multiple trucks and multiple drones, by which drones are carried on trucks to perform deliveries within a radius pertinent to drones' range (Boysen *et al.*, 2018; Dukkanci *et al.*, 2021). Trucks do not perform deliveries in this approach; they only carry drones to optimal launch locations, where they park and await drones to complete their deliveries (Kang and Lee, 2021). Drones, on their part, may deliver to one receiver at a time (Huang *et al.*, 2022a), or serve multiple receivers per trip (Gu *et al.*, 2022). This approach is especially suited for humanitarian relief missions since drones can avoid physical barriers to reach those affected (Jeong *et al.*, 2020). Third, a flying warehouse, which has been patented by Amazon under the label "airborne fulfillment center". Here, a large aircraft floats over service areas to dispatch loaded drones from midair (Jeong *et al.*, 2022; Wang *et al.*, 2022a). An alternative to this approach is proposed by Wen and Wu (2022), where multiple drones are carried inside a larger drone.

In certain instances, a reversed setup is proposed: only trucks performing the delivery, resupplied by drones from the depot due to trucks' finite capacities (Dienstknecht *et al.*, 2022). Another mentioned application involves a combination of a drone with an unmanned ground vehicle (in one unit), capable of both flying and traveling on the ground (Kumar *et al.*, 2022). In any case, senders must select the right truck-drone combination based on their investment capability, drones' capacity, urgency of intended deliveries, geographical orientation of served areas and available infrastructure (Karak and Abdelghany, 2019; Macrina *et al.*, 2020; Huang *et al.*, 2022a). Here, deep learning methods (e.g. Q-learning) were suggested to aid choosing between trucks and drones (Chen *et al.*, 2022). The literature also recommends selecting several truck-drone combinations to optimize the LMD process and enhance its flexibility (Kirschstein, 2020; Rave *et al.*, 2022).

5.1.3 Capacity. Drones' limited capacity – in terms of travel range, speed, battery, payload and extreme weather resistance – is viewed as one of the main challenges to their adoption in LMD (Cheng *et al.*, 2020; Tamke and Buscher, 2021). Tezza and Andujar (2019) stress that current drone models can fly up to only ~5 miles (8 km) away from their pilots, while Choi and Schonfeld (2021) note that drones' flight time can rarely exceed 30 min due to the limited capacity of their lithium-ion batteries (which most drones rely on today). Drones trialed by companies like Amazon and UPS can carry payloads up to 5 pounds (2.27 kg) and fly at speeds up to 50 mph (80.47 kph) (Cheng *et al.*, 2020). One of the highest payloads reported in the literature was when drones carried 6.4 kg of blood samples at 10 m/s velocity (Homier *et al.*, 2021).

Drone capacities vary based on their model and type, resulting in trade-offs. For instance, multirotor drones excel in maneuverability but have a limited payload capacity, while hybrid drones, which combine propellers and wings, offer a longer range but compromise on maneuverability (Buldeo Rai *et al.*, 2022; Pasha *et al.*, 2022). Further trade-offs are cited amid drones' speed vs travel range (Murray and Chu, 2015), speed vs energy efficiency (Liu and Sun, 2022), travel range vs battery capacity (Glick *et al.*, 2022), battery capacity vs payload (Jeon *et al.*, 2021) and payload vs battery weight (Cheng *et al.*, 2020).

Undeniably, drones' limited capacities make them inferior to conventional trucks on several fronts, which explains their frequent integration with trucks in LMD setups. Besides working with trucks, the literature suggests several solutions to boost the capacity of drones themselves, such as recharging drones – fully or optimally (Huang *et al.*, 2022b) – along delivery routes (Glick *et al.*, 2022), deploying battery swapping/maintenance points across distribution networks (Shao *et al.*, 2020), or a combination of both (Huang and Savkin, 2022). Yet careful planning is advised before implementing such solutions; charging consumes time and blocks other drones from using the station (Huang *et al.*, 2022b), whilst replacing batteries demands human access for assistance (Boysen *et al.*, 2021). Hence, it is advised to find optimal locations of drones' charging/swapping stations while limiting their quantity to lower cost (Dhote and Limbourg, 2020). This can be achieved through several joint routing-charging strategies, compiled in Table 5.

Hub type	Description	References
Stationary	Charging in depots/warehouses where delivery items are stored	Ghelichi *et al.* (2021)
	Charging in docking stations alongside delivery routes	Pachayappan and Sudhakar (2021)
	Charging on trucks parked at non-customer locations	Salama and Srinivas (2022)
Mobile	Charging on trucks that also carry delivery items	Cha *et al.* (2022)
	Charging in aircrafts hovering over service areas	She and Ouyang (2021)
	Hitchhiking on the roofs of willing passenger vehicles	Liu *et al.* (2022)
	Hitchhiking on the roofs of cooperative public busses	Moadab *et al.* (2022)

Source(s): Created by authors

Table 5.
Hubs for drone battery charging and swapping

Other approaches to overcome drone capacity limitations include optimizing the number of launch points in relation to receivers' density and drone speed (Liu and Sun, 2022), scheduling deliveries based on drones' battery capacity (Conte *et al.*, 2022), having multiple drones carry the payload (Mohammadi *et al.*, 2022) and equipping drones with multiple propellers (Schiano *et al.*, 2022) or multiple mini-jet engines (Altuğ and Türkmen, 2022).

5.2 Receivers' priorities

5.2.1 Time. One key advantage of using drones in LMD is the possibility to deliver to receivers faster. Thanks to their flying capability, drones can reduce delivery time through avoiding buildings, traffic congestions, rivers, or other geographical/physical barriers (Hernández *et al.*, 2020). Using real-time simulations, drones' ability to reduce delivery time were proven in scenarios where they delivered in tandem with trucks (Masone *et al.*, 2022; Murray and Chu, 2015; Tong *et al.*, 2022) and when trucks were utilized as landing/take-off hubs for drones (Boysen *et al.*, 2018; Carlsson and Song, 2018). Pilot trials of drones have seen success on 30 min delivery intervals (Harn *et al.*, 2021), to as low as 5 min in medical emergencies (Baumgarten *et al.*, 2022; Mateen *et al.*, 2020).

However, realizing such short delivery times may require operating dedicated drones for individual orders (Perera *et al.*, 2020). This can create a shift towards decentralized distribution systems (Kunovjanek and Wankmüller, 2021), bringing along further cost constraints since additional delivery centers must be erected in close proximities to receivers (Pinto and Lagorio, 2022). To save both cost and time here, it is advised to share workloads between drones based on the unique capacities of the used models (Thida San and Chang, 2022), or having drones simultaneously pick-up and deliver items (Shi *et al.*, 2022), which is most relevant in medical contexts. The literature also recommends assigning deliveries to trucks, drones, or a combination of both, based on either relaxed (Luo *et al.*, 2022b) or strict time slots (Xing *et al.*, 2023) – met by penalties if exceeded (Li *et al.*, 2022b). Such time slots can be linked to the perishability of carried items to ensure their preservation while delivering them on time (Gentili *et al.*, 2022).

A question that often arises is to what extent receivers care about significant reductions in delivery times. The literature hangs this debate on the time sensitivity of the deliveries (Gentili *et al.*, 2022) and the socio-demographic characteristics of receivers such as age, gender and income (Kim, 2020) – where younger populations tend to opt for drone deliveries (Kim, 2020). Although e-commerce receivers prioritize delivery speed over other parameters such as cost and environmental impact (Nogueira *et al.*, 2021), the situation is more critical in medical or disaster relief missions where a speedy delivery can save a life. In light of this, Table 6 demonstrates highly promising time savings enabled by drones for medical deliveries,

Article	Delivered item(s)	Trial location	Average reductions in delivery time*
Homier *et al.* (2021)	Blood products	Canada	41%
Gunaratne *et al.* (2022)	Vaccines	Sri Lanka	58%
Sylverken *et al.* (2022)	Covid-19 samples	Ghana	67%
Oakey *et al.* (2022)	Diagnostic specimens	UK	72%
Mateen *et al.* (2020)	Antiepileptic drugs	Republic of Guinea	79%
Amicone *et al.* (2021)	Various medical products	Italy	80%

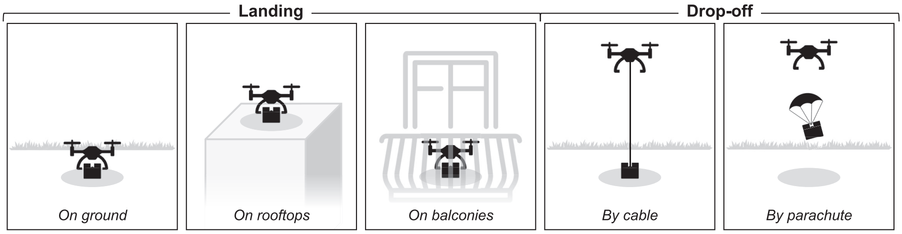
Note(s):*Compared to traditional delivery methods
Source(s): Created by authors

Table 6.
Time savings by drone medical deliveries

as tested in several studies. Nonetheless, factors like travel distance, weather conditions, wind speed, geographic location, item weight and drone capacity can significantly impact the time savings achieved by drone deliveries (Johannessen *et al.*, 2021; Kunovjanek and Wankmüller, 2021; Oakey *et al.*, 2022).

5.2.2 Reach. A functional LMD system should enable reaching receivers no matter where they are located. Drones, in fact, have both strengths and weaknesses in this regard. Their strength lies in overcoming physical constraints (as discussed earlier). This is especially relevant in rescue and medical emergency missions, where drones can deliver time-critical items to people in hard-to-access zones such as mountains (Holzmann *et al.*, 2021), hurricanes (Chowdhury *et al.*, 2017), earthquakes (Kamat *et al.*, 2022), or areas with poor transportation infrastructure (Hernández *et al.*, 2020). In many instances – especially humanitarian-relief missions – the demand point of the delivery can be unknown (Ghelichi *et al.*, 2022) or disrupted by weak/interrupted signals (Zhu *et al.*, 2022). Equipping drones with Artificial Intelligence, thermographic cameras and strong zooming functionality may significantly expand their reach capacity and reduce arrival times in such conditions (Amicone, 2021; Holzmann *et al.*, 2021).

Figure 9 shows the most discussed drone landing and item drop-off methods in the literature. To enhance the precision of landing/drop-off events, it has been suggested to supply drones with fiducial markers (Innocenti *et al.*, 2022), satellite and street imaging capability (Li *et al.*, 2022c), or precision airdrop algorithms (Zhang *et al.*, 2022).



Source(s): Created by authors

Figure 9.
Drone landing and drop-off methods

As for reach weaknesses, drone deliveries are constrained in urban environments due to inadequate landing space for receivers situated in high-rise buildings or without access to open yards (Boysen *et al.*, 2021). Additionally, most countries limit drone operations to rural areas to avoid interfering with other aircrafts or posing safety risks to residents (Boccia *et al.*, 2021; García *et al.*, 2021). Such constraints could eventually turn drone deliveries into a privilege enjoyed by populations within certain zip codes only. In response, the literature proposed a few solutions to foster drone deliveries in urban areas, such as installing "common delivery zones" (Pachayappana and Sundarakani, 2022) or accessing receivers amid no-fly-zones (Jia *et al.*, 2022).

Most countries also limit drone flights to Visual-Line-Of-Sight (VLOS) zones, where pilots should keep the flown drones within their field of vision (Harn *et al.*, 2021; Mohamed *et al.*, 2020). In the EU, efforts have been made to ease sighting restrictions to reap the full benefits of drone deliveries, considering flights in Extended-Visual-Line-Of-Sight (EVLOS) and Beyond-Visual-Line-Of-Sight (BVLOS) zones (García *et al.*, 2021). The former refers to the zone beyond the pilot's visual sight but within other observers' view, while the latter denotes the zone beyond any visual contact with the drone (Alamouri *et al.*, 2021) – Figure 10. Flying in BVLOS zones is often carried out by fully autonomous drones, backed by Detect-and-Avoid systems to prevent collisions and warrant safe maneuvers (García *et al.*, 2021). However, even if drone flights were fully

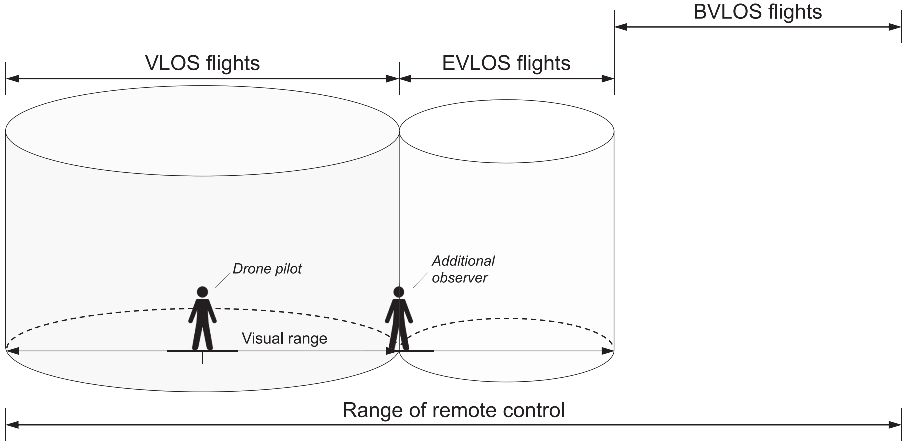


Figure 10.
Drone flight ranges

Source(s): Re-illustrated from Stöcker *et al*. (2017)

autonomous, human intervention is still needed to reduce collision risks through pre-programming flights and supervising them in real time (Buldeo Rai *et al.*, 2022).

5.2.3 Item condition. Delivering items free from all forms of damage – such as physical dents, surpassing expiration times or temperature ranges – is one of LMD's necessities. This is especially relevant in medical deliveries, where the way blood products, laboratory samples, or organs are transported impacts their quality (Scalea *et al.*, 2021). Organs and blood products, which cannot be manufactured but only donated, benefit significantly from drone deliveries due to possible time savings that help preserve the products' integrity (Amicone *et al.*, 2021). Here, blood products have a limited quality period before rapid deterioration sets in (Gentili *et al.*, 2022), while organs require immediate deliveries to prevent damage to their tissues after cutting blood circulation (Amicone *et al.*, 2021). Temperature ranges should also be calibrated based on the idiosyncrasies of transported items (Amukele *et al.*, 2017). Red cells, for instance, should be maintained within 2–6 °C, whilst plasma should be kept frozen at below −25 °C (Niglio *et al.*, 2022).

To warrant such meticulous preservation conditions, wet ice, dry ice, expanded polystyrene foams and pre-calibrated thermal packs can be added to the boxes containing the items delivered by drones (Ong *et al.*, 2022; Zailani *et al.*, 2022), with a possibility of live monitoring via smart capsules (Niglio *et al.*, 2022). Live monitoring can also reduce time spent at the delivery destination. For instance, measuring product features (e.g. pH levels of blood samples) during drone flights can save up to 30 min upon arrival (Liu *et al.*, 2022b), with package quick-release systems suggested to attain further time savings (Saponi *et al.*, 2022). Drone deliveries may also reduce waste from carried items (e.g. blood), since their high success rates can lower resupply requests (Nisingizwe *et al.*, 2022). Yet given drones' airborne maneuvers, using them for deliveries may damage the carried items – let alone damaging the drones themselves (De Silvestri *et al.*, 2022). Indeed, some of Kornatowski *et al.*'s (2018) experiments resulted in damaged items after drones fell to the ground due to accidental battery detachments – prompting the authors to recommend using reliable drone components and reinforcing the boxes preserving the carried items.

5.3 Regulators' priorities

5.3.1 Policies. Drone deliveries may overcrowd the airspace that is also shared by other aircrafts with different functions (Ribiero *et al.*, 2021). This calls for crafting new policies to govern the airspace and reconcile potentially competing interests (Ben Dor and Hoffman, 2022). Today, governmental policies are seen by many scholars as a large, if not the largest, challenge to drone adoption in LMD (Dhote and Limbourg, 2020; Raj and Sah, 2019; Rathore *et al.*, 2022). Such policies encompass routing, elevation, sighting, proximity to people/buildings, permissible flight times, classification/weight of transported items, pilot certification/training, insurance and allocation of liability (Cracknell, 2017; Innocenti *et al.*, 2022; Sah *et al.*, 2021). A challenge here is that drones' policies are steered independently in each country, resulting in dissimilar or even conflicting rules (García *et al.*, 2021). Countries like the US and Canada are known for their strict aviation policies, such as mandating a special UAV controller license (i.e. "pilot license") to fly drones in BVLOS zones and demanding human supervision of flights at all times (Mateen *et al.*, 2020). In Australia, it is not compulsory to hold a UAV controller license to operate certain drone models (e.g. radio-controlled drones), yet rules to govern responsible operations apply (Cracknell, 2017). In India, the process of registering drones via government portals can get tedious, with numerous restrictions concerning fly zones and trespassing, accompanied by a lack of UAV-dedicated frequencies to support flights (Kamat *et al.*, 2022). Some low-income countries, in turn, have limited-to-no legislations for commercially operated drones, which may give them a "leapfrog" advantage but also backfire due to the lack of support from legislative bodies (Mateen *et al.*, 2020) [3].

Despite the presence of policies of a strict nature in most parts of the world, many countries started relaxing their aviation policies to accommodate drone deliveries over their territories. The EU has passed a uniform set of rules to standardize drone guidelines across its 27 states, addressing various operational, technical, risk and safety matters (Dhote and Limbourg, 2020; García *et al.*, 2021). In the US, the Federal Aviation Administration (FAA) has been granting companies like Amazon and Wing exemptions to operate drones weighing less than 25 kg for commercial purposes since 2016 (Ghelichi *et al.*, 2021; Jeon *et al.*, 2021). China exempted drones weighing below 1.5 kg (including fuel) from registration to lower barriers to entry (Cracknell, 2017). Australia has gone far in legalizing drone deliveries for commercial use (Rao *et al.*, 2016), whilst Rwanda has incubated drone medical deliveries since 2016 (Lockhart *et al.*, 2021). These remarks indicate that the world's nations started recognizing the value of drone deliveries and are taking progressive – yet careful – steps to facilitate their adoption.

5.3.2 Infrastructure. For drone deliveries to succeed, having a robust air-mobility infrastructure is vital. Regulators may enable funding, establishing and operating such infrastructures thanks to their frequent involvements with stakeholders from public and private domains (Comtet and Johannessen, 2022). According to the literature, infrastructural assets for drone deliveries may fall into two categories: tangible and intangible – outlined in Table 7.

Asset type	Includes . . .	References
Tangible	Battery charging/swapping hubs; take-off/landing stations (e.g. vertiports); road networks (for drone-truck setups); dedicated 3D aerial highways; warehouse facilities; operational teams	Boysen *et al.* (2021), Cherif *et al.* (2021), Hou *et al.* (2021), Serrano-Hernandez *et al.* (2021)
Intangible	Data and communication networks (e.g. 5G, 6G, blockchain); operating licenses; conflict reconciliation schemes; data protection mechanisms; air-traffic management systems (e.g. UTM)	Ali and Ali (2022), García *et al.* (2021), Kellerman *et al.* (2020), Rao *et al.* (2016), Verma *et al.* (2022), Pei *et al.* (2022)

Source(s): Created by authors

Table 7.
Infrastructural assets for drones

Cokyasar (2021) finds that an infrastructure of drone-truck deliveries yields higher cost savings than a truck-only or drone-only infrastructure. Notwithstanding either, Kellermann *et al.* (2020) argue that many local planning authorities are not yet prepared for integrating drone deliveries into their current infrastructures or resolving conflicting interests that may arise parallel to implementation. In agreement, Aurambout *et al.* (2019) note that only a few major cities in Europe have the necessary resources to accommodate drone deliveries – though the situation may soon improve after the EU's introduction of a framework that fosters drones' innovation, investment and business development opportunities across its states.

One of the most cited initiatives in the infrastructural domain is the Unmanned Traffic Management (UTM), defined as a highly digitized automated control system that enables safe and efficient access to lower airspace for a large number of drones (Kellerman *et al.*, 2020). UTM integrates numerous parameters into flight planning, such as drone/local airborne traffic, population density, number of people and objects on ground, geofences, physical obstacles and weather forecasts (Lundberg *et al.*, 2018; Oosedo *et al.*, 2021; Shao, 2020). UTM also utilizes data from drones' sensors and cameras to ensure safe maneuverability and landing (Lundberg *et al.*, 2018), especially in BVLOS zones (Oosedo *et al.*, 2021). Having a functional cellphone/GPS network is essential for UTM's success, as it allows drones to communicate with each other as well as with their operators (Miranda *et al.*, 2022). Such networks should warrant speedy, reliable and uninterrupted service to enable the massive information exchange needed for operation (Ali and Ali, 2022). However, weak signals are sometimes inevitable in complex environments with high interferences, calling for innovative solutions such as having drones act as a means to deliver packages and transmit data simultaneously (Qin *et al.*, 2022), or utilizing deep learning to aid drones in autonomously finding delivery spots via visual information (Luo *et al.*, 2022a). Pre-flight conflict detection and resolution methods are also proposed to enable collision-free flights in the UTM's shared airspace and institute fairness to all parties involved (Li *et al.*, 2022a; Ho *et al.*, 2022).

Extensive testing of UTM has been carried out globally. In the US, the National Aeronautics and Space Administration (NASA), in partnership with the FAA, has already run successful UTM trials in both rural and urban areas (Kitjacharoenchai *et al.*, 2019). UTM trials have stretched out to the UK and Europe under the "U-Space" program and to China under the "UAV Operations Management" initiative (Grote *et al.*, 2021).

5.3.3 Public acceptance. Regulators need to consider public acceptance before legalizing a certain act at large. That is, even if drone deliveries proved success from operational and technical standpoints, careful measures should still be followed to avoid wreaking chaos in societies upon their launch (Moshref-Javadi and Winkenbach, 2021). Indeed, drone deliveries may deviate from their originally intended objectives and fall into ethical misconduct at individual, organizational and societal echelons (Luppicini and So, 2016). Examples contain spying on residents or organizations via drones' cameras and sensors, or using the collected data to influence the decisions of certain individuals or organizations (Mohamed *et al.*, 2020). In fact, drones are already stigmatized in the public eye after some military applications led to unintended deaths of civilians, which affected their acceptance in non-military applications too (Luppicini and So, 2016). Table 8 provides a synopsis of the articles investigating public acceptance of drone deliveries across three levels: general public, potential receivers and potential senders and receivers.

Public acceptance is more critical now than ever, given rising public awareness on safety, privacy and ethical questions alongside growing governmental mistrust in some nations (Leon *et al.*, 2021). Fear of losing one's job – especially truck drivers – is also mentioned as a factor harming public acceptance of drone deliveries (Cherif *et al.*, 2021). To protect the public and garner their acceptance on drone use, it is advised to define clear guidelines and codes of ethics (Mohamed *et al.*, 2020), enforce strict safety measures (Luppicini and So, 2016), educate

Article	Sample	Country (city)	Study focus	Relevant key findings
General public				
Kellermann and Fischer (2020)	5 focus groups of residents	Germany (Berlin, Stuttgart, Erfurt)	Drones for parcel/passenger transport	While most residents were ambivalent on drone deliveries, issues such as safety, security, sustainability and usefulness were raised
Troug *et al.* (2020)	450 residents	Malawi, Mozambique, D.R. Congo, D. Republic	Drones for medical deliveries	While residents believed in the importance of drones in medical emergencies, concerns about drones crashing and damaging property/payloads were stressed across all countries
Zhu *et al.* (2020)	1,465 residents	USA	Risk beliefs of drones in LMD	11 risk beliefs were linked to different risk belief systems. Risk-mitigating messages targeting central risk beliefs were more effective in changing public risk perceptions
Serrano-Hernandez *et al.* (2021)	107 residents	Spain (Pamplona)	Drone deliveries in smart cities	Residents preferred it if drones took routes surrounding the city center instead of crossing it, attributing this to factors related to life quality, pedestrian safety and noise pollution
Buko *et al.* (2022)	267 residents	Poland (Dobra)	Drones vs delivery couriers for LMD	Social skepticism about drone deliveries reached 43% among the sample
Potential receivers				
Kim (2020)	400 online consumers	South Korea	Drone vs traditional modes for LMD	Consumers' preference was impacted by item specs (e.g. price, type) and socio-demographics (e.g. gender, age, income) – younger individuals opt for drone deliveries
Kim and Hwang (2020)	401 online food consumers	South Korea	Drones for food deliveries	Consumers' knowledge about the benefits of drone deliveries impacted acceptance levels
Leon *et al.* (2021)	617 online consumers	USA	Drones for LMD	Increased perceived privacy risk reduced acceptance of drone deliveries. Legislation, usefulness and trust were key factors affecting such acceptance
Merkert *et al.* (2022)*	709 online consumers	Australia	Innovative vs traditional LMD	Consumers still preferred a traditional "postie" over drone deliveries, considering factors like delivery speed, time window and safety

(*continued*)

Table 8.
Drone public acceptance studies

Article	Sample	Country (city)	Study focus	Relevant key findings
Polydoropoulou *et al.* (2022)*	336 online consumers	Greece	Mode choice for sustainable LMD	Consumers had "no interest" in drone deliveries, nor were they willing to pay extra for them
Jasim *et al.* (2022)	209 online food consumers	Malaysia (Kajang)	Drones for food deliveries	A significant relationship was found between consumer behavioral intention and acceptance of drones for food deliveries
Borghetti *et al.* (2022)	100 consumers	Italy (Milan)	Drones vs other modes for LMD	Participants favored drone deliveries as these would lower the number of vans circulating (thus reducing congestions, accidents and pollution)
Potential senders and receivers				
Michael *et al.* (2019)	200 healthcare workers	Nigeria	Drones for vaccine deliveries	Despite limited knowledge about the technology, workers perceived drones as highly feasible for vaccine deliveries
Holzmann *et al.* (2021)	146 mountain rescuers	Alps Region	Drones for mountain rescue missions	Adopting drone deliveries for mountain rescue missions relied on performance gains, facilitating conditions and favorable supporting conditions. Experience with drones influenced this relationship
Sham *et al.* (2022)	272 healthcare workers	Malaysia (Perak, Selangor, Sarawak)	Drones for vaccine deliveries during Covid-19 (rural areas)	>50% of the sample commended drone use for medicine/vaccine deliveries in rural areas. Such preferences correlated with drones' potentials (e.g. speed, compatibility, low complexity, environmental friendliness)
Valencia-Arias *et al.* (2022)	121 delivery professionals	Colombia (Medellín)	Drone for LMD during Covid-19	Performance risk, compatibility, personal innovativeness and relative advantage of environmental friendliness were the most influential factors on intentions to use drone deliveries (mediated by attitude towards the technology)

Note(s): *Applied experimental survey design.
Acceptance of potential senders and receivers are included in Table 8 since they count as part of societies
Source(s): Created by authors

Table 8.

pilots (Scalea *et al.*, 2018) and apply stringent violation penalties (Rao *et al.*, 2016). To expedite acceptance rates of drone applications (especially urgent ones like medical deliveries), the literature mentions familiarizing receivers and communities with drones' benefits by disseminating educational information across various channels, such as community leaders, radio/TV announcements, marketing campaigns and social media outlets (Jasim *et al.*, 2022; Troug *et al.*, 2020).

5.4 Societies' priorities

5.4.1 Safety. Drone deliveries may bring several safety benefits to societies. First, their potential to substituting traditional vehicles can alleviate traffic congestions and time spent by drivers on the road, minimizing road accidents (Jasim *et al.*, 2022). This may also lower air- and noise pollution from traditional delivery vehicles, protecting the public from respiratory complications and stress-related illness (Buko *et al.*, 2022; Kellermann *et al.*, 2020). Second, drone deliveries eliminate drivers' physical contact with receivers and consequently limit the spread of contagious diseases such as Covid-19 (Du *et al.*, 2022). Third, drones' speedy deliveries of medical items (e.g. blood, organs) can be life-saving for the patients in need (Boutilier and Chan, 2022). This also holds in humanitarian relief missions where drones enable delivering critical items to displaced/endangered persons (Hachiya *et al.*, 2022). Fourth, drones' ability to lively monitor the status of carried items (via, e.g. sensors, smart capsules) may preserve their characteristics and lower risks of theft, loss, or damage (Amicone *et al.*, 2021).

On the flipside, if drones were to replace other modes of delivery, a massive increase in traffic in the airspace would result (Ribeiro *et al.*, 2021), bringing both mental- and physical distress to societies. Risk assessment studies reveal that drones pose safety threats during both (1) flying, with chances of crashes or falling packages (Ren and Cheng, 2020) and (2) take-off/landing, with potential harm to nearby pedestrians, children, pets, or property from exposed propellers or crashes (Oosedo *et al.*, 2021). Han *et al.* (2022) identified four root causes of drone accident risks: ground control computer failures, communication interferences, human operational errors and drone component failures. Such risks intensify under emergency landing situations and extreme weather conditions (Glick *et al.*, 2022), especially in urban environments (Shao, 2020). This urged regulators and operators alike to carefully specify maximum payloads and flight altitudes to warrant safe drone operations (Macrina *et al.*, 2020). In light of this, Ren and Cheng (2020) find that flying at higher altitudes lowers drone delivery risk in urban areas, whilst flying at lower altitudes reduces the risk over open spaces such as lakes, woods and roads.

The literature suggests several measures to improve the safety of drone deliveries, including equipping drones with redundant systems (e.g. extra motors, sensors) to avoid crashing (Murray and Chu, 2015), using collision-free paths that lively consider space congestion and battery charge (Lee *et al.*, 2022), employing deep learning for allocating safe landing spots based on current battery level (Conte *et al.*, 2022), implementing event-based emergency detection systems (Kim *et al.*, 2022) and forming dedicated aerial highways and standardized routing protocols (Moshref-Javadi and Winkenbach, 2021).

5.4.2 Privacy. Drones require sensing and surveillance technologies (e.g. cameras, radars) to avoid collisions and facilitate take-off, landing and item drop-off events (Nentwich and Horváth, 2018). Such technologies may also entail capturing/storing videos, images and other sorts of data (Mohamed *et al.*, 2020), posing sociological concerns as they may invade people's privacy (Dhote and Limbourg, 2020), especially if the captured data landed in the wrong hands (Rao *et al.*, 2016). In fact, people have already voiced their discomfort about feeling observed after the military began using drones for surveillance (Luppicini and So, 2016). The rise of cyberattacks has also reduced the approval rates of drone deliveries in fear of losing the captured data to malicious actors (Cherif *et al.*, 2021; da Silva *et al.*, 2022). This urged several scholars to promote data-encryption methods, such as blockchains, as a medium for secure and fast drone-related transactions (Kwon *et al.*, 2022; Verma *et al.*, 2022). Nonetheless, Kellermann and Fischer (2020) find that the public did not explicitly mention the privacy concern while expressing their views of drone *deliveries* in particular, which they attributed to the limited public awareness of the technical aspects of such deliveries. As McKinnon (2016) puts it, privacy concerns may intensify once drone deliveries become a norm and people start seeing them hovering over their homes and gardens. Looking at the matter from a legal perspective, Rao *et al.* (2016) stress that while present laws allow recording public spaces such as streets and parks, these laws prohibit recording the interior of homes or privately-owned buildings. This makes one wonder if flying drones over private spaces violates such laws – pointing towards possible loopholes in privacy laws. Ben Dor and Hoffman (2022) propose giving landowners the rights to commercialize and sell access to – or prohibit drones from entering – their private airspace, especially for low-latitude flights. In turn, Mohamed *et al.* (2020) recommend incorporating the case of drone deliveries under national privacy laws, such as the Data Protection Act in the UK.

5.4.3 Environment. Drones may relieve traffic congestion thanks to their flying ability (Serrano-Hernandez *et al.*, 2021) and emit low emissions per package-km thanks to their electric batteries (Figliozzi, 2020). Nonetheless, the literature appears inconclusive on their environmental friendliness. ElSayed and Mohamed (2020) find that drone deliveries – in rural areas with relaxed aviation policies – may lower CO_2 emissions at 1000-fold compared to diesel vehicles and by 35% compared to electric vans. Yet in urban areas, they find that drones' emissions may increase up to 400% due to stricter policies, extra travel to circumvent buildings and the need for additional service points. Worth noting in their model is that electricity for charging drones mostly came from low-emission sources such as nuclear and hydroelectric. If drone chargers were powered by carbon-intensive sources like coal, emissions can vary depending on drone's range, speed and weight (Goodchild and Toy, 2018). Distinctions were made between drones' power sources too; Stolaroff *et al.* (2018) note that hydrogen fuel-cells outpace lithium-ion batteries in energy density and range, though the technology is not mature yet with many unresolved safety concerns.

Several studies concur on the challenging nature of operating drones in urban areas. Kirschstein (2020) finds that using only drones for delivery is generally less energy-efficient compared to both diesel and electric ground vehicles – attributing this to the high receiver density and relatively short truck tours in urban settings. Similarly, Figliozzi (2020) compares drones with other transport modes (e.g. autonomous robots, electric/diesel vans), finding that drones are the most efficient alternative only under time-constrained and low-receiver-density scenarios. Goodchild and Toy (2018), however, note that using drones could lead to greener results in urban areas when receivers are close to depots and delivery routes comprise a few stops. In turn, Choi *et al.* (2022) propose operating drones through underground subways to circumvent urban delivery hurdles altogether.

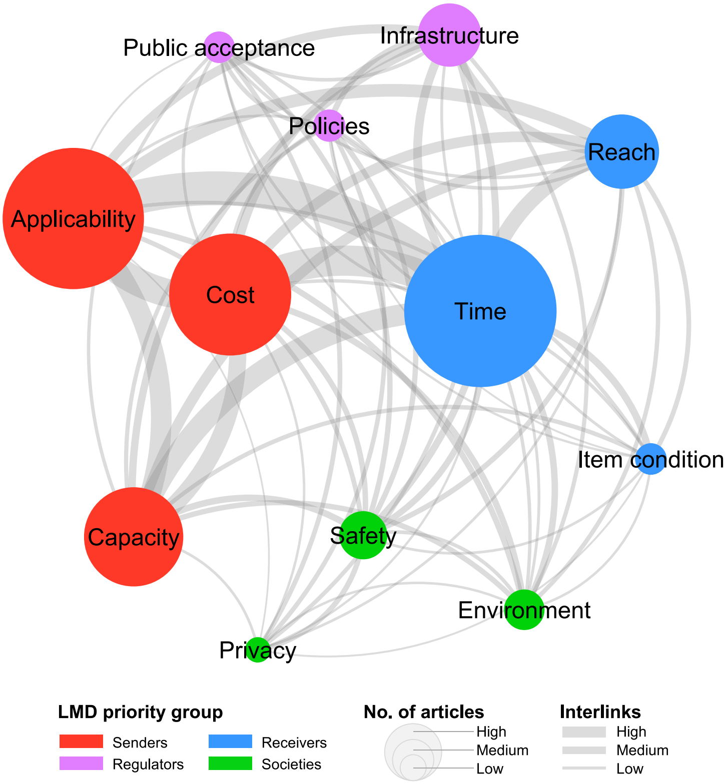
Using Life Cycle Assessment (LCA), some scholars examined the environmental impact of drone deliveries beyond their operational phase. Koiwanit (2018) applied LCA to reveal that producing drones' parts has a higher environmental impact compared to drones' operation. Park *et al.* (2018), also using LCA, compared the environmental impact of drones against motorcycles (both petrol-powered and electric), finding that drones were by far the most sustainable, especially in rural areas. The authors also suggest utilizing clean energy sources (e.g. solar, wind) to further tip the balance in drones' favor. Combining electric trucks with drones has also been proposed to maximize emission savings (Baldisseri *et al.*, 2022), which may reach up to 87% in some cases (Bányai, 2022).

On the flipside, drone deliveries can cause unintended environmental externalities such as wildlife interference (especially with birds), noise and collision debris (Nentwich and Horváth, 2018). Moreover, tradeoffs between drones' CO_2 reduction and costs seem to exist; Oakey *et al.*'s (2022) experiments reported a 20% emission reduction by drones but a 56% increase in equipment, charging and insurance costs.

6. Cross-thematic analysis

Figure 11 illustrates a network analysis of the 12 LMD criteria, delineating the degrees of emphasis of each criterion in the reviewed sample and their interconnectedness. At a glance, *time*, *applicability* and *cost* surge to the forefront as the most addressed – and most interlinked – criteria in the literature. This prevalence is not coincidental; modeling studies – which dominate the sample – lean heavily into evaluating the practical uses of drone-based deliveries and their potential to outperform traditional delivery methods such as trucks and vans. By doing so, researchers discern how drones can be best utilized to achieve both time and cost efficiencies – with time being an essential metric for receivers and cost being an essential metric for senders. Adjacent to these core criteria, *capacity*, *reach* and *infrastructure* emerge as vital, albeit less explored, areas of inquiry. Their presence in the literature, although not as dominant, is intrinsically linked to the primary criteria mentioned above. That is, when discussing potential time and cost savings by drone deliveries, one invariably touches upon the limitations posed by drones' payload/battery capacity and existent infrastructures to reach potential receivers, including the physical and technological frameworks available to warrant success of drone deliveries.

A careful observation of Figure 11 also reveals an area of opportunity. Crucial criteria such as *environmental* impact, *safety* considerations, governing *policies*, *privacy* and *public acceptance* have remained relatively less explored. This oversight perhaps stems from the



Source(s): Created by authors

Figure 11.
Network analysis

nascent nature of drone technology and the initial industry inclination towards proving its operational efficacy. In other words, scholars in this realm seem to have wanted to prove that drone deliveries actually work as intended before exploring the adjacent ramifications for their facilitation. That being said, the landscape appears to be shifting, with more recent scholarly endeavors delving into these overlooked criteria (see Figure A1 in Appendix). This shift underscores the realization that for drone delivery systems to be holistically effective and accepted, they must address not only operational challenges but also legal, societal and environmental concerns.

Our further dissection of the relationships between the 12 LMD criteria resulted in forming a comprehensive 12 × 12 matrix (Table 9), from which we derived one positive and one negative relationship for each set of LMD criteria to elucidate their inherent interdependencies and the trade-offs involved for pursuing them. These associations highlight the highly challenging and intricate task of enabling drone deliveries in a manner that satisfies all stakeholder groups while fulfilling all LMD criteria simultaneously.

7. Further research directions

Grounded in the literature on drone applications in LMD, we identify nine research directions (RDs) for further investigation in the logistics management field.

RD1. Elucidating drone applications in LMD from a managerial perspective.

The reviewed literature is predominated by studies from transportation science, engineering and computer science, viewing the topic mainly from optimization and simulation standpoints. While these studies aid logistics managers' decision-making on drone deliveries based on key logistics criteria (e.g. cost, time, facility location), a comprehensive managerial perspective on the topic is rather scarce. This is a crucial gap to bridge, given the myriad of managerial factors affecting the applicability of drone deliveries coupled with the fact that they still lack scale economies, public acceptance, ready infrastructures and governing laws. As such, logistics managers are still left to wonder about the strategic considerations for investing in drone deliveries and the optimal timing and location for implementation. A large opportunity presents itself here to logistics management scholars to examine drone deliveries from strategic, marketing, financial, operational and supply chain outlooks. Theories such as transaction-cost economics, resource-based view, stakeholder theory and network theory may be applied to elucidate whether firms should internalize their drone applications or outsource them to third-party vendors. The relational view may also be relevant to explore whether supply chain partners can enact relation-specific assets or knowledge-sharing routines to leverage drone applications for desired win-wins.

RD2. Creating generalizable and contextualized knowledge on behavioral issues surrounding drone deliveries, using empirical research methods.

As discussed in Section 4.3, the literature on drone deliveries is dominated by modeling studies, utilizing approaches like the Vehicle Routing Problem and Facility Location Problem. While such non-empirical methods are invaluable for decision-making, they are limited in capturing the behavioral nuances surrounding drone use. Although our review identified 11 surveys and 10 case studies (of which three are qualitative), none of them focused on the behaviors of logistics firms, while only a few examined the behaviors of other stakeholders such as consumers and residents. This signals a need for more research to understand the perspectives of logistics managers, delivery experts, regulators, among others, to empirically assess their acquaintance with the technology.

Table 9.
12 × 12 matrix

	Cost	Applicability	Capacity	Time	Reach	Item condition	Policies	Infrastructure	Public acceptance	Safety	Privacy	Environment
Cost	*169*	142	85	154	50	12	16	42	11	23	7	27
Applicability	(+) Operating drones in tandem with trucks can lower LMD cost (−) Drone-truck setups require substantial upfront investments	*197*	103	173	61	14	9	42	4	19	3	25
Capacity	(+) Joint routing-charging strategies can lower cost and boost range capacity (−) Drones' limited payload/battery capacity entails costs of building extra hubs	(+) Drone-truck setups improve capacity by utilizing both means (−) Drones' limited capacity remains a barrier even when combined with trucks	*136*	106	50	17	16	33	12	28	8	22
Time	(+) Drones' timely/speedy deliveries reduce cost of delayed/failed deliveries (−) Realizing short delivery times incurs costs of dedicated drones and extra depots	(+) Drone-truck setups reduce delivery time by utilizing speed/access features of each mode (−) Optimizing time saving requires complex drone-truck setups	(+) Drones' flying capacity enables faster deliveries due to skipping barriers (−) Tradeoffs exist between travel range and time (due to wait times for charging/replacing batteries)	*213*	76	31	12	40	11	27	6	28

(*continued*)

Table 9.

	Cost	Applicability	Capacity	Time	Reach	Item condition	Policies	Infrastructure	Public acceptance	Safety	Privacy	Environment
Reach	(+) Drones' ability to reach hard-to-access zones lowers driver- and land vehicles cost (−) Human intervention for reaching no-fly-zones can become costly	(+) Drone-truck setups can maximize reach potentials (−) Reach potentials of drone-truck setups can get obstructed by poor road networks	(+) Drones' flying capacity enables reaching hard-to-access zones (−) Drones' limited payload/battery capacity restricts their reach potentials	(+) Drones skip physical barriers to reach receivers faster (−) Possible delays in reaching receivers in urban areas due to limited landing space	*100*	19	13	38	11	22	8	17
Item condition	(+) Drones' preservation of items can lower wastage levels and cost (−) Damaging items by drones' aerial maneuvers raises insurance cost	(+) Drone-truck setups can increase item preservation through optimized speed (−) Drone-truck setups can increase susceptibility to damage due to reliance on multiple modes	(+) Light protection materials (e.g. foams) exist to accommodate drone's limited payload capacity (−) Drone's limited payload/battery capacity restricts preservations to small and lightweight items	(+) Drones' fast deliveries preserve items from perishability (−) Haste may increase risks of drones crashing and damaging items	(+) Drones can deliver well-preserved items to hard-to-access zones (−) Reaching receivers in urban areas is accompanied with higher accident/damage risks	*38*	4	9	6	8	4	7

(*continued*)

Table 9.

	Cost	Applicability	Capacity	Time	Reach	Item condition	Policies	Infrastructure	Public acceptance	Safety	Privacy	Environment
Policies	(+) Policies can standardize drone operations and lower tailoring cost (–) Regulatory compliance (e.g. licenses, airspace charges) can get costly	(+) Policies can facilitate drone-truck setups through streamlining operational, safety and risk issues (–) Drone-truck setups lack policies to guide route planning and inventory allocation	(+) Policies may endorse constructing charging hubs along delivery routes (–) Deficient regulatory support of UAV frequency extensions to boost drone range	(+) Policies can sponsor dedicated aerial highways to speed up drone deliveries (–) Some policies restrict drone flights to certain time frames	(+) Policies can support data coverage to expand drones' reach potentials (–) Restricting drone flights to certain zones (e.g. VLOS) can limit their reach potentials	(+) Policies can support creating clear preservation criteria for each type of item (–) Payload restrictions limit item preservation potentials to small/lightweight items	*39*	25	17	22	18	9
Infrastructure	(+) Drone-truck delivery infrastructures are more feasible than truck/drone only ones (–) Drone deliveries require ample investments in tangible/intangible infrastructural assets	(+) Flexibility in selecting suitable drone-truck setups based on existent infrastructure (–) Deficient inclusive infrastructures to support drone-truck delivery setups	(+) Infrastructural assets (e.g. hubs, networks) can offset drones' limited payload/battery capacity (–) Lacking infrastructures to support battery charging/maintenance along routes	(+) Certain infrastructural assets (e.g. aerial highways, data networks) enable timely deliveries (–) Inadequate infrastructures (e.g. landing spots, hubs, data networks) delay deliveries	(+) Certain infrastructural assets (e.g. data networks) can maximize drone reach potentials (–) Weak signals in complex environments with high interferences limits reach potentials	(+) Data and communication networks enable live monitoring of item's conditions (–) Communication interferences increase risk of drones crashing and damaging items	(+) Regulators can host air-traffic management systems (e.g. UTM) to provide inclusive infrastructures (–) Most cities' infrastructures are not ready for drone deliveries	*84*	13	31	16	16

(*continued*)

Table 9.

	Cost	Applicability	Capacity	Time	Reach	Item condition	Policies	Infrastructure	Public acceptance	Safety	Privacy	Environment
Public acceptance	(+) Public acceptance enables widespread adoption (scale economies) (−) People are not willing to pay extra for drone deliveries	(+) Public acceptance can expedite adopting drone-truck setups in/around cities (−) Public's preference of drones surrounding city centers limits drone-truck applicability	(+) Public acceptance can prompt installing charging hubs to revive capacity (−) Public skepticism can limit the spread of charging hubs along routes	(+) Public acceptance can expand flight domains to shorten travel time (−) Public disapproval of flights in certain zones can prolong deliveries	(+) Public acceptance can expand flight domains and reach potentials (−) Public disapproval of flights in certain zones restricts reaching these zones	(+) Public acceptance can expand flight domains, shorten time and preserve items from perishability (−) Public skepticism of drones' utility can demotivate preservation innovations	(+) Public opinions can guide policies on prioritized drone issues (−) Antigovernment movements can hinder/slow down drones' adoption	(+) Public acceptance can expedite rollout of infrastructural assets (−) Public disapproval can obstruct installing/operating supportive infrastructures	*38*	22	19	12
Safety	(+) Drones' potential to save lives lowers cost of health emergency services (−) Risks of drones' accidents entails new insurance costs	(+) Distributing loads between drones and trucks lowers traffic congestions and accidents (−) Drone-truck setups are prone to both road and flight accidents	(+) Charging drones lowers chance of accidents due to battery outage (−) Drone's battery outage/detachment can lead to crashes	(+) Drones' fast deliveries of critical items create health benefits to receivers (−) Haste may increase risks of drones crashing and pausing safety risks	(+) Drones can deliver life-saving items to hard-to-access patients/affected persons (−) Reaching receivers in urban areas accompanies high accident risks	(+) Drones' ability to preserve/monitor medical items can save lives (−) Drone crashes can damage delivered items	(+) Drones' ability to preserve/monitor medical items can save lives (−) Drone accidents can damage delivered items	(+) Pre-flight conflict detection and resolution systems enable collision-free flights (−) Most cities do not have adequate infrastructures to warrant safe flights	(+) Drone's potential to bring health benefits can expedite public acceptance (−) The public voiced serious concerns about drone's safety risks	*62*	22	13

(*continued*)

	Cost	Applicability	Capacity	Time	Reach	Item condition	Policies	Infrastructure	Public acceptance	Safety	Privacy	Environment
Privacy	(+) Drones can substitute costly invasive alternatives (e.g. helicopters, patrols) for rescue missions (−) Guarding against privacy violations incurs extra costs (e.g. licensing, insurance, lobbying)	(+) Drone-truck setups can replace invasive methods (e.g. dogs, break-ins) in last legs of rescue missions (−) Drone-truck setups demand adhering to privacy rules for both roads and airspace	(+) Extending drone's flight range enables capturing more data to support crime detection (−) Extending drone's flight range can increase risks of privacy violations	(+) Drones' fast deliveries lower the duration of data exposure through cameras/sensors (−) Evading flights over restrained zones (e.g. private spaces) can prolong deliveries	(+) Supplying drones with cameras expands reach and crime prevention potentials (−) Using cameras/sensors to reach receivers in crowded regions amplifies privacy concerns	(+) Drone can protect items from theft and loss to unauthorized parties (−) Monitoring preserved items can require GPS tracking, creating privacy concerns	(+) Policies can protect privacy violations by drone deliveries (−) Drone deliveries expose loopholes in privacy laws (e.g. filming interiors)	(+) Infrastructures can institute privacy protection mechanisms for all parties (−) Drone infrastructures require massive amount of data with privacy protection needs	(+) The potential to use flight data for a good cause (e.g. fighting crime) may expedite public acceptance (−) The public voiced serious privacy concerns with drone deliveries	(+) Privacy protection for drone use goes in line with safety protection (−) Privacy invasion of collected data can lead to safety risks	*29*	7
Environment	(+) Drones can substitute traditional vehicles with higher emissions and operational cost (−) Tradeoffs exist between drones' reduced CO_2 emissions and costs (e.g. equipment)	(+) Drone-truck setups can significantly lower LMD's energy consumption (−) Emission savings via drone-truck setups heavily relies on the power source for both modes	(+) Drones' flying capacity lowers traffic jams and their subsequent emissions (−) Charging drones along delivery routes requires numerous hubs alongside building/operating energy needs	(+) Drones can skip and reduce traffic jams, reducing both delivery time and emissions (−) Achieving faster deliveries requires operating new delivery centers with energy needs	(+) Drones' environmental performance excels when delivering to rural areas (−) Reaching receivers in urban areas accompanies higher environmental risks	(+) Drones' protection of items lowers wastage levels (−) Drone crashes can both damage carried items and emit harmful debris	(+) Policies can put pressure on lowering drones' emissions (especially in production) (−) Stricter flight policies in urban areas significantly increase drones' emissions	(+) Drones can become a better eco-solution in urban areas through greener infrastructures (e.g. hubs powered by clean energy) (−) Instructing/running full drone infrastructures consumes vast energy	(+) Drones' potential to lower traffic congestions and emissions expedites public acceptance (−) The public voiced concerns about drones' noise pollution	(+) Drone deliveries can lower harmful pollution from traffic congestions (−) Drone accidents can emit harmful debris and pose safety risks to people and wildlife	(+) Drones can benefit both environmental and privacy causes (−) Operating drones in urban areas suffers from amplified privacy and environmental concerns	*51*

Note(s): Diagonal values: number of articles emphasizing the factor; above diagonal values: interconnections; below diagonal values: relationships (+) positive (−) negative

Source(s): Created by authors

Table 9.

RD3. Resolving conflicting cost, technical, social, and environmental trade-offs arising from drone deliveries.

Our review revealed study-worthy trade-offs among the 12 LMD criteria, emerged after matching the potentials and challenges of drone deliveries for each set of criteria (Table 9). Examples include when drones enhance the quality of life for receivers through rapid and far-reaching deliveries yet raise safety and privacy concerns for societies due to surveillance applications and airborne maneuvers. This trade-off is especially relevant in humanitarian and healthcare contexts, where drone deliveries are not a mere luxury but a life-saving necessity. Another trade-off was found when drones minimize the socio-environmental externalities of urban transport (e.g. emissions, congestion, accidents) by substituting ground vehicles, yet the need to operate a large number of drones to serve such areas due to drones' limited payload/range capacity. Here, drones may overcrowd the lower airspace and lead to a new stream of externalities related to safety, privacy and noise. We also found a trade-off when drones reduce transport costs with their low investment and operating cost yet incur high total investment costs to secure full drone delivery systems with fleets, depots and refueling stations. As such, future research can investigate the circumstances under which the benefits of drone deliveries outweigh their drawbacks across different LMD criteria.

RD4. Unraveling the roles and responsibilities for infrastructural updates to accomodate drone deliveries.

As this review showed, most transport infrastructures are not yet prepared to handle drone deliveries. We also discussed the requirements for enabling these infrastructures and divided them into tangible and intangible assets (Table 7). What can be noted is that these assets differ in their application and associated roles and responsibilities. For example, providing new warehouses to offset drones' limited capacities may fall under the responsibility of logistics managers, yet building such warehouses is often handled by contractors, pending the permission of local authorities, especially in areas near the city center. Warehouse operators, drone pilots, technicians and possibly truck/van drivers (for drone-truck setups) may also be recruited to fulfill delivery orders. If the LMD system is intended for medical deliveries, the intervention of doctors and nurses may be needed – let alone approvals of legal bodies such as the Food and Drug Authority. This is a glimpse of the numerous requirements for a functional infrastructure for drone deliveries. Charging hubs, take-off/landing stations, revised road structures, 5G/6G networks, legal frameworks, insurance policies and air-traffic management systems (e.g. UTM) are all essential toward that end. Considering the latter alone, feeding the UTM system with live data on all airborne traffic, geometry of buildings/objects, pedestrian movement and weather conditions is vital to warrant smooth and safe drone operations. Such complex infrastructures with diverse (and possibly, overlapping) responsibilities necessitate detailed planning efforts akin to those made a century ago for road infrastructures. Scholars can aid here by defining the roles for facilitating these infrastructures and exploring the dynamics of responsibility allocation among various actors.

RD5. Examining the needs of end consumers for drone deliveries in e-commerce.

While the desire for swift and far-reaching drone deliveries is evident in humanitarian relief and healthcare contexts, the situation in e-commerce may differ. Perhaps consumers do not "need" one-hour (or five-minute) deliveries for their regular, day-to-day merchandise like toothpastes or garments. In contrast, a hungry person would obviously prefer their meal delivered as quickly – and as warm – as possible. Moreover, while some may argue that receivers don't care about how their deliveries are carried out, a counterargument suggests that some may find it "cooler" to see a drone delivering their orders instead of a traditional ("boring") van. As such, how will consumer preferences shape the marketing strategies of e-retailers with respect to promoting the technology? Will the situation normalize once drone deliveries become an established routine? Although the reviewed literature touched upon this topic, further research is still required to understand consumers' actual needs for drone deliveries and their impact on e-retailers' strategies, operations and revenues.

RD6. Elucidating human-drone interactions in LMD.

Human-drone interactions can be defined as "the study field focused on understanding, designing, and evaluating drone systems for use by or with human users" (Tezza and Andujar, 2019, p. 167439). Applying this concept on LMD allows specifying each of drone pilots, receivers and surrounding people as humans interacting with drones. Through informative screens at the pilot's end and cameras/sensors at the drone's end, a drone can virtually take its pilot to any point in the 3D airspace. This makes drones a medium for both input and output, where a pilot does not only interact with the drone but also with its physical surroundings. However, the reviewed literature revealed limited insights on how human-drone interactions take shape in LMD settings. This uncovers an opportunity for scholars to explore how pilot-drone interactions can utilize innovative control interfaces (e.g. speech, gesture, mental models) to enhance LMD performance, while discussing the required training/licensing to that end. Light can also be shed on how receivers and surrounding people interact with drones (or pilots) during drone flights and drop-off/landing events, considering factors such as interaction distance, drone feedback, remote communication and emotion encoding.

RD7. Understanding the actual societal repercussions of drone deliveries.

Since drone deliveries are not operational at large yet, their actual impact on societies remains barely known. Although our review uncovered societal opinions of drone deliveries from safety, privacy, ethical and environmental prospects, most of these opinions are speculative or experimentally controlled at best (i.e. they are not based on natural, day-to-day experiences with drone deliveries). Although controlled experiments enable studying a phenomenon before its widespread adoption, their external validity is limited due to researcher-imposed controls. Such experiments are also subject to bias, as participants often know they are being studied and may want to act positively. This is especially relevant in drone contexts, where there might be a desire to appear "tech-savvy" or "up-to-date". Given the growing drone applications in real life, scholars can now explore the societal repercussions of this technology using less biased methods such as field experiments, econometrics, data analytics, or triangulation of multiple methods.

RD8. Guiding the formation of – and compliance with – airspace policies for drone deliveries.

This reviewed literature revealed the extreme complexities involved in crafting all-inclusive policies to govern drone deliveries – and to no surprise such deliveries are not yet active in most parts of the world. Different aviation policies between countries, alongside their varying degrees of strictness, pose a challenge to drone manufacturers and adopters vis-à-vis compliance. This also raises a question on whether drone manufacturing and operating procedures should be customized for certain regions or standardized on a global scale. We also saw how drone deliveries may create conflicting interests between senders, receivers, societies and other operators in the airspace and how current legal frameworks suffer from loopholes in lodging the technology. All these issues invite scholars to guide the formation of, and compliance with, airspace policies to leverage drone deliveries across various contexts and regions.

RD9. Understanding – and minimizing – the environmental impact of drone deliveries

Against our hopes, the reviewed literature showed that drone deliveries may *not* always be an environmentally preferable alternative – especially in urban areas. Factors such as travel distance, payload restrictions, receivers' density, energy source for charging and service hubs were found to be substantially determinantal of the overall greenness of drone deliveries. Using LCA, some studies went beyond the drone's operational phase to reveal a higher environmental harm during production, though drones outpace other transport modes when seen from a "cradle-to-grave" standpoint. As such, more research is needed to understand whether drone manufacturers may capitalize on scale economies to lower energy demands per single unit, or if innovative solutions may be utilized to enhance the environmental friendliness of drone deliveries in urban areas.

8. Conclusions

We presented a deductive, theory refinement SLR of 307 interdisciplinary, peer-reviewed journal articles on drone applications in LMD during 2015–2022, extrapolating pertinent insights from and into the logistics management field. Our thematic analysis revealed the potentials, challenges and solutions of drone deliveries in relation to twelve key LMD criteria dispersed across four stakeholder groups: senders, receivers, regulators and societies – along with identifying relationships between these criteria. This review contributes to logistics management by offering a timely, inclusive, inter-connected and well-balanced discussion of this emergent technology. Nine directions for further research were identified and thoroughly discussed, setting the stage for a new stream of research to expand our understanding of drone deliveries across various sectors and regions in parallel with growing real-world applications.

This review offers several practical implications. First, it provides logistics managers with an inclusive roadmap to guide their decisions on drone adoption in LMD. Specifically, it covers both operational LMD criteria (e.g. cost, capacity, time) and non-operational ones (e.g. privacy, policies, public acceptance) to holistically support the decision-making intricacies for adopting the technology. Second, it helps logistics managers understand how drone deliveries resonate with the priorities of other stakeholders who are directly involved in the LMD process (e.g. receivers) or indirectly involved but play key roles in shaping its outcomes (e.g. regulators, societies). This may support them adjust their strategies to accommodate each stakeholder group based on the criterion at hand. Third, it breaks down the complex, highly technical and conjectural topic of drones in LMD into easy-to-understand elements for business executives, practitioners, regulators and society at large. Last, it offers a realistic overview of drones' abilities in enhancing the LMD process and the challenges hindering them from reaching their full potential.

Notes

1. Refer to Table A1 in Appendix that confirms the suitability of these criteria for drones by matching them against recent drone studies.
2. Refer to Figures A1 and A2 in Appendix for descriptive analysis across the 12 LMD criteria.
3. Refer to Stöcker *et al.* (2017) for a thorough cross-country comparison of UAV regulations.

References

Alamouri, A., Lampert, A. and Gerke, M. (2021), "An exploratory investigation of UAS regulations in Europe and the impact on effective use and economic potential", *Drones*, Vol. 5 No. 3, p. 63, doi: 10.3390/drones5030063.

Ali, Z.H. and Ali, H.A. (2022), "EEOMA: end-to-end oriented management architecture for 6G-enabled drone communications", *Peer-to-Peer Networking and Applications*, Vol. 15 No. 2, pp. 1232-1254, doi: 10.1007/s12083-022-01296-6.

Allen, J., Piecyk, M., Piotrowska, M., McLeod, F., Cherrett, T., Ghali, K., Nguyen, T., Bektas, T., Bates, O., Friday, A., Wise, S. and Austwick, M. (2018), "Understanding the impact of e-commerce on last-mile light goods vehicle activity in urban areas: the case of London", *Transportation Research Part D: Transport and Environment*, Vol. 61, pp. 325-338, doi: 10.1016/j.trd.2017.07.020.

Altuğ, E. and Türkmen, A. (2022), "A novel mini jet engine powered unmanned aerial vehicle: modeling and control", *Unmanned Systems*, Vol. 10 No. 1, pp. 31-43, doi: 10.1142/s2301385022500017.

Amazon (2016), "Amazon prime air's first customer delivery", available at: https://www.youtube.com/watch?v=vNySOrI2Ny8&t=69s

Amicone, D., Cannas, A., Marci, A. and Tortora, G. (2021), "A smart capsule equipped with artificial intelligence for autonomous delivery of medical material through drones", *Applied Sciences*, Vol. 11 No. 17, pp. 1-13, doi: 10.3390/app11177976.

Amukele, T., Ness, M., Tobian, A.A., Boyd, J. and Street, J. (2017), "Drone transportation of blood products", *Transfusion*, Vol. 57 No. 3, pp. 582-588, doi: 10.1111/trf.13900.

Archambault, É., Campbell, D., Gingras, Y. and Larivière, V. (2009), "Comparing bibliometric statistics obtained from the Web of Science and Scopus", *Journal of the American Society for Information Science and Technology*, Vol. 60 No. 7, pp. 1320-1326, doi: 10.1002/asi.21062.

Asadi, A., Nurre Pinkley, S. and Mes, M. (2022), "A Markov decision process approach for managing medical drone deliveries", *Expert Systems with Applications*, Vol. 204, 117490, doi: 10.1016/j.eswa.2022.117490.

Aurambout, J.P., Gkoumas, K. and Ciuffo, B. (2019), "Last mile delivery by drones: an estimation of viable market potential and access to citizens across European cities", *European Transport Research Review*, Vol. 11 No. 1, pp. 1-21, doi: 10.1186/s12544-019-0368-2.

Aurambout, J.-P., Gkoumas, K. and Ciuffo, B. (2022), "A drone hop from the local shop? Where could drone delivery as a service happen in Europe and the USA, and how many people could benefit from it?", *Transportation Research Interdisciplinary Perspectives*, Vol. 16, 100708, doi: 10.1016/j.trip.2022.100708.

Baldisseri, A., Siragusa, C., Seghezzi, A., Mangiaracina, R. and Tumino, A. (2022), "Truck-based drone delivery system: an economic and environmental assessment", *Transportation Research Part D: Transport and Environment*, Vol. 107, 103296, doi: 10.1016/j.trd.2022.103296.

Baloch, G. and Gzara, F. (2020), "Strategic network design for parcel delivery with drones under competition", *Transportation Science*, Vol. 54 No. 1, pp. 204-228, doi: 10.1287/trsc.2019.0928.

Banik, D., Ibne Hossain, N.U., Govindan, K., Nur, F. and Babski-Reeves, K. (2022), "A decision support model for selecting unmanned aerial vehicle for medical supplies: context of COVID-19 pandemic", *The International Journal of Logistics Management*, Vol. 34 No. 2, pp. 473-496, doi: 10.1108/ijlm-06-2021-0334.

Bányai, T. (2022), "Impact of the integration of first-mile and last-mile drone-based operations from trucks on energy efficiency and the environment", *Drones*, Vol. 6, p. 9, doi: 10.3390/drones6090249.

Baumgarten, M.C., Roper, J., Hahnenkamp, K. and Thies, K.C. (2022), "Drones delivering automated external defibrillators-Integrating unmanned aerial systems into the chain of survival: a simulation study in rural Germany", *Resuscitation*, Vol. 172, pp. 139-145, doi: 10.1016/j.resuscitation.2021.12.025.

Ben Dor, L.M. and Hoffman, J.M. (2022), "The emerging airspace economy: a framework for airspace rights in the age of drones", *Wisconsin Law Review*, Vol. 4, pp. 953-995.

Boccia, M., Masone, A., Sforza, A. and Sterle, C. (2021), "A column-and-row generation approach for the flying sidekick travelling salesman problem", *Transportation Research Part C: Emerging Technologies*, Vol. 124, 102913, doi: 10.1016/j.trc.2020.102913.

Borghetti, F., Caballini, C., Carboni, A., Grossato, G., Maja, R. and Barabino, B. (2022), "The use of drones for last-mile delivery: a numerical case study in Milan, Italy", *Sustainability*, Vol. 14, p. 3, doi: 10.3390/su14031766.

Boutilier, J.J. and Chan, T.C.Y. (2022), "Drone network design for cardiac arrest response", *Manufacturing and Service Operations Management*, Vol. 24 No. 5, pp. 2407-2424, doi: 10.1287/msom.2022.1092.

Boysen, N., Briskorn, D., Fedtke, S. and Schwerdfeger, S. (2018), "Drone delivery from trucks: drone scheduling for given truck routes", *Networks*, Vol. 72 No. 4, pp. 506-527, doi: 10.1002/net.21847.

Boysen, N., Fedtke, S. and Schwerdfeger, S. (2021), "Last-mile delivery concepts: a survey from an operational research perspective", *OR Spectrum*, Vol. 43 No. 1, pp. 1-58, doi: 10.1007/s00291-020-00607-8.

Braun, V. and Clarke, V. (2006), "Using thematic analysis in psychology", *Qualitative Research in Psychology*, Vol. 3 No. 2, pp. 77-101, doi: 10.1191/1478088706qp063oa.

Bruni, M.E. and Khodaparasti, S. (2022), "A variable neighborhood descent matheuristic for the drone routing problem with beehives sharing", *Sustainability*, Vol. 14 No. 16, p. 9978, doi: 10.3390/su14169978.

Bruni, M.E., Khodaparasti, S. and Moshref-Javadi, M. (2022), "A logic-based Benders decomposition method for the multi-trip traveling repairman problem with drones", *Computers and Operations Research*, Vol. 145, 105845, doi: 10.1016/j.cor.2022.105845.

Buko, J., Bulsa, M. and Makowski, A. (2022), "Spatial Premises and key conditions for the use of UAVs for delivery of items on the example of the polish courier and postal services market", *Energies*, Vol. 15, p. 4, doi: 10.3390/en15041403.

Buldeo Rai, H., Touami, S. and Dablanc, L. (2022), "Autonomous e-commerce delivery in ordinary and exceptional circumstances. The French case", *Research in Transportation Business and Management*, Vol. 45, 100774, doi: 10.1016/j.rtbm.2021.100774.

Canca, D., Navarro-Carmona, B. and Andrade-Pineda, J.L. (2022), "Design and assessment of an urban circular combined truck–drone delivery system using Continuum approximation models and integer programming", *Sustainability*, Vol. 14, p. 20, doi: 10.3390/su142013459.

Carlsson, J.G. and Song, S. (2018), "Coordinated logistics with a truck and a drone", *Management Science*, Vol. 64 No. 9, pp. 4052-4069, doi: 10.1287/mnsc.2017.2824.

Castillo, V.E., Bell, J.E., Rose, W.J. and Rodrigues, A.M. (2018), "Crowdsourcing last mile delivery: strategic implications and future research directions", *Journal of Business Logistics*, Vol. 39 No. 1, pp. 7-25, doi: 10.1111/jbl.12173.

Cha, H., Kim, D., Eun, J. and Cheong, T. (2022), "Collaborative traveling salesman problem with ground vehicle as a charger for unmanned aerial vehicle", *Transportation Letters*, Vol. 15 No. 7, pp. 1-15, doi: 10.1080/19427867.2022.2082006.

Chen, X., Ulmer, M.W. and Thomas, B.W. (2022), "Deep Q-learning for same-day delivery with vehicles and drones", *European Journal of Operational Research*, Vol. 298 No. 3, pp. 939-952, doi: 10.1016/j.ejor.2021.06.021.

Cheng, C., Adulyasak, Y. and Rousseau, L.M. (2020), "Drone routing with energy function: formulation and exact algorithm", *Transportation Research Part B: Methodological*, Vol. 139, pp. 364-387, doi: 10.1016/j.trb.2020.06.011.

Cherif, N., Jaafar, W., Yanikomeroglu, H. and Yongacoglu, A. (2021), "3D aerial highway: the key enabler of the retail industry transformation", *IEEE Communications Magazine*, Vol. 59 No. 9, pp. 65-71, doi: 10.1109/mcom.010.2100072.

Choi, Y. and Schonfeld, M. (2021), "A comparison of optimized deliveries by drone and truck", *Transportation Planning and Technology*, Vol. 44 No. 3, pp. 319-336, doi: 10.1080/03081060.2021.1883230.

Choi, B., Yeon, J., Min, J.U. and Lee, K. (2022), "Particulate matter (PM10 and PM2.5) and greenhouse gas emissions of UAV delivery systems on metropolitan subway tracks", *Sustainability*, Vol. 14, p. 14, doi: 10.3390/su14148630.

Chowdhury, S., Emelogu, A., Marufuzzaman, M., Nurre, S.G. and Bian, L. (2017), "Drones for disaster response and relief operations: a continuous approximation model", *International Journal of Production Economics*, Vol. 188, pp. 167-184, doi: 10.1016/j.ijpe.2017.03.024.

Cokyasar, T. (2021), "Optimization of battery swapping infrastructure for e-commerce drone delivery", *Computer Communications*, Vol. 168, pp. 146-154, doi: 10.1016/j.comcom.2020.12.015.

Comtet, H.E. and Johannessen, K.-A. (2022), "A socio-analytical approach to the integration of drones into health care systems", *Information*, Vol. 13, p. 2, doi: 10.3390/info13020062.

Conte, C., Rufino, G., de Alteriis, G., Bottino, V. and Accardo, D. (2022), "A data-driven learning method for online prediction of drone battery discharge", *Aerospace Science and Technology*, Vol. 130, 107921.

Cracknell, A.P. (2017), "UAVs: regulations and law enforcement", *International Journal of Remote Sensing*, Vol. 38 Nos 8-10, pp. 3054-3067, doi: 10.1080/01431161.2017.1302115.

da Silva, L.M., Menezes, H.B.B., Luccas, M.D.S., Mailer, C., Pinto, A.S.R., Boava, A., Rodrigues, M., Ferrao, I.G., Estrella, J.C. and Branco, K. (2022), "Development of an efficiency platform based on MQTT for UAV controlling and DoS attack detection", *Sensors (Basel)*, Vol. 22 No. 17, p. 6567, doi: 10.3390/s22176567.

Dallas News (2021), "Walgreens and Google's Wing are bringing store-to-door drone deliveries to Dallas-Fort Worth", available at: https://www.dallasnews.com/business/retail/2021/10/20/walgreen-and-googles-wing-are-bringing-store-to-door-drone-deliveries-to-dallas-fort-worth/

De Silvestri, S., Pagliarani, M., Tomasello, F., Trojaniello, D. and Sanna, A. (2022), "Design of a service for hospital internal transport of urgent Pharmaceuticals via drones", *Drones*, Vol. 6, p. 3, doi: 10.3390/drones6030070.

Dhote, J. and Limbourg, S. (2020), "Designing unmanned aerial vehicle networks for biological material transportation–The case of Brussels", *Computers and Industrial Engineering*, Vol. 148, 106652, doi: 10.1016/j.cie.2020.106652.

Dienstknecht, M., Boysen, N. and Briskorn, D. (2022), "The traveling salesman problem with drone resupply", *OR Spectrum*, Vol. 44 No. 4, pp. 1045-1086, doi: 10.1007/s00291-022-00680-1.

Dong, C., Akram, A., Andersson, D., Arnäs, O. and Stefansson, G. (2021), "The impact of emerging and disruptive technologies on freight transportation in the digital era: current state and future trends", *The International Journal of Logistics Management*, Vol. 32 No. 2, pp. 386-402, doi: 10.1108/ijlm-01-2020-0043.

Dorling, K., Heinrichs, J., Messier, G.G. and Magierowski, S. (2017), "Vehicle routing problems for drone delivery", *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, Vol. 47 No. 1, pp. 70-85, doi: 10.1109/tsmc.2016.2582745.

Du, L., Li, X., Gan, Y. and Leng, K. (2022), "Optimal model and algorithm of medical materials delivery drone routing problem under major public health emergencies", *Sustainability*, Vol. 14, p. 8, doi: 10.3390/su14084651.

Dukkanci, O., Kara, B.Y. and Bektaş, T. (2021), "Minimizing energy and cost in range-limited drone deliveries with speed optimization", *Transportation Research Part C: Emerging Technologies*, Vol. 125, 102985, doi: 10.1016/j.trc.2021.102985.

Durach, C.F., Kembro, J. and Wieland, A. (2017), "A new paradigm for systematic literature reviews in supply chain management", *Journal of Supply Chain Management*, Vol. 53 No. 4, pp. 67-85, doi: 10.1111/jscm.12145.

ElSayed, M. and Mohamed, M. (2020), "The impact of airspace regulations on unmanned aerial vehicles in last-mile operation", *Transportation Research Part D: Transport and Environment*, Vol. 87, 102480, doi: 10.1016/j.trd.2020.102480.

Esper, T.L., Jensen, T.D., Turnipseed, F.L. and Burton, S. (2003), "The last mile: an examination of effects of online retail delivery strategies on consumers", *Journal of Business Logistics*, Vol. 24 No. 2, pp. 177-203, doi: 10.1002/j.2158-1592.2003.tb00051.x.

Eun, J., Song, B.D., Lee, S. and Lim, D.E. (2019), "Mathematical investigation on the sustainability of UAV logistics", *Sustainability*, Vol. 11 No. 21, p. 5932, doi: 10.3390/su11215932.

Ewedairo, K., Chhetri, P. and Jie, F. (2018), "Estimating transportation network impedance to last-mile delivery: a case study of Maribyrnong city in Melbourne", *The International Journal of Logistics Management*, Vol. 29 No. 1, pp. 110-130, doi: 10.1108/ijlm-10-2016-0247.

Figliozzi, M.A. (2020), “Carbon emissions reductions in last mile and grocery deliveries utilizing air and ground autonomous vehicles”, *Transportation Research Part D: Transport and Environment*, Vol. 85, 102443, doi: 10.1016/j.trd.2020.102443.

García, I.Q., Vélez, N.V., Martínez, A., Ull, J.V. and Gallo, B.F. (2021), “A quickly deployed and UAS-based logistics network for delivery of critical medical goods during healthcare system stress periods: a real use case in Valencia (Spain)”, *Drones*, Vol. 5 No. 1, p. 13, doi: 10.3390/drones5010013.

Gentili, M., Mirchandani, B., Agnetis, A. and Ghelichi, Z. (2022), “Locating platforms and scheduling a fleet of drones for emergency delivery of perishable items”, *Computers and Industrial Engineering*, Vol. 168, 108057, doi: 10.1016/j.cie.2022.108057.

Ghelichi, Z., Gentili, M. and Mirchandani, P.B. (2021), “Logistics for a fleet of drones for medical item delivery: a case study for Louisville, KY”, *Computers and Operations Research*, Vol. 135, 105443, doi: 10.1016/j.cor.2021.105443.

Ghelichi, Z., Gentili, M. and Mirchandani, B. (2022), “Drone logistics for uncertain demand of disaster-impacted populations”, *Transportation Research Part C: Emerging Technologies*, Vol. 141, 103735, doi: 10.1016/j.trc.2022.103735.

Glick, T.B., Figliozzi, M.A. and Unnikrishnan, A. (2022), “Case study of drone delivery reliability for time-sensitive medical supplies with stochastic demand and meteorological conditions”, *Transportation Research Record*, Vol. 2676 No. 1, pp. 242-255, doi: 10.1177/03611981211036685.

Goodchild, A. and Toy, J. (2018), “Delivery by drone: an evaluation of unmanned aerial vehicle technology in reducing CO_2 emissions in the delivery service industry”, *Transportation Research Part D: Transport and Environment*, Vol. 61, pp. 58-67, doi: 10.1016/j.trd.2017.02.017.

Grote, M., Pilko, A., Scanlan, J., Cherrett, T., Dickinson, J., Smith, A., Oakey, A. and Marsden, G. (2021), “Pathways to unsegregated sharing of airspace: views of the uncrewed aerial vehicle (UAV) industry”, *Drones*, Vol. 5, p. 4, doi: 10.3390/drones5040150.

Gu, R., Poon, M., Luo, Z., Liu, Y. and Liu, Z. (2022), “A hierarchical solution evaluation method and a hybrid algorithm for the vehicle routing problem with drones and multiple visits”, *Transportation Research Part C: Emerging Technologies*, Vol. 141, 103733, doi: 10.1016/j.trc.2022.103733.

Gunaratne, K., Thibbotuwawa, A., Vasegaard, A.E., Nielsen, P. and Perera, H.N. (2022), “Unmanned aerial vehicle adaptation to facilitate healthcare supply chains in low-income countries”, *Drones*, Vol. 6, p. 11, doi: 10.3390/drones6110321.

Hachiya, D., Mas, E. and Koshimura, S. (2022), “A reinforcement learning model of multiple UAVs for transporting emergency relief supplies”, *Applied Sciences*, Vol. 12, p. 20, doi: 10.3390/app122010427.

Hagberg, J. and Hulthén, K. (2022), “Consolidation through resourcing in last-mile logistics”, *Research in Transportation Business and Management*, Vol. 45, 100834, doi: 10.1016/j.rtbm.2022.100834.

Han, P., Yang, X., Zhao, Y., Guan, X. and Wang, S. (2022), “Quantitative ground risk assessment for urban logistical unmanned aerial vehicle (UAV) based on Bayesian network”, *Sustainability*, Vol. 14, p. 9, doi: 10.3390/su14095733.

Harn, P.-W., Zhang, J., Shen, T., Wang, W., Jiang, X., Ku, W.S., Sun, M.T. and Chiang, Y.Y. (2021), “Multiple ground/aerial parcel delivery problem: a Weighted Road Network Voronoi Diagram based approach”, *Distributed and Parallel Databases*, Vol. 41 No. 4, pp. 1-21, doi: 10.1007/s10619-021-07347-w.

Hernández, E.J.U., Martínez, J.A.S. and Saucedo, J.A.M. (2020), “Optimization of the distribution network using an emerging technology”, *Applied Sciences*, Vol. 10 No. 3, p. 857, doi: 10.3390/app10030857.

Ho, F., Geraldes, R., Goncalves, A., Rigault, B., Sportich, B., Kubo, D., Cavazza, M. and Prendinger, H. (2022), “Decentralized multi-agent path finding for UAV traffic management”, *IEEE Transactions on Intelligent Transportation Systems*, Vol. 23 No. 2, pp. 997-1008, doi: 10.1109/tits.2020.3019397.

Holzmann, P., Wankmüller, C., Globocnik, D. and Schwarz, E.J. (2021), "Drones to the rescue? Exploring rescue workers' behavioral intention to adopt drones in mountain rescue missions", *International Journal of Physical Distribution and Logistics Management*, Vol. 51 No. 4, pp. 381-402, doi: 10.1108/ijpdlm-01-2020-0025.

Homier, V., Brouard, D., Nolan, M., Roy, M.A., Pelletier, P., McDonald, M., de Champlain, F., Khalil, E., Grou-Boileau, F. and Fleet, R. (2021), "Drone versus ground delivery of simulated blood products to an urban trauma center: the Montreal Medi-Drone pilot study", *The Journal of Trauma and Acute Care Surgery*, Vol. 90 No. 3, pp. 515-521, doi: 10.1097/ta.0000000000002961.

Hou, W., Fang, T., Pei, Z. and He, Q.C. (2021), "Integrated design of unmanned aerial mobility network: a data-driven risk-averse approach", *International Journal of Production Economics*, Vol. 236, 108131, doi: 10.1016/j.ijpe.2021.108131.

Huang, H. and Savkin, A.V. (2022), "Deployment of charging stations for drone delivery assisted by public transportation vehicles", *IEEE Transactions on Intelligent Transportation Systems*, Vol. 23 No. 9, pp. 15043-15054, doi: 10.1109/tits.2021.3136218.

Huang, S.-H., Huang, Y.-H., Blazquez, C.A. and Chen, C.-Y. (2022a), "Solving the vehicle routing problem with drone for delivery services using an ant colony optimization algorithm", *Advanced Engineering Informatics*, Vol. 51, 101536, doi: 10.1016/j.aei.2022.101536.

Huang, C., Ming, Z. and Huang, H. (2022b), "Drone stations-aided beyond-battery-lifetime flight planning for parcel delivery", *IEEE Transactions on Automation Science and Engineering*, Vol. 20 No. 4, pp. 2294-2304.

Ignat, B. and Chankov, S. (2020), "Do e-commerce customers change their preferred last-mile delivery based on its sustainability impact?", *The International Journal of Logistics Management*, Vol. 31 No. 3, pp. 521-548, doi: 10.1108/ijlm-11-2019-0305.

Innocenti, E., Agostini, G. and Giuliano, R. (2022), "UAVs for medicine delivery in a smart city using fiducial markers", *Information*, Vol. 13 No. 10, p. 501, doi: 10.3390/info13100501.

Jasim, N.I., Kasim, H. and Mahmoud, M.A. (2022), "Towards the development of smart and sustainable transportation system for Foodservice industry: modelling factors influencing customer's intention to adopt drone food delivery (DFD) services", *Sustainability*, Vol. 14 No. 5, p. 2852, doi: 10.3390/su14052852.

Jeon, A., Kang, J., Choi, B., Kim, N., Eun, J. and Cheong, T. (2021), "Unmanned aerial vehicle last-mile delivery considering backhauls", *IEEE Access*, Vol. 9, pp. 85017-85033, doi: 10.1109/access.2021.3087751.

Jeong, H.Y., David, J.Y., Min, B.C. and Lee, S. (2020), "The humanitarian flying warehouse", *Transportation Research Part E: Logistics and Transportation Review*, Vol. 136, 101901, doi: 10.1016/j.tre.2020.101901.

Jeong, H.Y., Song, B.D. and Lee, S. (2022), "Optimal scheduling and quantitative analysis for multi-flying warehouse scheduling problem: amazon airborne fulfillment center", *Transportation Research Part C: Emerging Technologies*, Vol. 143, 103831, doi: 10.1016/j.trc.2022.103831.

Jia, Y., Zhang, Y., Luo, K. and Wen, W. (2022), "Drone-fleet-enabled logistics: a joint design of flight trajectory and package delivery", *Sensors (Basel)*, Vol. 22 No. 8, p. 3056, doi: 10.3390/s22083056.

Johannessen, K.A., Comtet, H. and Fosse, E. (2021), "A drone logistic model for transporting the complete analytic volume of a large-scale university laboratory", *International Journal of Environmental Research and Public Health*, Vol. 18 No. 9, p. 4580, doi: 10.3390/ijerph18094580.

Jouhet, G., González-Jiménez, L.E., Meza-Aguilar, M.A., Mayorga-Macías, W.A. and Luque-Vega, L.F. (2020), "Model-based fault detection of permanent magnet synchronous motors of drones using current sensors", in *New Trends in Robot Control*, Springer, pp. 301-318.

Kämäräinen, V., Saranen, J. and Holmström, J. (2001), "The reception box impact on home delivery efficiency in the e-grocery business", *International Journal of Physical Distribution and Logistics Management*, Vol. 31 No. 6, pp. 414-426, doi: 10.1108/09600030110399414.

Kamat, A., Shanker, S. and Barve, A. (2022), “Assessing the factors affecting implementation of unmanned aerial vehicles in Indian humanitarian logistics: a g-DANP approach”, *Journal of Modelling in Management*, Vol. 18 No. 2, pp. 416-456, doi: 10.1108/jm2-02-2021-0037.

Kang, M. and Lee, C. (2021), “An exact algorithm for heterogeneous drone-truck routing problem”, *Transportation Science*, Vol. 55 No. 5, pp. 1088-1112, doi: 10.1287/trsc.2021.1055.

Karak, A. and Abdelghany, K. (2019), “The hybrid vehicle-drone routing problem for pick-up and delivery services”, *Transportation Research Part C: Emerging Technologies*, Vol. 102, pp. 427-449, doi: 10.1016/j.trc.2019.03.021.

Kellermann, R. and Fischer, L. (2020), “Drones for parcel and passenger transport: a qualitative exploration of public acceptance”, *Sociology and Technoscience*, Vol. 10 No. 2, pp. 106-138.

Kellermann, R., Biehle, T. and Fischer, L. (2020), “Drones for parcel and passenger transportation: a literature review”, *Transportation Research Interdisciplinary Perspectives*, Vol. 4, 100088, doi: 10.1016/j.trip.2019.100088.

Kiba-Janiak, M., Marcinkowski, J., Jagoda, A. and Skowrońska, A. (2021), “Sustainable last mile delivery on e-commerce market in cities from the perspective of various stakeholders. Literature review”, *Sustainable Cities and Society*, Vol. 71, 102984, doi: 10.1016/j.scs.2021.102984.

Kim, S.H. (2020), “Choice model based analysis of consumer preference for drone delivery service”, *Journal of Air Transport Management*, Vol. 84, 101785, doi: 10.1016/j.jairtraman.2020.101785.

Kim, J.J. and Hwang, J. (2020), “Merging the norm activation model and the theory of planned behavior in the context of drone food delivery services: does the level of product knowledge really matter?”, *Journal of Hospitality and Tourism Management*, Vol. 42, pp. 1-11, doi: 10.1016/j.jhtm.2019.11.002.

Kim, I., Kim, H.-G., Kim, I.-Y., Ohn, S.-Y. and Chi, S.-D. (2022), “Event-based emergency detection for safe drone”, *Applied Sciences*, Vol. 12 No. 17, p. 8501, doi: 10.3390/app12178501.

Kirschstein, T. (2020), “Comparison of energy demands of drone-based and ground-based parcel delivery services”, *Transportation Research Part D: Transport and Environment*, Vol. 78, 102209, doi: 10.1016/j.trd.2019.102209.

Kitjacharoenchai, P., Ventresca, M., Moshref-Javadi, M., Lee, S., Tanchoco, J.M. and Brunese, A. (2019), “Multiple traveling salesman problem with drones: mathematical model and heuristic approach”, *Computers and Industrial Engineering*, Vol. 129, pp. 14-30, doi: 10.1016/j.cie.2019.01.020.

Koiwanit, J. (2018), “Analysis of environmental impacts of drone delivery on an online shopping system”, *Advances in Climate Change Research*, Vol. 9 No. 3, pp. 201-207, doi: 10.1016/j.accre.2018.09.001.

Kornatowski, P.M., Bhaskaran, A., Heitz, G.M., Mintchev, S. and Floreano, D. (2018), “Last-centimeter personal drone delivery: field deployment and user interaction”, *IEEE Robotics and Automation Letters*, Vol. 3 No. 4, pp. 3813-3820, doi: 10.1109/lra.2018.2856282.

Kostrzewski, M., Abdelatty, Y., Eliwa, A. and Nader, M. (2022), “Analysis of modern vs Conventional development technologies in transportation-the case study of a last-mile delivery process”, *Sensors (Basel)*, Vol. 22 No. 24, p. 9858, doi: 10.3390/s22249858.

Kovács, G. and Spens, K.M. (2007), “Humanitarian logistics in disaster relief operations”, *International Journal of Physical Distribution and Logistics Management*, Vol. 37 No. 2, pp. 99-114, doi: 10.1108/09600030710734820.

Kumar, R., Gour, S.S., Pandey, A., Kumar, S., Mohan, A., Shashwat, P. and Sahoo, A.K. (2022), “Design and analysis of a novel concept-based unmanned aerial vehicle with ground traversing capability”, *Acta Mechanica et Automatica*, Vol. 16 No. 3, pp. 169-179, doi: 10.2478/ama-2022-0021.

Kunovjanek, M. and Wankmüller, C. (2021), “Containing the COVID-19 pandemic with drones-feasibility of a drone enabled back-up transport system”, *Transport Policy*, Vol. 106, pp. 141-152, doi: 10.1016/j.tranpol.2021.03.015.

Kwon, H., Kim, J. and Park, Y. (2017), “Applying LSA text mining technique in envisioning social impacts of emerging technologies: the case of drone technology”, *Technovation*, Vols 60-61, pp. 15-28.

Kwon, D., Son, S., Park, Y., Kim, H., Park, Y., Lee, S. and Jeon, Y. (2022), "Design of secure handover authentication Scheme for urban air mobility environments", *IEEE Access*, Vol. 10, pp. 42529-42541, doi: 10.1109/access.2022.3168843.

Lamb, J.S., Wirasinghe, S.C. and Waters, N.M. (2022), "Planning delivery-by-drone micro-fulfilment centres", *Transportmetrica A: Transport Science*, pp. 1-32, doi: 10.1080/23249935.2022.2107729.

Lee, S., Hong, D., Kim, J., Baek, D. and Chang, N. (2022), "Congestion-aware multi-drone delivery routing framework", *IEEE Transactions on Vehicular Technology*, Vol. 71 No. 9, pp. 9384-9396, doi: 10.1109/tvt.2022.3179732.

Lemardelé, C., Estrada, M., Pagès, L. and Bachofner, M. (2021), "Potentialities of drones and ground autonomous delivery devices for last-mile logistics", *Transportation Research Part E: Logistics and Transportation Review*, Vol. 149, 102325, doi: 10.1016/j.tre.2021.102325.

Leon, S., Chen, C. and Ratcliffe, A. (2021), "Consumers' perceptions of last mile drone delivery", *International Journal of Logistics Research and Applications*, Vol. 26 No. 3, pp. 1-20, doi: 10.1080/13675567.2021.1957803.

Li, A., Hansen, M. and Zou, B. (2022a), "Traffic management and resource allocation for UAV-based parcel delivery in low-altitude urban space", *Transportation Research Part C: Emerging Technologies*, Vol. 143, 103808, doi: 10.1016/j.trc.2022.103808.

Li, J., Liu, H., Lai, K.K. and Ram, B. (2022b), "Vehicle and UAV collaborative delivery path optimization model", *Mathematics*, Vol. 10 No. 20, p. 3744, doi: 10.3390/math10203744.

Li, S., Xue, L., Feng, L., Yao, C. and Wang, D. (2022c), "Hybrid Convolutional-Transformer framework for drone-based few-shot weakly supervised object detection", *Computers and Electrical Engineering*, Vol. 102, 108154, doi: 10.1016/j.compeleceng.2022.108154.

Lim, S.F.W., Jin, X. and Srai, J.S. (2018), "Consumer-driven e-commerce: a literature review, design framework, and research agenda on last-mile logistics models", *International Journal of Physical Distribution and Logistics Management*, Vol. 48 No. 3, pp. 308-332, doi: 10.1108/ijpdlm-02-2017-0081.

Lin, I.C., Lin, T.-H. and Chang, S.-H. (2022), "A decision system for routing problems and rescheduling issues using unmanned aerial vehicles", *Applied Sciences*, Vol. 12 No. 12, p. 6140, doi: 10.3390/app12126140.

Liu, W. and Sun, X. (2022), "Energy-aware and delay-sensitive management of a drone delivery system", *Manufacturing and Service Operations Management*, Vol. 24 No. 3, pp. 1294-1310, doi: 10.1287/msom.2021.1056.

Liu, W., Li, W., Zhou, Q., Die, Q. and Yang, Y. (2022a), "The optimization of the 'UAV-vehicle' joint delivery route considering mountainous cities", *PLoS One*, Vol. 17 No. 3, e0265518, doi: 10.1371/journal.pone.0265518.

Liu, B., Ni, W., Liu, R.P., Zhu, Q., Guo, Y.J. and Zhu, H. (2021), "Novel integrated framework of unmanned aerial vehicle and road traffic for energy-efficient delay-sensitive delivery", *IEEE Transactions on Intelligent Transportation Systems*, pp. 1-16.

Liu, R., Pitruzzello, G., Rosa, M., Battisti, A., Cerri, C. and Tortora, G. (2022b), "Towards an innovative sensor in smart capsule for aerial drones for blood and blood component delivery", *Micromachines (Basel)*, Vol. 13 No. 10, p. 1664, doi: 10.3390/mi13101664.

Lockhart, A., While, A., Marvin, S., Kovacic, M., Odendaal, N. and Alexander, C. (2021), "Making space for drones: the contested reregulation of airspace in Tanzania and Rwanda", *Transactions of the Institute of British Geographers*, Vol. 46 No. 4, pp. 850-865, doi: 10.1111/tran.12448.

Lundberg, J., Palmerius, K.L. and Josefsson, B. (2018), "Urban air traffic management (UTM) implementation in cities-sampled side-effects", *IEEE Xplore*, pp. 1-7, doi: 10.1109/DASC.2018.8569869.

Luo, H., Chen, T., Li, X., Li, S., Zhang, C., Zhao, G. and Liu, X. (2022a), "KeepEdge: a knowledge distillation empowered edge intelligence framework for visual assisted positioning in UAV delivery", *IEEE Transactions on Mobile Computing*, p. 1, doi: 10.1109/tmc.2022.3199812.

Luo, Q., Wu, G., Ji, B., Wang, L. and Suganthan, N. (2022b), "Hybrid multi-objective optimization approach with Pareto local search for collaborative truck-drone routing problems considering flexible time windows", *IEEE Transactions on Intelligent Transportation Systems*, Vol. 23 No. 8, pp. 13011-13025, doi: 10.1109/tits.2021.3119080.

Luppicini, R. and So, A. (2016), "A technoethical review of commercial drone use in the context of governance, ethics, and privacy", *Technology in Society*, Vol. 46, pp. 109-119, doi: 10.1016/j.techsoc.2016.03.003.

Macrina, G., Pugliese, L.D.P., Guerriero, F. and Laporte, G. (2020), "Drone-aided routing: a literature review", *Transportation Research Part C: Emerging Technologies*, Vol. 120, 102762, doi: 10.1016/j.trc.2020.102762.

Mangiaracina, R., Perego, A., Seghezzi, A. and Tumino, A. (2019), "Innovative solutions to increase last-mile delivery efficiency in B2C e-commerce: a literature review", *International Journal of Physical Distribution and Logistics Management*, Vol. 49 No. 9, pp. 901-920, doi: 10.1108/ijpdlm-02-2019-0048.

Masone, A., Poikonen, S. and Golden, B.L. (2022), "The multivisit drone routing problem with edge launches: an iterative approach with discrete and continuous improvements", *Networks*, Vol. 80 No. 2, pp. 193-215, doi: 10.1002/net.22087.

Mateen, F.J., Leung, K.B., Vogel, A.C., Cissé, A.F. and Chan, T.C. (2020), "A drone delivery network for antiepileptic drugs: a framework and modelling case study in a low-income country", *Transactions of The Royal Society of Tropical Medicine and Hygiene*, Vol. 114 No. 4, pp. 308-314, doi: 10.1093/trstmh/trz131.

McKinnon, A.C. (2016), "The possible impact of 3D printing and drones on last-mile logistics: an exploratory study", *Built Environment*, Vol. 42 No. 4, pp. 617-629, doi: 10.2148/benv.42.4.617.

Merkert, R. and Bushell, J. (2020), "Managing the drone revolution: a systematic literature review into the current use of airborne drones and future strategic directions for their effective control", *Journal of Air Transport Management*, Vol. 89, 101929, doi: 10.1016/j.jairtraman.2020.101929.

Merkert, R., Bliemer, M.C.J. and Fayyaz, M. (2022), "Consumer preferences for innovative and traditional last-mile parcel delivery", *International Journal of Physical Distribution and Logistics Management*, Vol. 52 No. 3, pp. 261-284, doi: 10.1108/ijpdlm-01-2021-0013.

Michael, O.T., Olusegun, A., Paul, O.A., Felix, S.O., Kaniki, F.R., Ayosanmi, O.S., Wade, D., Faith, A.O., Terna, G.Z., Musa, A. and Lateef, O. (2019), "The use of UAV/Drones in the optimization of Nigeria vaccine supply chain", *International Journal of Scientific and Engineering Research*, Vol. 10 No. 10, pp. 1273-1279.

Miranda, V.R.F., Rezende, A.M.C., Rocha, T.L., Azpúrua, H., Pimenta, L.C.A. and Freitas, G.M. (2022), "Autonomous navigation system for a delivery drone", *Journal of Control, Automation and Electrical Systems*, Vol. 33 No. 1, pp. 141-155, doi: 10.1007/s40313-021-00828-4.

Moadab, A., Farajzadeh, F. and Fatahi Valilai, O. (2022), "Drone routing problem model for last-mile delivery using the public transportation capacity as moving charging stations", *Scientific Reports*, Vol. 12 No. 1, p. 6361, doi: 10.1038/s41598-022-10408-4.

Mohamed, N., Al-Jaroodi, J., Jawhar, I., Idries, A. and Mohammed, F. (2020), "Unmanned aerial vehicles applications in future smart cities", *Technological Forecasting and Social Change*, Vol. 153, 119293, doi: 10.1016/j.techfore.2018.05.004.

Mohammadi, K., Sirouspour, S. and Grivani, A. (2022), "Passivity-based control of multiple Quadrotors carrying a cable-suspended payload", *IEEE/ASME Transactions on Mechatronics*, Vol. 27 No. 4, pp. 2390-2400, doi: 10.1109/tmech.2021.3102522.

Moshref-Javadi, M. and Winkenbach, M. (2021), "Applications and Research avenues for drone-based models in logistics: a classification and review", *Expert Systems with Applications*, Vol. 177, 114854, doi: 10.1016/j.eswa.2021.114854.

Murray, C.C. and Chu, A.G. (2015), "The flying sidekick traveling salesman problem: optimization of drone-assisted parcel delivery", *Transportation Research Part C: Emerging Technologies*, Vol. 54, pp. 86-109, doi: 10.1016/j.trc.2015.03.005.

Naclerio, A.G. and De Giovanni, P. (2022), "Blockchain, logistics and omnichannel for last mile and performance", *The International Journal of Logistics Management*, Vol. 33 No. 2, pp. 1-24, doi: 10.1108/ijlm-08-2021-0415.

Nentwich, M. and Horváth, D.M. (2018), "The vision of delivery drones: call for a technology assessment perspective", *Journal for Technology Assessment in Theory and Practice*, Vol. 27 No. 2, pp. 46-52.

Nguyen, M.A., Dang, G.T.H., Hà, M.H. and Pham, M.T. (2022), "The min-cost parallel drone scheduling vehicle routing problem", *European Journal of Operational Research*, Vol. 299 No. 3, pp. 910-930, doi: 10.1016/j.ejor.2021.07.008.

Niglio, F., Comite, P., Cannas, A., Pirri, A. and Tortora, G. (2022), "Preliminary clinical validation of a drone-based delivery system in urban scenarios using a smart capsule for blood", *Drones*, Vol. 6 No. 8, p. 195, doi: 10.3390/drones6080195.

Nisingizwe, M.P., Ndishimye, P., Swaibu, K., Nshimiyimana, L., Karame, P., Dushimiyimana, V., Musabyimana, J.P., Musanabaganwa, C., Nsanzimana, S. and Law, M.R. (2022), "Effect of unmanned aerial vehicle (drone) delivery on blood product delivery time and wastage in Rwanda: a retrospective, cross-sectional study and time series analysis", *Lancet Glob Health*, Vol. 10 No. 4, pp. e564-e569, doi: 10.1016/s2214-109x(22)00048-1.

Nogueira, G.P.M., de Assis Rangel, J.J. and Shimoda, E. (2021), "Sustainable last-mile distribution in B2C e-commerce: Do consumers really care?", *Cleaner and Responsible Consumption*, Vol. 3, 100021, doi: 10.1016/j.clrc.2021.100021.

Oakey, A., Grote, M., Smith, A., Cherrett, T., Pilko, A., Dickinson, J. and AitBihiOuali, L. (2022), "Integrating drones into NHS patient diagnostic logistics systems: flight or fantasy?", *PLoS One*, Vol. 17 No. 12, e0264669, doi: 10.1371/journal.pone.0264669.

Olsson, J., Hellström, D. and Pålsson, H. (2019), "Framework of last mile logistics research: a systematic review of the literature", *Sustainability*, Vol. 11 No. 24, p. 7131, doi: 10.3390/su11247131.

Ong, J.W., Abid, H.A., Minifie, T., Lin, E.S., Song, Z., Katariya, M., Liew, O.W. and Ng, T.W. (2022), "Unmanned aerial vehicle transport of frozen blood samples using phase change materials", *Biosystems Engineering*, Vol. 221, pp. 30-42, doi: 10.1016/j.biosystemseng.2022.06.008.

Oosedo, A., Hattori, H., Yasui, I. and Harada, K. (2021), "Unmanned aircraft system traffic management (UTM) simulation of drone delivery models in 2030 Japan", *Journal of Robotics and Mechatronics*, Vol. 33 No. 2, pp. 348-362, doi: 10.20965/jrm.2021.p0348.

Pachayappan, M. and Sudhakar, V. (2021), "A solution to drone routing problems using docking stations for pickup and delivery services", *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2675 No. 12, pp. 1056-1074, doi: 10.1177/03611981211032219.

Pachayappan, M. and Sundarakani, B. (2022), "Drone delivery logistics model for on-demand hyperlocal market", *International Journal of Logistics Research and Applications*, Vol. 26 No. 12, pp. 1-33, doi: 10.1080/13675567.2022.2107189.

Park, J., Kim, S. and Suh, K. (2018), "A comparative analysis of the environmental benefits of drone-based delivery services in urban and rural areas", *Sustainability*, Vol. 10 No. 3, p. 888, doi: 10.3390/su10030888.

Pasha, J., Elmi, Z., Purkayastha, S., Fathollahi-Fard, A.M., Ge, Y.-E., Lau, Y.-Y. and Dulebenets, M.A. (2022), "The drone scheduling problem: a systematic state-of-the-art review", *IEEE Transactions on Intelligent Transportation Systems*, Vol. 23 No. 9, pp. 14224-14247, doi: 10.1109/tits.2022.3155072.

Pawson, R. (2006), *Evidence-Based Policy: A Realist Perspective*, Sage, London.

Pei, Z., Fang, T., Weng, K. and Yi, W. (2022), "Urban on-demand delivery via autonomous aerial mobility: formulation and exact algorithm", *IEEE Transactions on Automation Science and Engineering*, Vol. 20 No. 3, pp. 1675-1689, doi: 10.1109/TASE.2022.3184324.

Peppel, M., Ringbeck, J. and Spinler, S. (2022), "How will last-mile delivery be shaped in 2040? A Delphi-based scenario study", *Technological Forecasting and Social Change*, Vol. 177, 121493, doi: 10.1016/j.techfore.2022.121493.

Perera, S., Dawande, M., Janakiraman, G. and Mookerjee, V. (2020), "Retail deliveries by drones: how will logistics networks change?", *Production and Operations Management*, Vol. 29 No. 9, pp. 2019-2034, doi: 10.1111/poms.13217.

Pinto, R. and Lagorio, A. (2022), "Point-to-point drone-based delivery network design with intermediate charging stations", *Transportation Research Part C: Emerging Technologies*, Vol. 135, 103506, doi: 10.1016/j.trc.2021.103506.

Pohjosenperä, T., Kekkonen, P., Pekkarinen, S. and Juga, J. (2018), "Service modularity in managing healthcare logistics", *The International Journal of Logistics Management*, Vol. 30 No. 1, pp. 174-194, doi: 10.1108/ijlm-12-2017-0338.

Polydoropoulou, A., Tsirimpa, A., Karakikes, I., Tsouros, I. and Pagoni, I. (2022), "Mode choice modeling for sustainable last-mile delivery: the Greek perspective", *Sustainability*, Vol. 14 No. 15, p. 8976, doi: 10.3390/su14158976.

Qin, Y., Kishk, M.A. and Alouini, M.-S. (2022), "Stochastic geometry-based analysis of multi-purpose UAVs for package and data delivery", *IEEE Internet of Things Journal*, Vol. 10 No. 5, pp. 4664-4676, doi: 10.1109/jiot.2023.3320359.

Raj, A. and Sah, B. (2019), "Analyzing critical success factors for implementation of drones in the logistics sector using grey-DEMATEL based approach", *Computers and Industrial Engineering*, Vol. 138, 106118, doi: 10.1016/j.cie.2019.106118.

Ranieri, L., Digiesi, S., Silvestri, B. and Roccotelli, M. (2018), "A review of last mile logistics innovations in an externalities cost reduction vision", *Sustainability*, Vol. 10 No. 3, p. 782, doi: 10.3390/su10030782.

Rao, B., Gopi, A.G. and Maione, R. (2016), "The societal impact of commercial drones", *Technology in Society*, Vol. 45, pp. 83-90, doi: 10.1016/j.techsoc.2016.02.009.

Rathore, B., Gupta, R., Biswas, B., Srivastava, A. and Gupta, S. (2022), "Identification and analysis of adoption barriers of disruptive technologies in the logistics industry", *The International Journal of Logistics Management*, Vol. 33 No. 5, pp. 136-169, doi: 10.1108/ijlm-07-2021-0352.

Rave, A., Fontaine, P. and Kuhn, H. (2022), "Drone location and vehicle fleet planning with trucks and aerial drones", *European Journal of Operational Research*, Vol. 308 No. 1, pp. 113-130, doi: 10.1016/j.ejor.2022.10.015.

Rejeb, A., Rejeb, K., Simske, S.J. and Treiblmaier, H. (2023), "Drones for supply chain management and logistics: a review and research agenda", *International Journal of Logistics Research and Applications*, Vol. 26 No. 6, pp. 708-731, doi: 10.1080/13675567.2021.1981273.

Ren, X. and Cheng, C. (2020), "Model of third-party risk index for unmanned aerial vehicle delivery in urban environment", *Sustainability*, Vol. 12 No. 20, p. 8318, doi: 10.3390/su12208318.

Research and Markets (2022), *Commercial Drone Market Research Report*, available at: https://www.researchandmarkets.com/reports/5336407/commercial-drone-market-research-report-by-wing?utm_source=BW&utm_medium=PressRelease&utm_code=49mlxl&utm_campaign=1704833+-+Global+Commercial+Drone+Market+Report+2022+-+Global+Forecast+to+2027+-+Venture+Capital+Investments+in+Drone+Technology&utm_exec=chdo54prd

Ribeiro, M., Ellerbroek, J. and Hoekstra, J. (2021), "Velocity obstacle based conflict avoidance in urban environment with variable speed limit", *Aerospace*, Vol. 8 No. 4, p. 93, doi: 10.3390/aerospace8040093.

Rutner, S.M. and Langley, C.J. (2000), "Logistics value: definition, process and measurement", *The International Journal of Logistics Management*, Vol. 11 No. 2, pp. 73-82, doi: 10.1108/09574090010806173.

Sah, B., Gupta, R. and Bani-Hani, D. (2021), "Analysis of barriers to implement drone logistics", *International Journal of Logistics Research and Applications*, Vol. 24 No. 6, pp. 531-550, doi: 10.1080/13675567.2020.1782862.

Salama, M.R. and Srinivas, S. (2022), "Collaborative truck multi-drone routing and scheduling problem: package delivery with flexible launch and recovery sites", *Transportation Research Part E: Logistics and Transportation Review*, Vol. 10 No. 5, pp. 4664-4676, doi: 10.1109/JIOT.2022.3218674.

Saponi, M., Borboni, A., Adamini, R., Faglia, R. and Amici, C. (2022), "Embedded payload solutions in UAVs for medium and small package delivery", *Machines*, Vol. 10 No. 9, p. 737, doi: 10.3390/machines10090737.

Sawadsitang, S., Niyato, D., Tan, S. and Wang, P. (2018), "Joint ground and aerial package delivery services: a stochastic optimization approach", *IEEE Transactions on Intelligent Transportation Systems*, Vol. 20 No. 6, pp. 2241-2254, doi: 10.1109/tits.2018.2865893.

Scalea, J.R., Restaino, S., Scassero, M., Blankenship, G., Bartlett, S.T. and Wereley, N. (2018), "An initial investigation of unmanned aircraft systems (UAS) and real-time organ status measurement for transporting human organs", *IEEE Journal of Translational Engineering in Health and Medicine*, Vol. 6, pp. 1-7, doi: 10.1109/jtehm.2018.2875704.

Scalea, J.R., Pucciarella, T., Talaie, T., Restaino, S., Drachenberg, C.B., Alexander, C., Al Qaoud, T., Barth, R.N., Wereley, N.M. and Scassero, M. (2021), "Successful implementation of Unmanned aircraft use for delivery of a human organ for transplantation", *Annals of Surgery*, Vol. 274 No. 3, pp. e282-e288, doi: 10.1097/sla.0000000000003630.

Schiano, F., Kornatowski, P.M., Cencetti, L. and Floreano, D. (2022), "Reconfigurable drone system for transportation of parcels with variable Mass and size", *IEEE Robotics and Automation Letters*, Vol. 7 No. 4, pp. 12150-12157, doi: 10.1109/lra.2022.3208716.

Serrano-Hernandez, A., Ballano, A. and Faulin, J. (2021), "Selecting freight transportation modes in last-mile urban distribution in Pamplona (Spain): an option for drone delivery in smart cities", *Energies*, Vol. 14 No. 16, p. 4748, doi: 10.3390/en14164748.

Seuring, S., Yawar, S.A., Land, A., Khalid, R.U. and Sauer, P. (2021), "The application of theory in literature reviews–illustrated with examples from supply chain management", *International Journal of Operations and Production Management*, Vol. 41 No. 1, pp. 1-20, doi: 10.1108/ijopm-04-2020-0247.

Sham, R., Siau, C.S., Tan, S., Kiu, D.C., Sabhi, H., Thew, H.Z., Selvachandran, G., Quek, S.G., Ahmad, N. and Ramli, M.H.M. (2022), "Drone usage for medicine and vaccine delivery during the COVID-19 pandemic: attitude of health care workers in rural medical centres", *Drones*, Vol. 6 No. 5, p. 109, doi: 10.3390/drones6050109.

Shao, P.-C. (2020), "Risk assessment for UAS logistic delivery under UAS traffic management environment", *Aerospace*, Vol. 7 No. 10, p. 140, doi: 10.3390/aerospace7100140.

Shao, J., Cheng, J., Xia, B., Yang, K. and Wei, H. (2020), "A novel service system for long-distance drone delivery using the 'ant Colony+A*' algorithm", *IEEE Systems Journal*, Vol. 15 No. 3, pp. 3348-3359, doi: 10.1109/jsyst.2020.2994553.

Shapiro, R.D. and Heskett, J.L. (1985), *Logistics Strategy: Cases and Concepts*, West Group, Saint Paul, Minnesota.

Sharman, G. (1984), "The rediscovery of logistics", *Harvard Business Review*, Vol. 62 No. 5, pp. 71-80.

Shavarani, S.M., Golabi, M. and İzbirak, G. (2019a), "A capacitated biobjective location problem with uniformly distributed demands in the UAV-supported delivery operation", *International Transactions in Operational Research*, Vol. 28 No. 6, pp. 1-24, doi: 10.1111/itor.12735.

Shavarani, S.M., Mosallaeipour, S., Golabi, M. and İzbirak, G. (2019b), "A congested capacitated multi-level fuzzy facility location problem: an efficient drone delivery system", *Computers and Operations Research*, Vol. 108, pp. 57-68, doi: 10.1016/j.cor.2019.04.001.

She, R. and Ouyang, Y. (2021), "Efficiency of UAV-based last-mile delivery under congestion in low-altitude air", *Transportation Research Part C: Emerging Technologies*, Vol. 122, 102878, doi: 10.1016/j.trc.2020.102878.

Shi, Y., Lin, Y., Li, B. and Li, R.Y.M. (2022), "A bi-objective optimization model for the medical supplies' simultaneous pickup and delivery with drones", *Computers and Industrial Engineering*, Vol. 171, 108389, doi: 10.1016/j.cie.2022.108389.

Siragusa, C., Tumino, A., Mangiaracina, R. and Perego, A. (2022), “Electric vehicles performing last-mile delivery in B2C e-commerce: an economic and environmental assessment”, *International Journal of Sustainable Transportation*, Vol. 16 No. 1, pp. 22-33, doi: 10.1080/15568318.2020.1847367.

Stöcker, C., Bennett, R., Nex, F., Gerke, M. and Zevenbergen, J. (2017), “Review of the current state of UAV regulations”, *Remote Sensing*, Vol. 9 No. 5, p. 459, doi: 10.3390/rs9050459.

Stolaroff, J.K., Samaras, C., O’Neill, E.R., Lubers, A., Mitchell, A.S. and Ceperley, D. (2018), “Energy use and life cycle greenhouse gas emissions of drones for commercial package delivery”, *Nature Communications*, Vol. 9 No. 1, pp. 1-13, doi: 10.1038/s41467-017-02411-5.

Sylverken, A.A., Owusu, M., Agbavor, B., Kwarteng, A., Ayisi-Boateng, N.K., Ofori, P., El-Duah, P., Yeboah, R., Aryeetey, S., Addo Asamoah, J., Ekekpi, R.Z., Oppong, M., Gorman, R., Brempong, K.A., Nyarko-Afriyie, E., Owusu Bonsu, F., Larsen-Reindorf, R., Rockson Adjei, M., Boateng, G., Asiedu-Bekoe, F., Sarkodie, B., Laryea, D.O., Tinkorang, E., Kumah Aboagye, P., Nsiah Asare, A., Obiri-Danso, K., Owusu-Dabo, E., Adu-Sarkodie, Y. and Phillips, R.O. (2022), “Using drones to transport suspected COVID-19 samples; experiences from the second largest testing centre in Ghana, West Africa”, *PLoS One*, Vol. 17 No. 11, e0277057, doi: 10.1371/journal.pone.0277057.

Tamke, F. and Buscher, U. (2021), “A branch-and-cut algorithm for the vehicle routing problem with drones”, *Transportation Research Part B: Methodological*, Vol. 144, pp. 174-203, doi: 10.1016/j.trb.2020.11.011.

Tech.co (2021), *Tech’s Biggest Winners and Losers of 2021*, available at: https://tech.co/news/tech-biggest-winners-losers-2021

Tezza, D. and Andujar, M. (2019), “The state-of-the-art of human–drone interaction: a survey”, *IEEE Access*, Vol. 7, pp. 167438-167454, doi: 10.1109/access.2019.2953900.

Thida San, K. and Chang, Y.S. (2022), “Drone-based delivery: a concurrent heuristic approach using a genetic algorithm”, *Aircraft Engineering and Aerospace Technology*, Vol. 94 No. 8, pp. 1312-1326, doi: 10.1108/aeat-07-2020-0138.

Tong, B., Wang, J., Wang, X., Zhou, F., Mao, X. and Zheng, W. (2022), “Optimal route planning for truck–drone delivery using variable neighborhood Tabu search algorithm”, *Applied Sciences*, Vol. 12 No. 1, p. 529, doi: 10.3390/app12010529.

Tranfield, D., Denyer, D. and Smart, P. (2003), “Towards a methodology for developing evidence-informed management knowledge by means of systematic review”, *British Journal of Management*, Vol. 14 No. 3, pp. 207-222, doi: 10.1111/1467-8551.00375.

Truog, S., Maxim, L., Matemba, C., Blauvelt, C., Ngwira, H., Makaya, A., Moreira, S., Lawrence, E., Ailstock, G., Weitz, A., West, M. and Defawe, O. (2020), “Insights before flights: how community perceptions can make or break medical drone deliveries”, *Drones*, Vol. 4 No. 3, p. 51, doi: 10.3390/drones4030051.

Valencia-Arias, A., Rodríguez-Correa, A., Patiño-Vanegas, J.C., Benjumea-Arias, M., De La Cruz-Vargas, J. and Moreno-López, G. (2022), “Factors associated with the adoption of drones for product delivery in the context of the COVID-19 pandemic in Medellín, Colombia”, *Drones*, Vol. 6 No. 9, p. 225, doi: 10.3390/drones6090225.

Vanelslander, T., Deketele, L. and Van Hove, D. (2013), “Commonly used e-commerce supply chains for fast moving consumer goods: comparison and suggestions for improvement”, *International Journal of Logistics Research and Applications*, Vol. 16 No. 3, pp. 243-256, doi: 10.1080/13675567.2013.813444.

Verma, A., Bhattacharya, P., Zuhair, M., Tanwar, S. and Kumar, N. (2022), “VaCoChain: blockchain-based 5G-assisted UAV vaccine distribution Scheme for future pandemics”, *IEEE Journal of Biomedical and Health Informatics*, Vol. 26 No. 5, pp. 1997-2007, doi: 10.1109/jbhi.2021.3103404.

Wang, H. and Odoni, A. (2016), “Approximating the performance of a ‘last mile’ transportation system”, *Transportation Science*, Vol. 50 No. 2, pp. 659-675, doi: 10.1287/trsc.2014.0553.

Wang, X., Wong, Y.D., Li, K.X. and Yuen, K.F. (2021), “A critical assessment of co-creating self-collection services in last-mile logistics”, *The International Journal of Logistics Management*, Vol. 32 No. 3, pp. 846-871, doi: 10.1108/ijlm-09-2020-0359.

Wang, K., Pesch, E., Kress, D., Fridman, I. and Boysen, N. (2022a), "The Piggyback Transportation Problem: transporting drones launched from a flying warehouse", *European Journal of Operational Research*, Vol. 296 No. 2, pp. 504-519, doi: 10.1016/j.ejor.2021.03.064.

Wang, Y., Wang, Z., Hu, X., Xue, G. and Guan, X. (2022b), "Truck–drone hybrid routing problem with time-dependent road travel time", *Transportation Research Part C: Emerging Technologies*, Vol. 144, 103901.

Wen, X. and Wu, G. (2022), "Heterogeneous multi-drone routing problem for parcel delivery", *Transportation Research Part C: Emerging Technologies*, Vol. 141, 103763, doi: 10.1016/j.trc.2022.103763.

Xing, J., Su, L., Hong, W., Tong, L., Lyu, R. and Du, W. (2023), "Aerial-ground collaborative routing with time constraints", *Chinese Journal of Aeronautics*, Vol. 36 No. 2, pp. 270-283, doi: 10.1016/j.cja.2022.09.009.

Zailani, M.A.H., Raja Sabudin, R.Z.A., Ismail, A., Abd Rahman, R., Mohd Saiboon, I., Sabri, S.I., Seong, C.K., Mail, J., Md Jamal, S., Beng, G.K. and Mahdy, Z.A. (2022), "Influence of drone carriage material on maintenance of storage temperature and quality of blood samples during transportation in an equatorial climate", *PLoS One*, Vol. 17 No. 9, e0269866, doi: 10.1371/journal.pone.0269866.

Zang, X., Jiang, L., Liang, C., Dong, J., Lu, W. and Mladenovic, N. (2022), "Optimization approaches for the urban delivery problem with trucks and drones", *Swarm and Evolutionary Computation*, Vol. 75, 101147, doi: 10.1016/j.swevo.2022.101147.

Zhang, Y. and Kamargianni, M. (2022), "A review on the factors influencing the adoption of new mobility technologies and services: autonomous vehicle, drone, micromobility and mobility as a service", *Transport Reviews*, Vol. 43 No. 3, pp. 407-429.

Zhang, A., Xu, H., Bi, W. and Xu, S. (2022), "Adaptive mutant particle swarm optimization based precise cargo airdrop of unmanned aerial vehicles", *Applied Soft Computing*, Vol. 130, 109657, doi: 10.1016/j.asoc.2022.109657.

Zhu, X., Pasch, T.J. and Bergstrom, A. (2020), "Understanding the structure of risk belief systems concerning drone delivery: a network analysis", *Technology in Society*, Vol. 62, 101262, doi: 10.1016/j.techsoc.2020.101262.

Zhu, T., Boyles, S.D. and Unnikrishnan, A. (2022), "Two-stage robust facility location problem with drones", *Transportation Research Part C: Emerging Technologies*, Vol. 137, 103563, doi: 10.1016/j.trc.2022.103563.

(The Appendix follows overleaf)

Appendix

Table A1. Post-hoc analysis: suitability of selected LMD criteria based on drone studies

	Luppicini and So (2016)	Kwon *et al.* (2017)	Stöcker *et al.* (2017)	Mohamed *et al.* (2020)	Tezza and Andujar (2019)	Kellermann *et al.* (2020)	Macrina *et al.* (2020)	Boysen *et al.* (2021)	Dong *et al.* (2021)	Moshref-Javadi and Winkenbach (2021)	Rejeb *et al.* (2021)	Comtet and Johannessen (2022)	Pasha *et al.* (2022)	Zhang and Kamargini (2022)	Merkert *et al.* (2022)	Kostrzewski *et al.* (2022)
Cost		✓	✓	✓			✓	✓	✓	✓	✓		✓		✓	✓
Applicability			✓	✓		✓	✓			✓	✓	✓	✓	✓	✓	
Capacity			✓		✓		✓			✓			✓			✓
Time						✓	✓	✓	✓	✓	✓		✓		✓	✓
Reach				✓		✓	✓		✓					✓	✓	
Item condition															✓	
Policies	✓	✓	✓	✓					✓		✓	✓				✓
Infrastructure			✓	✓		✓	✓	✓						✓		
Public acceptance				✓	✓	✓			✓			✓		✓		
Safety	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓
Privacy	✓		✓	✓		✓				✓						
Environment		✓				✓		✓			✓			✓		✓
This study	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Source(s): Created by authors

Table A2.
Summary of drones' potentials, challenges and solutions in LMD

	Potentials	Challenges	Solutions
Senders			
Cost	• Reaching 28–93% cost savings compared to conventional delivery methods • Low investment and operating costs (for single drones) • Improving efficiency by shortening travel distance/time and reducing reliance on fuels • Lowering drivers cost by reducing work shifts • Lowering storage cost by relieving amassed inventory volumes • Lowering cost of delayed/failed deliveries through speedy/timely deliveries	• Difficulty in considering a myriad of factors impacting economic viability (e.g. scale economies, maintenance and depreciation rates, payload-to-energy ratio, time-window penalties, service coverage, population density, labor cost, battery charging/replacement, insurance, regulatory compliance, facility operation) • Large investment cost in drone fleets, depots, charging stations, and operating systems	• Adopting a "system-thinking" approach for cost estimation • Sharing drones across multiple warehouses (via "sharing economy" schemes) • Operating drones with autonomous ground vehicles • Syncing drones with trucks along delivery routes
Applicability	• Increasing flexibility by offering a variety of truck-drone configurations (Figure 8) • Lowering traffic congestions, transport cost, and emissions through distributing loads between drones and trucks • Enabling senders to choose suitable delivery configurations based on the LMD context at hand (e.g. trucks carrying drones to furthest launch points for humanitarian missions)	• Challenge in selecting the *right* truck-drone configuration as it relies on several factors (e.g. cost, urgency of delivery, existent infrastructure) • Need of capital to invest in truck-drone fleets, their operating systems, and associated depots • Lack of policies to guide structuring warehouses, fleets, inventory allocation, and battery management • Deficient infrastructure to accommodate drone-truck setups	• Utilizing deep learning (e.g. Q-learning) to aid the selection between drones and trucks • Selecting multiple truck-drone configurations to optimize the LMD process • Adopting airborne fulfillment centers ("flying warehouses") to reduce dependency on land infrastructure
Capacity	• Drones' flying capacity enables avoiding buildings, traffic, rivers, and other geographical/physical barriers • Improving LMD's overall capacity (e.g. speed, range, accessibility, payload) when combined with trucks • Enabling utilizing the capacity of each delivery mode (e.g. drones: reaching inaccessible zones; trucks: carrying heavier loads)	• Limited capacity of drones (in terms of travel range, speed, battery, payload, and extreme weather resistance) • Difficulty in balancing between competing capacity tradeoffs (e.g. speed vs travel range, travel range vs battery capacity, battery capacity vs payload) • Meticulous planning requirements for boosting capacity (e.g. charging consumes times, replacing batteries demands human access)	• Operating in tandem with trucks • Deploying battery charging/swapping points (or docking stations) along routes • Charging on trucks carrying drones • Hitchhiking on private/public vehicles • Scheduling deliveries based on drones' capacity • Adopting airborne fulfillment centers ("flying warehouses") • Having multiple drones carry the payload • Equipping drones with multiple propellers or mini jet engines

(*continued*)

	Potentials	Challenges	Solutions
Receivers			
Time	• Reaching 60–79% reductions in delivery time compared to conventional delivery methods • Drones' ability to avoid barriers (e.g. buildings, traffic, rivers) facilitates time reductions • Achieving time reductions is possible using drones only or in combination with trucks • Delivering vital items (e.g. blood products, organs, vaccines, drugs) to those in need in record time • Attaining substantial health benefits and success rates of urgent missions through speedy deliveries • Enhancing customer satisfaction in e-commerce by speedy deliveries (especially for consumables such as food)	• Shortening delivery times requires operating dedicated drones for individual orders (which can increase LMD cost by increasing the number of drones and delivery centers) • Drones' limited payload/battery capacity can restrict time-savings to light-weight items and nearby receivers • Difficulty in balancing between several variables to achieve optimal time reductions (e.g. travel distance, weather conditions, geographical coverage, item's weight, drone's capacity)	• Using simultaneous pick-up and delivery setups to reduce time and cost • Sharing workloads among drones based on their capacities • Allotting deliveries between drones and trucks • Using relaxed/strict delivery time slots based on item perishability and urgency of delivery • Applying penalty charges for exceeding delivery time slots to warrant arriving on time
Reach	• Drones can skip physical barriers (e.g. mountains, hurricanes, poor transport infrastructure) to reach receivers in hard-to-access zones • Drones' reach potential can be enhanced in drone-only deliveries and drone-truck setups • If supplied with the right tools (e.g. AI), drones hold potentials to deliver to unknown delivery points	• Limited applications in urban areas due to deficient landing space (especially amid high-rise buildings) • Restricted flights to rural areas to avoid interfering with other aircrafts or creating risks to residents • Most countries limit drone flights to VLOS zones (hence creating a need for human intervention) • Inability to reach people within no-fly-zones (e.g. near airports)	• Installing "common delivery zones" in urban areas • Utilizing algorithms to reach receivers between no-fly-zones • Using different landing (on, e.g. ground, balconies, rooftops) and drop-off methods (by, e.g. cable, parachute) to increase accessibility • Supplying drones with AI, zooming and thermographic cameras to increase reach capacity • Equipping drones with fiducial markers, satellite/street imaging and precision drop algorithms to enhance accuracy

Table A2.

(*continued*)

	Potentials	Challenges	Solutions
Item condition	• Preserving items from perishability due to substantial savings in delivery time (especially medical items) • Ability to provide and monitor special temperature requirements using box attachments • Lowering wastage of medical items	• Risk of damaging items due to drones' airborne maneuvers • Preservation remains limited to small/lightweight items due to drones' limited payload/battery capacity and restricting policies • Need to deliver close to depots for time-sensitive items	• Placing items in reinforced boxes to lower damage risk • Using wet/dry ice, polystyrene foams and pre-calibrated thermal packs to maintain temperature requirements • Utilizing quick-release systems to expedite item detachments for time-sensitive deliveries • Using smart capsules with sensors for live monitoring of carried items
Regulators			
Policies	• Governing the airspace and reconciling competing interests • Ensuring safe drone operations (through specifying altitudes, proximity to people/property, maximum weight, flight zones, etc.) • Protecting privacy of individuals through laws for data collection and data use • Standardizing drone guidelines across operational, technical, infrastructural, risk, safety and environmental issues • Promoting innovations and investments in drones for LMD	• Policies steered independently in each country (creating dissimilar/conflicting rules) • Drone registration processes can get tedious • Restricted drone flights to certain zones (e.g. VLOS) limits their utility • Difficulty in sponsoring overarching infrastructures (with comprehensive laws, UAV-dedicated frequencies, etc.) • Challenge in resolving competing interests of involved parties • Loopholes in current laws to accommodate drone deliveries	• The EU passed a uniform set of rules across its 27 states to streamline drone delivery guidelines • The FAA started granting commercial companies licenses to operate drone deliveries in the US • Many countries (e.g. US, UK, China, Australia, Rwanda) are relaxing their aviation policies to accommodate drone deliveries over their territories
Infrastructure	• Incubating drone deliveries by integrating live data into holistic transport systems (e.g. airborne traffic, number of people/objects on ground, geofences, physical obstacles, weather forecasts) • Promoting safe and collision-free drone operations through utilizing data transmitted by drones and surrounding objects • Ensuring uninterrupted drone-to-drone and drone-to-pilot communications • Instituting fairness to all parties involved	• Challenge in expanding UAV-dedicated frequencies across large areas of land • Difficulty in maintaining uninterrupted signals in complex environments with high interferences • Challenge in gathering and streamlining live data from all involved units (e.g. drone operators, airports, weather forecast centers, satellites, etc.) • Most cities' infrastructures are unprepared to accommodate drone deliveries	• Having drones act as a means of delivery and data transmission simultaneously • In absence of signal: utilizing deep learning to aid drones auto allocate deliveries using visual information • Adopting pre-flight conflict detection and resolution systems • Sponsoring the adoption of digitized automated control systems (e.g. UTM, U-Space)

(*continued*)

Table A2.

	Potentials	Challenges	Solutions
Public acceptance	• Supporting and expediting drone adoption in LMD (especially for urgent applications such as medical deliveries) • Shedding light on critical considerations such as safety, privacy, security, sustainability and usefulness • Needed to circumvent chaos upon launch	• Public skepticism about the need for the technology and its usefulness • Safety, privacy and noise pollution concerns are voiced extensively by the public (especially in urban areas) • Challenge in alleviating the "stigma" of drones after misguided military applications • Drivers' fear of losing their jobs to the technology	• Defining clear guidelines and codes of ethics • Enforcing strict aviation safety measures • Educating and training pilots • Applying stringent violation penalties • Familiarizing the public with drones' usefulness via various channels (e.g. word of mouth, marketing campaigns, TV/radio channels)
Societies			
Safety	• Minimizing road accidents by substituting traditional delivery vehicles • Reducing health risks from air- and noise pollution associated with traditional vehicles • Enabling "contactless" deliveries to limit spread of disease • Saving lives of patients/endangered persons due to substantial savings in delivery times • Preserving delivered items from theft, loss, or damage	• Creating physical/mental stress to societies through overcrowding the airspace • Accidents can happen both in-flight (drone crash; package falling) and take-off/landing events (exposed propellers; drone crash) • Drone accidents can harm people, animals and objects • Intensified safety risks in urban areas (esp. at lower altitudes) • Susceptibility to communication interference, computer disturbances, operator errors and drone component failures	• Equipping drones with redundant systems (e.g. additional motors, sensors) to avoid accidents • Adopting collision free paths based on space congestion and battery status • Utilizing deep learning to allocate safe landing spots based on remaining battery level • Installing event-based emergency detection systems • Ordaining dedicated airways and standardized routing protocols
Privacy	• Drones' recording of videos and images of public areas during flights could help preventing crime and reducing reliance on potentially more intrusive surveillance methods (e.g. police patrols, fixed cameras) • Using drones in rescue missions can lower the need for potentially more intrusive search methods (e.g. helicopters, dogs)	• Drones capture large amount of data (e.g. locations, identities), posing privacy concerns if shared with third parties without their consent • Capturing videos and images via drones' cameras can make them a means of undesired surveillance to people and their private space • Risk of accessing, stealing, or tampering with drones' collected data by malicious actors through cyberattacks • Operating drones in LMD might violate laws that prohibit recording the interiors of private property	• Adopting secure data-encryption methods (e.g. blockchain) for drone-related transactions • Giving landowners the rights to allow, lease, or prohibit drones from entering their private airspace (especially at low altitudes) • Incorporating the case of drone deliveries under national privacy laws (e.g. Data Protection Act, GDPR)

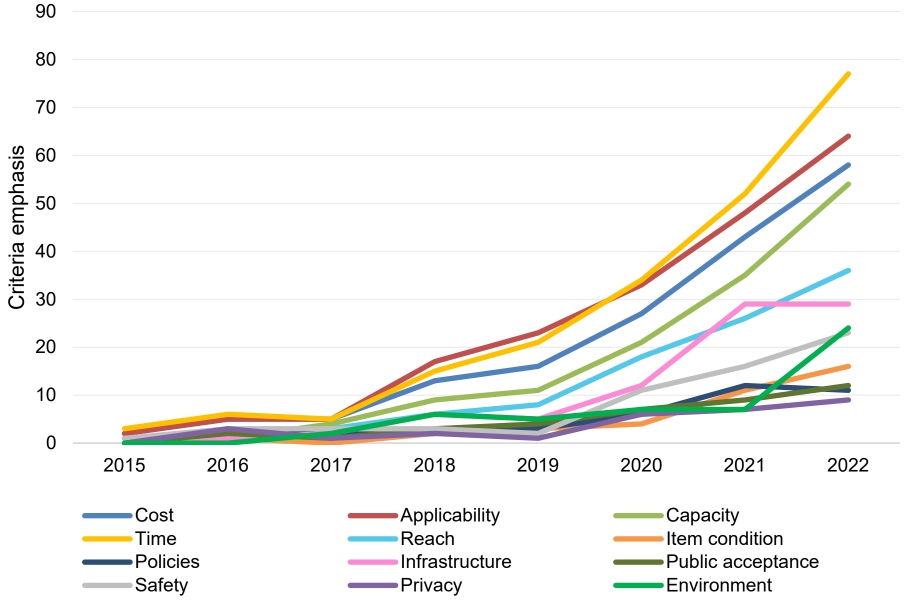
Table A2.

(*continued*)

	Potentials	Challenges	Solutions
Environment	• Relieving traffic congestion and emissions through substituting traditional vehicles • Reducing air- and noise pollution associated with traditional vehicles • Lowering CO_2 emissions due to drones' reliance on electric batteries • Reducing energy consumption due to drones' light weight • Most promising environmental performance in rural areas	• Challenge to lower emissions in urban areas due to stricter policies, circumventing buildings, need for depots and higher receiver density • Drones' limited payload/ battery capacity make them always in need of traditional vehicles (along with their emissions) • Tradeoffs between lowering CO_2 emissions and costs (in terms of, e.g. equipment, charging, insurance) • High energy consumption during drones' production phase • Drones can interfere with wildlife (especially birds) • Emitting debris from potential drone collisions	• Installing depots closer to receivers in urban areas to increase environmental friendliness • Lowering number of stops the drones make • Relying on clean energy courses (e.g. solar, wind) for charging drones • Operating drones through underground subways to alleviate environmental challenges in urban areas • Integrating drones with (electric) trucks in LMD

Source(s): Created by authors

Table A2.



Source(s): Created by authors

Figure A1.
Emphasis of the 12 LMD criteria over time

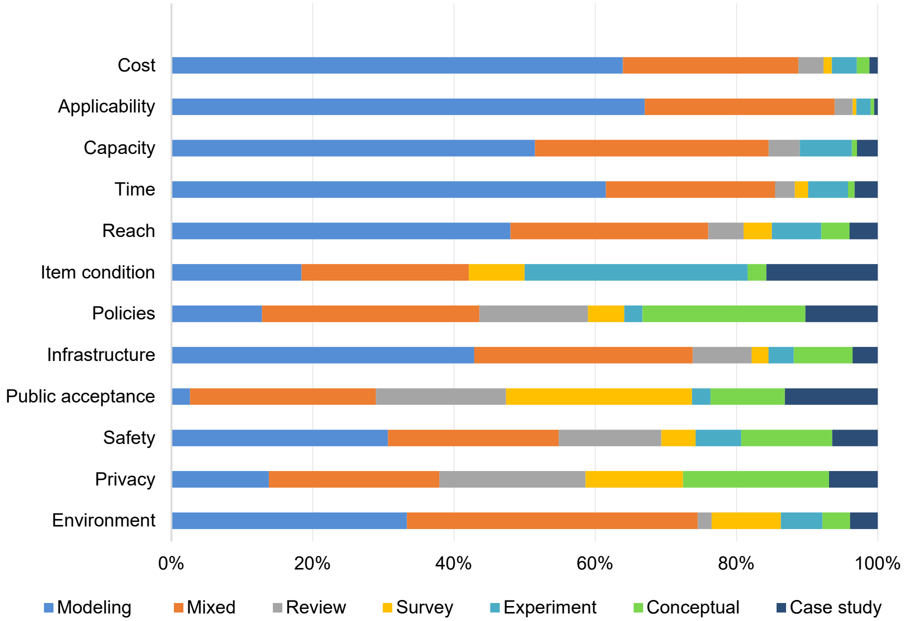


Figure A2.
Distribution of research methods across the 12 LMD criteria

Source(s): Created by authors

Articles included in the review but not referenced in the text*

*Agatz, N., Bouman, P. and Schmidt, M. (2018), "Optimization Approaches for the Traveling Salesman Problem with Drone", *Transportation Science*, *52*(4), 965–981.

*Amukele, T., Sokoll, L.J., Pepper, D., Howard, D.P. and Street, J. (2015), "Can unmanned aerial systems (drones) be used for the routine transport of chemistry, hematology, and coagulation laboratory specimens?", *PLoS One, 10*(7), e0134020.

*Arafat, M.Y. and Moh, S. (2022), "JRCS: Joint Routing and Charging Strategy for Logistics Drones", *IEEE Internet of Things Journal*, *9*(21), 21751–21764.

*Aurambout, J.P., Gkoumas, K. and Ciuffo, B. (2019), "Last mile delivery by drones: an estimation of viable market potential and access to citizens across European cities", *European Transport Research Review*, *11*(1), 1–21.

*Bai, X., Cao, M., Yan, W. and Ge, S.S. (2019), "Efficient routing for precedence-constrained package delivery for heterogeneous vehicles", *IEEE Transactions on Automation Science and Engineering*, *17*(1), 248–260.

*Baniasadi, P., Foumani, M., Smith-Miles, K. and Ejov, V. (2020), "A transformation technique for the clustered generalized traveling salesman problem with applications to logistics", *European Journal of Operational Research*, *285*(2), 444–457.

*Benayad, A., Malasse, O., Belhadaoui, H. and Benayad, N. (2022), "Unmanned Aerial Vehicle in the Logistics of Pandemic Vaccination: An Exact Analytical Approach for Any Number of Vaccination Centres", *Healthcare (Basel)*, *10*(10), 2102.

*Betti Sorbelli, F., Corò, F., Das, S.K., Palazzetti, L. and Pinotti, C.M. (2022), "On the Scheduling of Conflictual Deliveries in a last-mile delivery scenario with truck-carried drones", *Pervasive and Mobile Computing*, *87,* 101700.

*Betti Sorbelli, F., Pinotti, C.M. and Rigoni, G. (2023), "On the Evaluation of a Drone-Based Delivery System on a Mixed Euclidean-Manhattan Grid", *IEEE Transactions on Intelligent Transportation Systems*, *24*(1), 1276–1287.

*Chauhan, D., Unnikrishnan, A. and Figliozzi, M. (2019), "Maximum coverage capacitated facility location problem with range constrained drones", *Transportation Research Part C: Emerging Technologies*, *99*, 1–18.

*Chen, H., Liu, Z., Luo, Y. and Wang, H. (2019), "The Optimization Scheme of Drones in Rescue", *International Journal of Applied Mathematics and Soft Computing*, *5*(1), 47–54.

*Chen, M.F., Liu, Y.Q., Song, Y. and Sun, Q. (2019), "A contract coordination model of dual-channel delivery between UAVs and couriers considering the uncertainty of delivery for last mile", *Discrete Dynamics in Nature and Society*, 1–11.

*Chiang, W.C., Li, Y., Shang, J. and Urban, T.L. (2019), "Impact of drone delivery on sustainability and cost: Realizing the UAV potential through vehicle routing optimization", *Applied Energy, 242*, 1164–1175.

*Choi, Y. and Schonfeld, M. (2021), "A comparison of optimized deliveries by drone and truck", *Transportation Planning and Technology*, *44*(3), 319–336.

*Choudhury, S., Solovey, K., Kochenderfer, M.J. and Pavone, M. (2021), "Efficient large-scale multi-drone delivery using transit networks", *Journal of Artificial Intelligence Research, 70*, 757–788.

*Chuang Liu, Chen, H., Li, X. and Liu, Z. (2021), "A scheduling decision support model for minimizing the number of drones with dynamic package arrivals and personalized deadlines", *Expert Systems with Applications*, *167,* 114157.

Chung, J. (2018), "Heuristic method for collaborative parcel delivery with drone", Journal of Distribution Science*, *16*(2), 19–24.

*Coindreau, M.A., Gallay, O. and Zufferey, N. (2021), "Parcel delivery cost minimization with time window constraints using trucks and drones", *Networks*, *78*(4), 400–420.

*de Freitas, J.C. and Penna, H.V. (2020), "A variable neighborhood search for flying sidekick traveling salesman problem", *International Transactions in Operational Research*, 27(1): 267–290.

*Dell'Amico, M., Montemanni, R. and Novellani, S. (2021), "Algorithms based on branch and bound for the flying sidekick traveling salesman problem", *Omega*, *104,* 102493.

*Di Puglia Pugliese, L., Macrina, G. and Guerriero, F. (2021), "Trucks and drones cooperation in the last-mile delivery process", *Networks*, *78*(4), 371–399.

*Di Puglia Pugliese, L., Guerriero, F. and Scutellá, M.G. (2021), "The last-mile delivery process with trucks and drones under uncertain energy consumption", *Journal of Optimization Theory and Applications*, *191*(1), 31–67.

*do C. Martins, L., Hirsch, P. and Juan, A.A. (2021), "Agile optimization of a two-echelon vehicle routing problem with pickup and delivery", *International Transactions in Operational Research, 28*(1), 201–221.

*Doole, M., Ellerbroek, J., Knoop, V.L. and Hoekstra, J.M. (2021), "Constrained urban airspace design for large-scale drone-based delivery traffic", *Aerospace*, *8*(2), 38.

*Dukkanci, O., Kara, B.Y. and Bektaş, T. (2021), "Minimizing energy and cost in range-limited drone deliveries with speed optimization", *Transportation Research Part C: Emerging Technologies*, *125,* 102985.

*ElSayed, M. and Mohamed, M. (2022), "The Impact of Airspace Discretization on the Energy Consumption of Autonomous Unmanned Aerial Vehicles (Drones)", *Energies*, *15*(14), 5074.

*Feng, X., Murray, A.T. and Church, R.L. (2021), "Drone service response: Spatiotemporal heterogeneity implications", *Journal of Transport Geography*, *93*, 103074.

*Ferrandez, S.M., Harbison, T., Weber, T., Sturges, R. and Rich, R. (2016), "Optimization of a truck-drone in tandem delivery network using k-means and genetic algorithm", *Journal of Industrial Engineering and Management*, *9*(2), 374–388.

*Figliozzi, M.A. (2017), "Lifecycle modeling and assessment of unmanned aerial vehicles (Drones) CO2e emissions", *Transportation Research Part D: Transport and Environment*, *57*, 251–261.

*Fikar, C., Gronalt, M. and Hirsch, P. (2016), "A decision support system for coordinated disaster relief distribution", *Expert Systems with Applications*, *57,* 104–116.

*Flemons, K., Baylis, B., Khan, A.Z., Kirkpatrick, A.W., Whitehead, K., Moeini, S., Schreiber, A., Lapointe, S., Ashoori, S., Arif, M., Berenger, B., Conly, J. and Hawkins, W. (2022), "The use of drones for the delivery of diagnostic test kits and medical supplies to remote First Nations communities during Covid-19", *American Journal of Infection Control*, *50*(8), 849–856.

*Gómez-Lagos, J., Candia-Véjar, A. and Encina, F. (2021), "A new truck-drone routing problem for parcel delivery services aided by parking lots", *IEEE Access*, *9,* 11091–11108.

*Gonzalez-R, L., Canca, D., Andrade-Pineda, J.L., Calle, M. and Leon–Blanco, J.M. (2020), "Truck-drone team logistics: A heuristic approach to multi-drop route planning", *Transportation Research Part C: Emerging Technologies*, *114*, 657–680.

*Ha, Q.M., Deville, Y., Pham, Q.D. and Hà, M.H. (2018), "On the min-cost traveling salesman problem with drone", *Transportation Research Part C: Emerging Technologies*, *86*, 597–621.

*Ha, Q.M., Deville, Y., Pham, Q.D. and Hà, M.H. (2020), "A hybrid genetic algorithm for the traveling salesman problem with drone", *Journal of Heuristics*, *26*(2), 219–247.

*Ham, A.M. (2018), "Integrated scheduling of m-truck, m-drone, and m-depot constrained by time-window, drop-pickup, and m-visit using constraint programming", *Transportation Research Part C: Emerging Technologies*, *91*, 1–14.

*Han, S., Özer, B., Alioglu, B., Polat, Ö. and Aktin, A.T. (2019), "A mathematical model for the delivery routing problem via drones", *Pamukkale University Journal of Engineering Science, 25*(1), 89–97.

*Hii, M.S.Y., Courtney, P. and Royall, G. (2019), "An evaluation of the delivery of medicines using drones", *Drones*, *3*(3), 52.

*Hong, I., Kuby, M. and Murray, A.T. (2018), "A range-restricted recharging station coverage model for drone delivery service planning", *Transportation Research Part C: Emerging Technologies*, *90,* 198–212.

*Hossain, N.U.I., Sakib, N. and Govindan, K. (2022), "Assessing the performance of unmanned aerial vehicle for logistics and transportation leveraging the Bayesian network approach", *Expert Systems with Applications*, *209, 118301*.

*Huang, H. and Savkin, A.V. (2020), "A method of optimized deployment of charging stations for drone delivery", *IEEE Transactions on Transportation Electrification*, *6*(2), 510–518.

*Huang, H., Savkin, A.V. and Huang, C. (2020), "A new parcel delivery system with drones and a public train", *Journal of Intelligent and Robotic Systems*, *100*(3), 1341–1354.

*Huang, H., Savkin, A.V. and Huang, C. (2020), "Reliable path planning for drone delivery using a stochastic time-dependent public transportation network", *IEEE Transactions on Intelligent Transportation Systems*, *22*(8), 4941–4950.

*Huang, H., Savkin, A.V. and Huang, C. (2020), "Round trip routing for energy-efficient drone delivery based on a public transportation network", *IEEE Transactions on Transportation Electrification*, *6*(3), 1368–1376.

*Huang, H., Savkin, A.V. and Huang, C. (2020), "Scheduling of a parcel delivery system consisting of an aerial drone interacting with public transportation vehicles", *Sensors*, *20*(7), 2045.

*Huang, H., Savkin, A.V. and Huang, C. (2021), “Drone routing in a time-dependent network: Toward low-cost and large-range parcel delivery”, *IEEE Transactions on Industrial Informatics*, *17*(2), 1526–1534.

*Ito, S., Nishikawa, H., Kong, X., Funabashi, Y., Shibata, A., Negoro, S., Taniguchi, I. and Tomiyama, H. (2021), “Energy-aware Routing of Delivery Drones under WIndy Conditions”, *IPSJ Transactions on System LSI Design Methodology*, *14,* 30–39.

*Jasim, N.I., Kasim, H. and Mahmoud, M.A. (2022), “Towards the Development of Smart and Sustainable Transportation System for Foodservice Industry: Modelling Factors Influencing Customer’s Intention to Adopt Drone Food Delivery (DFD) Services”. *Sustainability*, *14*(5), 2852.

*Jeon, S., Lee, H., Kaliappan, V.K., Nguyen, T.A., Jo, H., Cho, H. and Min, D. (2022), “Multiagent Reinforcement Learning Based on Fusion-Multiactor-Attention-Critic for Multiple-Unmanned-Aerial-Vehicle Navigation Control”, *Energies*, *15*(19), 7426.

*Jie Zhang and Li, Y. (2023), “Collaborative vehicle-drone distribution network optimization for perishable products in the epidemic situation”, *Computers and Operations Research*, *149*, 106039.

*Juan Zhang, Campbell, J.F., Sweeney II, D.C. and Hupman, A.C. (2021), “Energy consumption models for delivery drones: A comparison and assessment”, *Transportation Research Part D: Transport and Environment*, *90,* 102668.

*Jung, H. and Kim, J. (2022), “Drone scheduling model for delivering small parcels to remote islands considering wind direction and speed”, *Computers and Industrial Engineering*, *163*, 107784.

*Kai Wang, Pesch, E., Kress, D., Fridman, I. and Boysen, N. (2022), “The Piggyback Transportation Problem: Transporting drones launched from a flying warehouse”, *European Journal of Operational Research*, *296*(2), 504–519.

*Kamat, A., Shanker, S., Barve, A., Muduli, K., Mangla, S.K. and Luthra, S. (2022), “Uncovering interrelationships between barriers to unmanned aerial vehicles in humanitarian logistics”, *Operations Management Research*, *15*(3–4), 1134–1160.

*Khan, S.I., Qadir, Z., Munawar, H.S., Nayak, S.R., Budati, A.K., Verma, K.D. and Prakash, D. (2021), “UAVs path planning architecture for effective medical emergency response in future networks”, *Physical Communication*, *47,* 101337.

*Khosravi, M., Enayati, S., Saeedi, H. and Pishro-Nik, H. (2021), “Multi-purpose drones for coverage and transport applications”, *IEEE Transactions on Wireless Communications*, *20*(6), 3974–3987.

*Kim, J., Moon, H. and Jung, H. (2020), “Drone-based parcel delivery using the rooftops of city buildings: Model and solution”, *Applied Sciences*, *10*(12), 4362.

*Kim, S. and Moon, I. (2019), “Traveling salesman problem with a drone station”, *IEEE Transactions on Systems, Man and Cybernetics: Systems*, *49*(1), 42–52.

*Kloster, K., Moeini, M., Vigo, D. and Wendt, O. (2023), “The multiple traveling salesman problem in presence of drone- and robot-supported packet stations”, *European Journal of Operational Research*, *305*(2), 630–643.

*Kong, F., Li, J., Jiang, B., Wang, H. and Song, H. (2022), “Trajectory Optimization for Drone Logistics Delivery via Attention-Based Pointer Network”, *IEEE Transactions on Intelligent Transportation Systems*, *24*(4), 4519–4531.

Koshta, N., Devi, Y. and Chauhan, C. (2022), “Evaluating Barriers to the Adoption of Delivery Drones in Rural Healthcare Supply Chains: Preparing the Healthcare System for the Future”, IEEE Transactions on Engineering Management*, 1–13.

*Kundu, A., Escobar, R.G. and Matis, T.I. (2022), “An efficient routing heuristic for a drone-assisted delivery problem”, *IMA Journal of Management Mathematics*, *33*(4), 583–601.

*Kuo, R.J., Lu, S.-H., Lai:-Y. and Mara, S.T.W. (2022), “Vehicle routing problem with drones considering time windows”, *Expert Systems with Applications*, *191*, 116264.

*Kuru, K., Ansell, D., Khan, W. and Yetgin, H. (2019), “Analysis and optimization of unmanned aerial vehicle swarms in logistics: An intelligent delivery platform”, *IEEE Access*, *7*, 15804–15831.

*Kwon, H., Kim, J. and Park, Y. (2017), “Applying LSA text mining technique in envisioning social impacts of emerging technologies: The case of drone technology”, *Technovation*, *60,* 15–28.

*Larson, J., Isihara, P. Flores, G., Townsend, E., Diedrichs, D.R., Baars, C., Kwon, S., McKinnon, W., Nussbaum, J., Steggerda, C. and Yan, J. (2020), “A priori assessment of a smart-navigated unmanned aerial vehicle disaster cargo fleet”, *Simulation*, *96*(8), 641–653.

*Lee, C.-W. and Wong, W.-P. (2022), “Last-mile drone delivery combinatorial double auction model using multi-objective evolutionary algorithms”, *Soft Computing*, *26*(22), 12355–12384.

*Lee, M.T., Lai, Y.C., Chuang, M.L. and Chen, B.Y. (2021), “Design and validation of a route planner for logistic UAV swarm”, *Intelligent Automation and Soft Computing*, *28*(1), 227–240.

*Leon–Blanco, J.M., Gonzalez-R: L., Andrade-Pineda, J.L., Canca, D. and Calle, M. (2022), “A multi-agent approach to the truck multi-drone routing problem”, *Expert Systems with Applications*, *195,* 116604.

*Li, H., Wang, H., Chen, J. and Bai, M. (2020), “Two-echelon vehicle routing problem with time windows and mobile satellites”, *Transportation Research Part B: Methodological*, *138,* 179–201.

*Li, X., Gong, L., Liu, X., Jiang, F., Shi, W., Fan, L., Gao, H., Li, R. and Xu, J. (2022), “Solving the last mile problem in logistics: A mobile edge computing and blockchain-based unmanned aerial vehicle delivery system”, *Concurrency and Computation: Practice and Experience*, *34*(7), e6068.

*Li, Y., Zhang, G., Pang, Z. and Li, L. (2020), “Continuum approximation models for joint delivery systems using trucks and drones”, *Enterprise Information Systems*, *14*(4), 406–435.

*Liang, X., Yu, H., Zhang, Z., Liu, H., Fang, Y. and Han, J. (2023), “Unmanned Aerial Transportation System With Flexible Connection Between the Quadrotor and the Payload: Modeling, Controller Design, and Experimental Validation”, *IEEE Transactions on Industrial Electronics*, *70*(2), 1870–1882.

*Lin, M., Chen, Y., Han, R., Chen, Y. and Anderson, D.R. (2022), “Discrete Optimization on Truck-Drone Collaborative Transportation System for Delivering Medical Resources”. *Discrete Dynamics in Nature and Society*, 1–13.

*Liu, C., Huang, L. and Dong, Z. (2022), “A Two-Stage Approach of Joint Route Planning and Resource Allocation for Multiple UAVs in Unmanned Logistics Distribution”, *IEEE Access*, *10*, 113888–113901.

*Liu, R., Pitruzzello, G., Rosa, M., Battisti, A., Cerri, C. and Tortora, G. (2022), “Towards an Innovative Sensor in Smart Capsule for Aerial Drones for Blood and Blood Component Delivery”, *Micromachines (Basel)*, *13*(10), 1664.

*Lu, Y., Yang, C. and Yang, J. (2022), “A multi-objective humanitarian pickup and delivery vehicle routing problem with drones”, *Annals of Operations Research*, *319*(1), 291–353.

*Luo, Z., Poon, M., Zhang, Z., Liu, Z. and Lim, A. (2021), “The multi-visit traveling salesman problem with multi-drones”, *Transportation Research Part C: Emerging Technologies*, *128,* 103172.

*Macias, J.E., Angeloudis, P. and Ochieng, W. (2020), “Optimal hub selection for rapid medical deliveries using unmanned aerial vehicles”, *Transportation Research Part C: Emerging Technologies*, *110,* 56–80.

*Mahmoudi, B. and Eshghi, K. (2022), “Energy-constrained multi-visit TSP with multiple drones considering non-customer rendezvous locations”, *Expert Systems with Applications*, *210,* 118479.

*Malamule, D., Moreira, S., Madeira, C., Lutucuta, C., Ailstock, G., Maxim, L., Bechtel, R., Defawe, O. and Viegas, S. (2022), “Quality Analysis of Tuberculosis Specimens Transported by Drones versus Ground Transportation”, *Drones*, *6*(7), 155.

*Markelova, A.Y., Allahverdyan, A.L., Martemyanov, A.A., Sokolova, I.S., Petrosian, O.L. and Svirkin, M.V. (2022), “Applied routing problem for a fleet of delivery drones using a modified parallel genetic algorithm”, *Vestnik of Saint Petersburg University. Applied Mathematics. Computer Science. Control Processes*, *18*(1), 135–148.

*Markvica, K., Hu, B., Prandtstetter, M., Ritzinger, U., Zajicek, J., Berkowitsch, C., Hauger, G., Pfoser, S., Berger, T., Eitler, S. and Schodl, R. (2018), “On the development of a sustainable and fit-for-the-future transportation network”, *Infrastructures*, *3*(3), 23.

*Mathew, N., Smith, S.L. and Waslander, S.L. (2015), “Planning paths for package delivery in heterogeneous multirobot teams”, *IEEE Transactions on Automation Science and Engineering*, *12*(4), 1298–1308.

*Mbiadou Saleu, R.G., Deroussi, L., Feillet, D., Grangeon, N. and Quilliot, A. (2018), “An iterative two-step heuristic for the parallel drone scheduling traveling salesman problem”, *Networks*, *72*(4), 459–474.

*Mbiadou Saleu, R.G., Deroussi, L., Feillet, D., Grangeon, N. and Quilliot, A. (2022), “The parallel drone scheduling problem with multiple drones and vehicles”, *European Journal of Operational Research*, *300*(2), 571–589.

*Mora, P. and Araujo, C.A.S. (2021), “Delivering blood components through drones: a lean approach to the blood supply chain”, *Supply Chain Forum: An International Journal*, *23*(2), 113–123.

*Moshref-Javadi, M., Lee, S. and Winkenbach, M. (2020), “Design and evaluation of a multi-trip delivery model with truck and drones”, *Transportation Research Part E: Logistics and Transportation Review*, *136*, 101887.

*Murray, C.C. and Raj, R. (2020), “The multiple flying sidekicks traveling salesman problem: Parcel delivery with multiple drones”, *Transportation Research Part C: Emerging Technologies*, *110*, 368–398.

*Najy, W., Archetti, C. and Diabat, A. (2023), “Collaborative truck-and-drone delivery for inventory-routing problems”, *Transportation Research Part C: Emerging Technologies*, *146*, 103791.

*Ozkan, O. (2022), “Multi-objective optimization of transporting blood products by routing UAVs: the case of Istanbul”, *International Transactions in Operational Research*, *30*(1), 302–327.

*Pan, Y., Chen, Q., Zhang, N., Li, Z., Zhu, T. and Han, Q. (2022), “Extending Delivery Range and Decelerating Battery Aging of Logistics UAVs using Public Buses”, *IEEE Transactions on Mobile Computing*, *22*(9), 5280–5295.

*Pei, Z., Dai, X., Yuan, Y., Du, R. and Liu, C. (2021), “Managing price and fleet size for courier service with shared drones”, *Omega*, *104*, 102482.

*Peng, K., Du, J., Lu, F., Sun, Q., Dong, Y., Zhou, P. and Hu, M. (2019), “A hybrid genetic algorithm on routing and scheduling for vehicle-assisted multi-drone parcel delivery”, *IEEE Access*, *7*, 49191–49200.

*Perlee, D., van der Steege, K.H. and den Besten, G. (2021), “The effect of drone transport on the stability of biochemical, coagulation and hematological parameters in healthy individuals”, *Clinical Chemistry and Laboratory Medicine, 59*(11), 1772–1776.

*Pina-Pardo, J.C., Silva, D.F. and Smith, A.E. (2021), “The traveling salesman problem with release dates and drone resupply”, *Computers and Operations Research, 129,* 105170.

*Pinto, R., Zambetti, M., Lagorio, A. and Pirola, F. (2020), “A network design model for a meal delivery service using drones”, *International Journal of Logistics Research and Applications*, *23*(4), 354–374.

*Poikonen, S., Golden, B. and Wasil, E.A. (2019), “A branch-and-bound approach to the traveling salesman problem with a drone”, *INFORMS Journal on Computing*, *31*(2), 335–346.

*Poikonen, S., Wang, X. and Golden, B. (2017), “The vehicle routing problem with drones: Extended models and connections”, *Networks*, *70*(1), 34–43.

*Rabta, B., Wankmüller, C. and Reiner, G. (2018), "A drone fleet model for last-mile distribution in disaster relief operations", *International Journal of Disaster Risk Reduction*, *28*, 107–112.

*Radzki, G., Nielsen, I., Golińska-Dawson, P. Bocewicz, G. and Banaszak, Z. (2021), "Reactive UAV fleet's mission planning in highly dynamic and unpredictable environments", *Sustainability*, *13*(9), 5228.

*Raj, R. and Murray, C. (2020), "The multiple flying sidekicks traveling salesman problem with variable drone speeds", *Transportation Research Part C: Emerging Technologies*, *120*, 102813.

*Rashidzadeh, E., Molana, S.M.H., Soltani, R. and Hafezalkotob, A. (2021), "Assessing the sustainability of using drone technology for last-mile delivery in a blood supply chain", *Journal of Modelling in Management, 16*(4), 1376–1402.

*Resat, H.G. (2020), "Design and analysis of novel hybrid multi-objective optimization approach for data-driven sustainable delivery systems", *IEEE Access*, *8*, 90280–90293.

*Rezaei Kallaj, M., Hasannia Kolaee, M. and Mirzapour Al-e-hashem, S.M.J. (2022), "Integrating bloodmobiles and drones in a post-disaster blood collection problem considering blood groups", *Annals of Operations Research*, *321*(1–2), 783–811.

*Sacramento, D., Pisinger, D. and Ropke, S. (2019), "An adaptive large neighborhood search metaheuristic for the vehicle routing problem with drones", *Transportation Research Part C: Emerging Technologies*, *102*, 289–315.

*Sajid, M., Mittal, H., Pare, S. and Prasad, M. (2022), "Routing and scheduling optimization for UAV assisted delivery system: A hybrid approach", *Applied Soft Computing*, *126*, 109225.

*Salama, M. and Srinivas, S. (2020), "Joint optimization of customer location clustering and drone-based routing for last-mile deliveries", *Transportation Research Part C: Emerging Technologies*, *114*, 620–642.

*Sawadsitang, S., Niyato, D., Tan, S., Wang, P. and Nutanong, S. (2021), "Shipper Cooperation in Stochastic Drone Delivery: A Dynamic Bayesian Game Approach", *IEEE Transactions on Vehicular Technology*, *70*(8), 7437–7452.

*Schermer, D., Moeini, M. and Wendt, O. (2019), "A matheuristic for the vehicle routing problem with drones and its variants", *Transportation Research Part C: Emerging Technologies*, *106*, 166–204.

*Schermer, D., Moeini, M. and Wendt, O. (2020), "A b ranch-and-cut approach and alternative formulations for the traveling salesman problem with drone", *Networks*, *76*(2), 164–186.

*Scott, J.E. and Scott, C.H. (2019), "Models for drone delivery of medications and other healthcare items", *International Journal of Healthcare Information Systems and Informatics*, *13*(3), 20–34.

*Shavarani, S.M., Nejad, M.G., Rismanchian, F. and İzbirak, G. (2018), "Application of hierarchical facility location problem for optimization of a drone delivery system: a case study of Amazon prime air in the city of San Francisco", *The International Journal of Advanced Manufacturing Technology*, *95*(9), 3141–3153.

*Shen, Y., Xu, X., Zou, B. and Wang, H. (2021), "Operating policies in multi-warehouse drone delivery systems", *International Journal of Production Research*, *59*(7), 2140–2156.

*Sigari, C. and Biberthaler: (2021), "Medical drones: Disruptive technology makes the future happen", *Der Unfallchirurg*, *124*(12), 974–976.

*Simić, V., Lazarević, D. and Dobrodolac, M. (2021), "Picture fuzzy WASPAS method for selecting last-mile delivery mode: a case study of Belgrade", *European Transport Research Review*, *13*(1), 1–22.

*Song, B.D., Park, K. and Kim, J. (2018), "Persistent UAV delivery logistics: MILP formulation and efficient heuristic", *Computers and Industrial Engineering*, *120*, 418–428.

*Stalnov, O., Faran, M., Koral, Y. and Furst, M. (2022), "Auditory detection probability of propeller noise in hover flight in presence of ambient soundscape", *The Journal of the Acoustical Society of America*, *151*(6), 3719-3728.

Tavana, M., Khalili-Damghani, K., Santos-Arteaga, F.J. and Zandi, M.H. (2017), "Drone shipping versus truck delivery in a cross-docking system with multiple fleets and products", Expert Systems With Applications*, *72,* 93–107.

*Torabbeigi, M., Lim, G.J., Ahmadian, N. and Kim, S.J. (2021), "An optimization approach to minimize the expected loss of demand considering drone failures in drone delivery scheduling", *Journal of Intelligent and Robotic Systems*, *102*(1), 22.

*Troudi, A., Addouche, S.A., Dellagi, S. and Mhamedi, A.E. (2018), "Sizing of the drone delivery fleet considering energy autonomy", *Sustainability*, *10*(9), 3344.

*Ulmer, M.W. and Thomas, B.W. (2018), "Same-day delivery with heterogeneous fleets of drones and vehicles", *Networks*, *72*(4), 475–505.

*Vu, L., Vu, D.M., Hà, M.H. and Nguyen, V.P. (2022), "The two-echelon routing problem with truck and drones", *International Transactions in Operational Research*, *29*(5), 2968–2994.

*Wang, K., Yuan, B., Zhao, M. and Lu, Y. (2020), "Cooperative route planning for the drone and truck in delivery services: A bi-objective optimisation approach", *Journal of the Operational Research Society*, *71*(10), 1657–1674.

*Wang, X., Poikonen, S. and Golden, B. (2017), "The vehicle routing problem with drones: several worst-case results", *Optimization Letters*, *11*(4), 679–697.

*Wangsa, I.D., Wee, H.M., Hsiao, Y.L. and Rizky, N. (2021), "Identifying an effective last-mile customer delivery option with an integrated eco-friendly inventory model", *INFOR: Information Systems and Operational Research*, *60*(2), 165–200.

*Wankmüller, C., Kunovjanek, M. and Mayrgündter, S. (2021), "Drones in emergency response–evidence from cross-border, multi-disciplinary usability tests", *International Journal of Disaster Risk Reduction*, *65*, 102567.

*Windras Mara, S.T., Rifai, A.P. and Sopha, B.M. (2022), "An adaptive large neighborhood search heuristic for the flying sidekick traveling salesman problem with multiple drops", *Expert Systems with Applications*, *205*, 117647.

*Wright, D. and Moore, E. (2021), "DARC Matters: Repurposing Nineteenth-Century Property Law for the Twenty-First Century", *Iowa L. Rev.*, *107*, 2247.

*Yanchao Liu, (2019), "An optimization-driven dynamic vehicle routing algorithm for on-demand meal delivery using drones", *Computers and Operations Research*, *111*, 1–20.

*Yixuan Li, Yuan, X., Zhu, J., Huang, H. and Wu, M. (2020), "Multiobjective scheduling of logistics UAVs based on variable neighborhood search", *Applied Sciences*, *10*(10), 3575.

*Yurek, E.E. and Ozmutlu, H.C. (2018), "A decomposition-based iterative optimization algorithm for traveling salesman problem with drone", *Transportation Research Part C: Emerging Technologies*, *91*, 249–262.

*Yuyu Li, Yang, W. and Huang, B. (2020), "Impact of UAV delivery on sustainability and costs under traffic restrictions", *Mathematical Problems in Engineering, 2020*, 1–15.

*Zenezini, G., Mangano, G. and De Marco, A. (2022), "Experts' opinions about lasting innovative technologies in City Logistics", *Research in Transportation Business and Management*, *45,* 100865.

*Zhang, S., Liu, S., Xu, W. and Wang, W. (2022), "A novel multi-objective optimization model for the vehicle routing problem with drone delivery and dynamic flight endurance", *Computers and Industrial Engineering*, *173*, 108679.

*Zhang, Y. and Kamargianni, M. (2022), "A review on the factors influencing the adoption of new mobility technologies and services: autonomous vehicle, drone, micromobility and mobility as a service", *Transport Reviews*, *43*(3), 407–429.

*Zhao, L., Bi, X., Li, G., Dong, Z., Xiao, N. and Zhao, A. (2022), “Robust traveling salesman problem with multiple drones: Parcel delivery under uncertain navigation environments”, *Transportation Research Part E: Logistics and Transportation Review, 168,* 102967.

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