Utilizing unmanned aerial vehicles in commerce and managing supply chains - a literature review

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Abstract

Unmanned aerial vehicles, UAVs in short, possess the potential to transform the logistics industry as we know it. Drone technology is striving to meet several last-mile consumer needs for products such as pre-made food, convenience products, along with business-to-business needs, such as the transport of medical samples for laboratory examination. The concept of drone delivery has moved from pure fantasy to a very real phenomenon in the logistics sector. Leading businesses have been incorporating this technology into everyday operations as an alternative to traditional delivery methods’ clear shortcomings.
Congestion, long-distance delivery, and ever-growing demand for speedy delivery are but only a few of the challenges drone deliveries effectively addresses. Unlike conventional means, package delivery through drones is versatile, capable of negotiating diverse terrains and delivering goods at scale and with unprecedented speed. With this in mind, the objective of the study was to establish the available use cases for unmanned aerial vehicles in the logistics sphere, with an emphasis on the last mile, where goods are transported to the client and viewed as the most critical and costly phase of transportation. The paper examined the existing literature on how certain challenges with efficiency can be navigated and how regulatory barriers, in the case of the European Union (EU), with the concept of U-Space, can affect the full potential of drones as a method of delivery it also touched on strategies to make the last mile in drone transport more environmentally friendly. A systematic literature review and Meta-synthesis was utilized for analysis and interpretation of findings; it also touched on strategies to make the last mile in drone transport more environmentally friendly.
The study found that research has been focused on four issues regarding efficiency: (1) drone assignment; (2) charging process and recharging location; (3) vehicle routing; (4) fleet dimensioning. The solutions presented may provide a way forward for industry leaders, albeit with certain limitations acknowledged. Furthermore, the work also found that there are still many challenges, be it the regulations’ own contradictions, disconnects in airspace management or red tape, to a full rollout of drones in a common European airspace; despite this, certain case studies in Germany and France have showcased the possibilities of drones in becoming the premier transportation mode for goods in the future; greener developments still need to be made in order to ensure the lowest impact possible from drones onto the wider environment.

Keywords/tags (subjects)

Drone, Last-mile delivery, Efficiency, Unmanned aerial vehicles (UAVs), Regulation, U-space, Environment

Miscellaneous (Confidential information)

None

Contents

1 Methodology and justification

1.1 Research questions

This work is aiming to find answers to the following queries:

1. Operational Efficiency:

- What evidence exists regarding the operational efficiency gains achieved using UAVs in logistics?
- How do UAVs contribute to reducing delivery times, improving inventory management, and optimizing supply chain processes?

2. Environmental Impact:

- What is the environmental impact of integrating UAVs into supply chains, and how does it compare to traditional logistics methods?
- Are there sustainable practices and technologies associated with UAVs in the last-mile that address environmental concerns?

3. Regulatory barriers:

- What challenges and barriers are identified in the literature that may impact the continued integration and expansion of UAVs in logistics?

4. Case studies and best practices:

- What case studies exist that showcase successful implementations of UAVs in logistics operations?
- Are there identified best practices and lessons learned from real-world applications of UAVs in commerce and supply chains?

Conclusion:

- What are the anticipated future trends in the utilization of UAVs in online commerce and supply chains?

1.2 Defining features of literature review

Machi and McEvoy (2016) presented a literature review as being an argument in writing that promotes a thesis position through reasoning based on credible evidence found in prior research. Lambert (2012) presents a different definition, presenting it to be a critical study of common knowledge concerning the chosen topic, its connected themes, and all different perspectives provided with regards to the topic. Snyder (2019) finds that literature review is one research technique which, through the summary of previous works, is able to enhance theoretical progress in a real and meaningful way. Theoretical reviews aim to test the prognostic quality of theories that attempt to explain a given phenomenon and are made to determine which theory best describes the nature of said phenomenon.

The methodological approach to this literature review consists of formulating questions relevant to the research objectives, reviewing the literature, observation as well as analysis of information, before presenting findings, and presenting the audience with suggestions.

1.3 The correct form of literature review

There are four main variations of literature review:

• Systematic: The most well-known technique, a systematic review aims to systematically collect, critique as well as synthesize prior research, in order to answer a pre-determined research question. (Lasserson et al., 2019). Reviews of this type address the bias present by making use of transparent and systematic approaches aimed at minimizing bias, in the process gathering findings which are actionable (Grant and Booth, 2009). A work of this type ought to be conducted prior to primary research, so there is not an unnecessary overlap with the body of current existing bibliography.

• Meta-Analysis: A meta-analysis is a quantitative statistical approach where analysis is performed on a number of separate yet innately similar papers or works to provide statistically significant insights (Grant and Booth, 2009); it also assists in reaching conclusions, uncovering patterns and trends, as well as linking findings together.

• Narrative: A narrative review has an aim of selecting bibliography that specifically concerns a research topic (Grant and Booth, 2009). Any work of this form reviews published literature, with a different process for finding works worthy of consideration. This method is aimed at identifying previous findings in the field, allowing for consolidation or development of prior papers, for a state-of-play update, as well as pinpointing areas which have escaped academic attention, but may be vulnerable to personal bias (Grant and Booth, 2009).

• Meta-Synthesis: This method can be characterized as the integration of discoveries from papers performed in a qualitative manner with a view to interpreting findings as well as results (Leary and Walker, 2018), which consists of analyzing as well as synthesizing key components of a given study. It attempts to, through the results, reach new conceptualizations and interpretations, in contrast to meta-analysis, where findings are to be reduced.

This writer found a systematic literature review to be appropriate as it concerns this work. Newer research was preferred, which is a given as commercial use of these vehicles have only come into sharp relief since the turn of the century. However, certain older materials have also merited inclusion to provide background information to the study. This study also utilized the Meta-synthesis technique (non-statistical way to analyze as well as synthesize important components in studies of relevance to research).

1.4 Putting the work into progress

To gather input for a literature review starts with understanding boundaries of one's research work and then conduct searches accordingly to gather quality information as the systematic method is bound to fail if the input is lacking in quality. Finding peer-researched works were of the utmost importance in this author's search. Information was collected from conference proceedings, articles, scientific reports, books, as well as literature reviews concerning the same area of research. Literature databases, such as JAMK's search engine Finna, or the thesis database Theseus were utilized in finding similarly structured works. Additionally, the author has utilized more international scientific databases: ScienceDirect, Nature, ResearchGate, arXiv, Elsevier, MDPI as well. Both Google and Google Scholar were also utilized heavily as they were the most helpful in identifying keywords for easier searches of relevant bibliography. One of the techniques utilized was the backward search, which Levy & Ellis (2006) defined to be searching and studying bibliography referenced to in any given work, with a second level of backward searching occurring provided one makes use of sources alluded to within the initial work. Second-level backward searches have also been utilized within this work. One more maneuver used is forward searching, the exploration of other publications which happen to mention the same article.

The use of drones in addressing global logistical issues is rapidly gaining traction. Major online retailers, the likes of Amazon included, have, as of recently, been undertaking demonstration experiments, so before long we will see drones play an increasingly critical role as a transporter of goods via the air.

Although there are still many problems to be resolved and legislation still needs to be crafted to catch up, it is anticipated that the use of drones will help alleviate teething issues such as a shortage of truck drivers and the general worsening of the work environment, not to mention its potential speed advantage over other modes of transport. With such issues in mind, this work aims to examine the existing as well as future uses for drones in the field of logistics, as well as any knock-on effects that these uses may have in the future and the viability of using such devices now.

2 Background information

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2.1 Origin of drones

Drones, otherwise known as unmanned aerial vehicles, perform tasks from mundane to the highly risky. These robot-like aircraft can be found scouring earthquake sites for victims as well as leaving items at your doorstep — and almost everywhere in between.

The first pilotless aircraft came to be in 1916, the Ruston Proctor Aerial Target utilized the radio-guidance mechanism, the brainchild of British engineer Archibald Low. Although his projects had some success, earning him the moniker “the father of radio guidance”, they did not get improved upon in the post-war period, possibly stemming from the British government’s reluctance to accept its cutting-edge nature (Vyas, 2020).

Shortly afterwards, on the other side of the Atlantic, the United States constructed the Kettering Bug, equipped with gyroscope guidance and designed to play the role of an “aerial torpedo” , one to be loaded with explosives and steered into the enemy aircraft. Vyas (2020) noted that although both showed promise in testing, neither were put into combat operations during the war; the Ruslan Proctor due to lack of belief and the Kettering Bug due to lack of time. The two aircraft would prove to be the precursor to cruise missiles, which operate in the same vein as UAVs. Considering the 20th century saw the parallel development of both, these weapons are nearly indistinguishable from one another in their origin stories; both play important roles in our lives today.

Returning to the theme of drones, it is a fact that the first recoverable UAV on record is the de Havilland 82 Queen Bee, which came to be as a target aircraft for realistic, shoot-on-sight gunnery training for members of the Royal Navy. If the planes managed to survive the practice sessions as intended, they would be retrieved for re-use. These biplanes first took flight in 1935 and possessed wheels (airfield departure) or floats (maritime usage), they were also able to “reach altitudes of 17,000 feet and cover distances of up to 300 miles at above 100 miles per hour” (De Havilland Aircraft Museum, n.d.).

It is thought the term 'drone' started to come into widespread usage around this time, inspired by this model. The aircraft's function offers a clue as to the connection to its new name: it is an extension of the "bee" meaning. Drone bees are bulkier than worker bees, departing the hive and swarming in autumn time. Additionally, it has also been noted that these workers do not fulfill any other role other than to mate with the queen bee before perishing (Merriam-Webster, n.d.).

The similarity to which the drone aircraft bears to its namesake is that they can be viewed both as mindless specimens who could not maneuver and were only driven towards a singular goal, all the while producing a characteristic monotonous hum, which is reminiscent of the other meaning of the term drone.

3 Use cases

3.1 Drones as a means of managing inventory and picking orders

High-bay racking, or tall racking units which make use of all warehouse space from the ground up, is the standard in logistical operations. To ensure uninterrupted goods-in/goods-out movements, workers need to keep a constant eye on stock levels and ensure as few empty shelves as possible. This section is ripe for automation, with drones able to attend to these activities.

Instead of the manual scanning of codes and tracking of storage points, drones are able to attend to these tasks at speed without assistance from larger warehouse vehicles to check upper-level shelves. Drones armed with cameras and scanning technology can capture barcodes before subsequently sending them to a warehouse management system to compare and contrast current inventory levels with targeted figures, thus catching any deviation and inventory shortages. A large drone fleet can operate independently, with occasional manpower to perform tasks based off of the data that has been gathered.

As it concerns inventory checks in more spacious warehouses, stocks can be regularly checked by drones, rendering certain staff duties redundant, thus presenting cost savings in the process.

3.2 Measurements and inspections of large systems

Logistics firms must keep precise records of specialized equipment, real estate, or transit-bound items. Usually, staff members are tasked with inspecting objects for damage or quantifying their proportions, which could prove protracted, particularly in cases of oddly shaped or oversized equipment, and measurements that are missed or overlooked damage can have devastating consequences.

What’s more, certain inspection tasks pose safety risks, whether due to height or quantity of items; drones armed with cameras and sensors can conduct these surveys and checks in a satisfactory manner without endangering staff. Said vehicles which are able to measure large systems and deliveries accurately are invaluable to firms.

3.3 Surveillance and Inspection

Warehouses often store items of significant value. With large areas to be covered, accordingly, many security personnel is needed to monitor for break-ins or damage. Surveillance drones can provide logistical firms with a sense of safety when it comes to securing company grounds.

At present, there is a possibility to pre-program drones to carry out regular patrols of the warehouse at varying heights, with varying hovering intervals and camera angles. In the scenario of there being unauthorized entry, the relevant personnel will receive alerts. If the alarm system is set off, an integrated security system can promptly dispatch a drone on-site. Cutting-edge surveillance UAVs are armed with a wide range of optical technologies, be it infrared imaging, artificial intelligence, or night-sight vision, which makes them an important security asset.

3.4 Advanced air mobility

Last but not least, new developments in sensors and AI-powered vision means that the technical capability of drones within a delivery framework are getting better all the time. As a result of this, manufacturers are exploring the possibility of heavy-duty drones delivering major loads, up to tons worth of cargo.

Heavy-duty UAVs may be of good use in the mid-range, yet they need appropriate takeoff and landing facilities; as a consequence, they can be ruled out as a contributor in logistical operations in urban areas, where there is the most strain on supply chains. This is where interesting new use case is Advanced Air Mobility (AAM) comes in, which is a catch-all term for aircraft automated and run on electricity (FAA, n.d.). This program’s uses consist of Urban Air Mobility (UAM), Regional Air Mobility (RAM), public flights and also delivery missions of large-size goods. Shifting urban traffic from the roads to the airways should help in reducing greenhouse gases, improving mobility, cutting down on valuable work time being wasted due to traffic, as well as provide a fresh approach to time-sensitive distribution of goods or cargo. Introducing drones into civil use could also serve to better and information-gathering and observing processes (e.g., traffic management or collection of personal commuter mobility data). Whilst AAM ostensibly includes both cargo and passenger flights through eVTOL aircraft, this work will be focusing mainly on the usage of UAVs (drones).

Whilst UAM is still in a rather embryonic state, it has the potential to overcome mobility challenges within urban spaces; as an example, the unloading point of goods in city limits creates many unresolved problems: congestion, freight vehicular traffic that could overlap with more populated urban areas, as well as increasing fuel costs for operators.

Even though studies have shown that the advanced air mobility would be less harmful to the environment in rural areas when compared to conventional gas-powered or electric trucks (Park et al., 2018), the reason that Urban Air Mobility is gaining more attention at present than its rural counterpart is that although aircraft delivering cargo or passengers in cities would also prove to be great use in rural areas, the same cannot be said for the opposite. What’s more, once UAM services have come into significant use, they will prove their cost-effectiveness to important stakeholders, resulting in them becoming financially viable sooner, which also helps boost the more rural components of AAM profit-wise.

4 Efficiency

4.1 Factors affecting efficiency

The specific configurations for any given drone differs according to their mission. Gaining a certain level of familiarity with factors of the usage of determined energy would be very important in the design of energy consumption models which prove to have good efficiency. UAV activity is more energy-sensitive compared to more traditional vehicle operations (Cheng et al., 2020). Innate as well as outside factors can have an impact on energy consumption; to provide an example, temperatures and atmospheric density can be linked to battery drainage as well as aircraft lift issues; at sub-zero temperatures, drones cover lesser distances and experience increased operational issues. Also, Tennekes (2009) noted that lower UAV energy usage was detected in the presence of headwinds; this is due to increased thrust from translational lift occurring once the drone has shifted into forward flight. The weight as well as payload of UAVs are, on an individual basis, the most prominent factors impacting their energy use (Thibbotuwawa et al., 2018). Thibbotuwawa et al. (2019) provided, in their work, an examination of drone energy use; the hypothetical scenario provided was that of a drone delivering to three customer destinations to and from a depot. The paper found flight speed and load carried is not linearly correlated to energy use, whilst reconfirming that wind direction has a tangible impact upon energy consumption. The four key factors most impactful as it concerns UAV energy consumption are its inherent composition, environmental factors, drone dynamics, as well as delivery operations (Zhang et al., 2021)

4.2 Suggested strategies for efficiency

In this paper, the efficiency-related works can be placed under the following headings: (1) drone assignment; (2) charging process and recharging location; (3) vehicle routing; (4) fleet size design. A closer look at existing bibliography will be provided for the subjects above in order, with an in-depth view of one or more suggested solutions to be included.

4.2.1 Drone assignment

When it comes to assigning a drone to a given customer, a suitable decision system has to make many decisions regarding which drone to be tasked with delivering the parcel, which is a major roadblock to be overcome when developing optimization techniques to conduct the delivery in as little time as possible, along with more inherent constraining factors, for example battery range limitations and system operating costs. Once the shipments have been received, the system designates one drone on-hand to conduct a delivery based upon the urgency of client orders. To date, only a handful of papers have investigated this specific topic. Grippa et al. (2019) suggested a job-allocation approach to allocate client orders to drones with the aim of minimizing delivery times; it is done according to the principles of queuing theory, with Poisson processes modeling delivery requests for drones' arrival. A pair of task-allocation policy classifications were presented: one termed nearest job first to random vehicles (NJR), based upon client delivery point, whereas the latter is termed first job first to nearest vehicles (FJN), which schedules deliveries according to clients' preferred time of arrival. The FJN approach managed to achieve low expected average delivery times in the case of lighter payloads while still managing to perform well when saddled with heavier payloads. Sawadsitang et al. (2018) devised an approach where suppliers are able to cooperate and establish a pool of resources amongst themselves, meaning they are able to share their fleet with others in order to provide as much service as is possible; once any drone has completed a delivery, it is free to be land in any given designated storage area so long as it belongs to the cooperative network. The presented optimization model views the package-allocation question as a mixed-integer programming (MIP) issue. The battery allocation issue was also discussed in the work of Park and Zhang et al. (2017) with a view towards limiting battery wear-and-tear. Their work contained an algorithm with an ability to seek the most ideal point for battery allocation to services and also compute charging and task dispatching schedules. In addition to this, a scheduling model was formulated to pinpoint when a battery starts or halts its discharge or charge. As it stands, there seems to be precious few short-term assignment strategies that have been presented in order to make autonomous drone-based deliveries more efficient on a real-time basis; services during rush hour, for instance, have always proven to be a challenge for fleet scheduling.

4.2.2 Charging process and charging locations

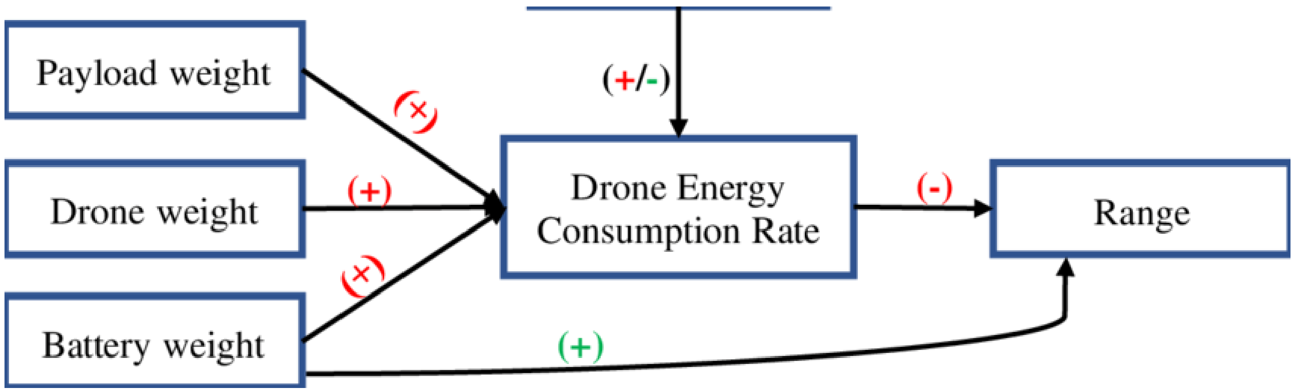


Fig 1. Related factors in energy usage for drone delivery (Zhang et al., 2021)

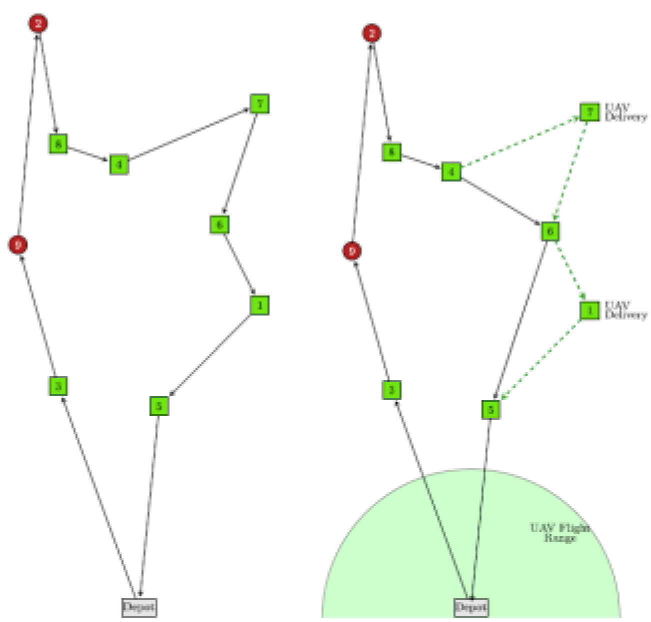
If the flying range for battery-dependent drones is to be extended towards levels more suitable for mass transport, then recharging or swapping infrastructure ought to be on the priority list. With regards to this topic, some of the literature presented charging infrastructure to be used to extend drone delivery coverage in terms of reachable distance. Hong et al. (2018) discussed recharging points for independent UAV-led delivery services, sans trucks, within city limits with a wide network of recharging hubs installed to provide support for drone fleets. The writers presented a coverage location model for the purpose of creating a delivery network which can simultaneously satisfy the most expected demand whilst still aiming to minimize average distance to be covered between depots and charging hubs. This strategy was devised with the help of heuristic approaches, alongside the Greedy algorithm (logical local steps, with a view to approximating rather than pinpointing the globally optimal approach). However, this paper overlooked the hypothetical effects of certain parameters on decision-making (charging station layout, duration of charge, quantity of batteries, drone battery range) on how well UAV delivery services work, those of which more precisely recreate the real-world characteristics of systems. What's more, this paper also homed in on the relocation issue, yet failed to address the issue of assignment. Another approach presented by Yu et al. (2017) to the issue of drone-coverage range was to have the drone get a recharge en route while upon static/mobile recharging stations. The presented algorithm devises an optimal route for the drone to cover a number of delivery destinations whilst dictating the place and time to visit the stations for a (re)charge. Additionally, the algorithm also can determine the routes for unmanned ground vehicles as well as the best landmarks to deploy charging hubs. A trio of different hypotheticals were provided: multiple static charging hubs, one lone portable station as well as a scenario with more than one portable hub. The first two scenarios were resolved through a proposed TSP-based algorithm, with an integer linear programming algorithm presented as a solution to the final scenario. Huang et al. (2020) proposed heuristic optimization deployment and suggested installing recharging hubs in locations around a given urban area for recharging or battery swaps. In this paper, it was considered that any given charging station could gain an uptick in coverage range through simple repositioning. Overall, what is apparent is that mobile recharging stations could prove viable for deployment if the difficulties in establishing communications from a drone to its station can be better understood. What's more, the identification of partner vehicles along with the independent descent of UAVs onto non-static vehicles is calling for additional research and development based on new advances in technology such as virtual sensing, image recognition and artificial intelligence; concerning this, Báča et al. (2019)'s work discussed the UAV's autonomous descent onto a non-static vehicle. The solution presented in the work involved the use of a multirotor platform which is able to process images. An innovative drone state prediction approach, using pictures taken by the multirotor, alongside a predictive trajectory tracking approach allows for the tracking as well as estimation of landing patterns. In order to gain the most accurate ground vehicle state prediction, a rapid as well as clear visual localization of landing patterns was suggested, while placements identified for the provided vehicle were filtered with the usage of a suggested unscented Kalman filter-based approach. It must be noted, however, that modelling the drone following of road vehicles at speed and attempting to predict the movements of mobile stations in the near future would be a tough challenge to overcome.

A different strategy to extend the delivery area of drones was also presented as an answer to the flight-range constraint, and key to it is the utilization of networks of public transport. Much in the same school of thought, Huang et al. (2020) presented a solution to limited flight range: an approach for planning round trips with public transportation networks so that the drone is able to make deliveries to faraway destinations from its warehouse. However, harmonizing drone flight scheduling with attempts to map out transportation networks means modelling of this system is a difficult challenge to be tackled. Additionally, this paper also attempted to address expected delivery time optimization with the help of a Dijkstra-based algorithm, wherein networks of public transport play a supporting role to the delivery system. However, the presented approach might lengthen expected delivery time in comparison with direct deliveries; what's more, the communications technology between drones and vehicles, the way drones are able to gather vehicle trip information through, is still in an embryonic stage as it concerns its use in a logistical sense. Some other works have also studied drones' role in conducting online fast-food deliveries, such as Liu (2019), which presented a model on the basis of MIP to attempt to resolve the dynamic pickup and delivery problem, under the condition that charging hubs for swapping batteries are available to support the delivery system. Pinto et al. (2020) is another work to have discussed the recharging hub deployment question. In that paper, drone meal deliveries were studied in the case of restaurant venues, wherein a system of charging hubs is suggested in order to further drone flight ranges. With a number of constraining factors, a coverage model was presented in order to create the optimal network structure for these hubs in relation to the positioning of clients as well as restaurants. Unlike deliveries of parcels, the e-commerce meal delivery business is faced with major roadblocks in terms of delivery time, especially during rush hour, where if a business keeps any given customer waiting, the prospect of repeat business will worsen considerably; what's more, word of mouth may spread and the business would stand to lose access to new customers (friends, family and acquaintances) as well.

During drone delivery flights to a client in the city, the onboard navigation system might be presented with unfamiliar obstacles in the shape of greenery, trucks, electricity lines as well as skyscrapers. In the face of said obstacles, additional research concerning the collision-avoidance aspect of drones is needed, predicated on artificial intelligence and computer-aided vision to improve precision levels in detection systems. What's more, recently devised artificial intelligence approaches for independently-operating ground vehicles could also prove helpful in addressing difficulties in the operation of autonomous drones, turning them into wholly independent machinery.

4.2.3 Vehicle routing

With regards to the Vehicle Routing Problem (VRP) with drones, most available works have discussed hybrid-delivery systems, a combination of a pair of delivery modes: the more traditional vehicular delivery system and a drone-based equivalent. Most of the time, it is imperative that the aerial vehicle is moved towards the intended endpoint of their delivery by road vehicles. This ensures that at the same time the drone conducts its intended delivery, the truck is able to provide service to those who are out of range of the drone. Meanwhile, the drone can continue providing for clients within its flight range, improving customer experience and enabling a flexible schedule. Murray and Chu (2015), in their landmark work on the routing problem concerning the case of the truck-drone tandem in delivery operations, presented their approach to two questions related to the minimization of travel times for both drone and truck, which makes the ideal condition for better service (Nozick and Turnquist, 2001).



(a) An optimal truck delivery sequence, without the aid of a UAV.

(b) The UAV is launched from a delivery truck, delivering parcels to two eligible customers.

Fig 2. Vehicle routing problem with drone synchronization mechanism (Murray and Chu, 2015)

First, they addressed the flying sidekick travelling salesman question (FSTSP). The setting for the problem is as follows: One truck transports the drone and once it arrives at a client's location, it can send the drone to a different customer destination. Once this delivery has been completed, the truck is responsible for collecting the drone at a different client meeting point. The paper contained a solution involving a mixed-integer linear programming (MILP) formulation in addition to a heuristic approach according to the idea of "Truck First, Drone Second", with truck routes created via the solving of the traveling salesman problem (TSP), before a relocation procedure is applied; it performs a check on every node within the TSP, considering whether or not they are fit to be a landing spot; if the node is confirmed suitable, a change is implemented; otherwise, the node is relocated elsewhere. This approach finds the most optimal routes out of every plausible option. Second on the agenda was TSP with one key difference: there is a relaxing of the synchronization question as truck and drone conduct their deliveries independent of one another, as such, a fleet, rather than a lone drone, is considered in this problem. The heuristic approach presented considers that the drone fleet will be serving every client in their maximum range with back-and-forth trips via the depot, leaving the truck to handle the remainder of the clients. Many assumptions were subsequently presented in an effort to make the model less complex, such as there being only a limited drone fleet, the speed and length of any given drone flight remains consistent at 25 mph, drone preparations are conducted by an individual situated inside the truck, with the depot given a location which, conveniently, is in close proximity to the middle point of between 20-80% of clients. However, the delivery problem is viewed to be stochastic; it also requires a significant contingent of fully autonomous UAVs to be available within the system, which would make modelling an extremely demanding task. Finally, 10-20% of customers were ruled to be drone-ineligible due to excessive package weights. Agatz et al. (2018) presented a different form of the FSTSP which was termed the Traveling Salesman Problem with Drone, but unlike the original it was based upon, made allowances for a drone's departure point and the meeting location with the ground vehicle to be one and the same. In the paper, the objective was presented as seeking the shortest tour for service to be provided to all client destinations via with either. This work contained a Integer Programming formulation along with a number of route first - cluster second heuristics. Dorling et al. (2016) provided an introduction on a unique question called Drone Delivery Problem, with a number of forms: which targets a minimization of total delivery costs and the latter which is aimed at lowering as much as possible total delivery times. For these multi-trip VRPs, deliveries are conducted solely by drones, with energy consumption being given explicitly consideration alongside payload. A MILP formulation was suggested along with a Simulated Annealing (SA) heuristic. To sum up, the presented approaches aim to streamline drone fleet sizes and number of turns taken for the purpose of delivery. The assumption was made in the paper that there is an adequate supply of charged batteries readily available on-hand for the operator to ensure the drone is well-charged before delivery starts and also that there is only one depot (charging station) within range. In real life, however, a delivery company would be facing prohibitive costs if they were to deploy multiple charging and battery-change stations and manage the switch of batteries in-between delivery turns to satisfy daily demand. Both Poikonen et al. (2017) and Wang et al. (2017) gave consideration to the VRP-D, wherein a truck fleet of a similar ilk each are tasked with transporting several identical drones. Either of the vehicles are capable of conducting deliveries, but an UAV deployed from any given truck is to be collected by the same truck later, with a stated goal of minimizing completion times. The authors presented a route-planning approach termed "The Drone Vehicle Traffic Problem", with a view to serving every customer in the least amount of time; they also presented additional examination of a number of doomsday scenarios that enabled them to obtain theoretical bounds concerning key benefits achieved in time when utilizing drones alongside trucks as compared to trucks as a standalone. Despite this, the automated descent of UAVs onto a ground vehicle, a major roadblock, was not discussed in this work.

Schermer et al. (2018) presented two heuristic-based solutions to the VRP-D that Wang et al. (2017) highlighted, which have two key stages: initialization and optimization. The authors selected for the initialization stage a route-first cluster-second approach, itself consisting of two parts: the creation of one large TSP tour that reaches all clients, before it gets broken down into a number of practical segments which corresponds to available fleet size. The optimization stage, meanwhile, consists of a number of local search moves. What differentiates the two solutions is that the two-phase heuristic overlooks drones at first before reintroducing them in the latter phase, whereas the single-phase heuristic, has the drone already in place prior to the beginning of the improving phase. The authors concluded that the two-stage heuristic is the optimal choice.

Ham (2018) was the first to study the collaboration between a truck fleet and a drone fleet with delivery-pickup synchronization within a multiple-depot arrangement. Once any given drone has completed its intended delivery, it could move on towards a new location for pickup, or, alternatively, it can return to depot to conduct a fresh round of deliveries. This is preferable to the integration of fresh drone tasks, such as collecting returned parcels, which demand further extensions of drone flight range, which make the modelling of delivery systems very challenging. Drones and trucks are to operate independently and need to begin as well as finish their routes at the depot, with the aim of minimizing completion times. The paper also presents a multi-depot variant, with an objective of minimizing makespan; the solution presented is a constraint programming formulation, optimized with the help of variable ordering heuristics. Additionally, Wang and Sheu (2019) addressed VRP-D in a real-life scenario through the utilization of an arc-based (later route-based, due to large numbers of constraints) model, as well as the devising of a branch-and-price algorithm. With most of the bibliography defaulting to a limited client base as assumption, the authors' implemented their chosen methodology to a major system which was comprised of, among others, multi-drones and trucks, and a handful of clients receiving service.

4.2.4 Fleet dimensioning

When it comes to dimensioning of fleets, the existing literature has been concentrating on approximating fleet sizes necessary to satisfy a pre-determined demand alongside approximating the starting point for the UAV. Troudi et al. (2018) presented an approach that attempts, through the solving of VRPs, to address drone fleet sizes in the context of delivery services. This paper presented a model devised on the basis of a pair of schedule-setting strategies, with one attempting to schedule deliveries whilst keeping flight distances to a minimum; the latter is conducted with a view to reaching a middle ground between distance covered and fleet dimensions. A number of different analytical hypotheticals were suggested with the aim of optimizing fleet costs through the optimization of drone quantities, lessening distances to be covered by UAVs alongside reductions in battery quantities. The paper failed to discuss the battery changing problem for operators (time and place it ought to be conducted). Furthermore, an assumption was made in the study that the battery ought to reach a full charge before every mission, with no consideration to still-available battery life after deliveries, with only a limited set of clients are to receive service within city limits. Grippa et al. (2019) developed an approach to determining fleet sizes which makes use of simulated scenarios as well as queuing theory. The authors presented two planning horizons: longer-term decisions to be made on general depot infrastructure and more immediate ones on drone fleet sizes, both of which impact costs as well as quality of service; consequently, they need to be done in conjunction with one another.

Through this writer's examination of the existing bibliography discussing drone-based delivery systems, a good many issues in delivery have received attention, which is another example of how drones stand to resolve all manner of logistics-related issues, the last mile especially, whilst also being potential agents of change representing the future way of deliveries. A key challenge to the rollout of any drone delivery system within an urban environment, however, is whether existing airspace is capable of handling such heavy air traffic. Regarding this, Doole et al. (2020) presented an approach which approximates the amount of drones in delivery for a typical European urban center, or more specifically in their case, the Paris metropolitan area. Final results from the paper indicate a forecast of an average of more than 60 thousand delivery drones on a hourly basis of smaller-sized items in Parisian skies by the year 2035. A caveat to be applied is that the authors failed to consider the battery charging problem in their work. Petrovsky et al. (2018) indicates that by the year 2050, there will be around 400 thousand UAVs present within the Very Low Level (0-500 feet), meaning there will be present a dense concentration of autonomous drone operations. The success or failure of the system will be contingent on the presence of safe air navigation, alongside decision-making tools and obstacle data analysis approaches, accounting for those closer distances to ground level which go hand-in-hand with added proximity to both man-made and natural obstacles. As such, considerable preconditions were set to make the modelling of this autonomously operating logistical mode simpler within the body of literature studied.

5 Regulatory challenges in the case of Europe

As UAVs have become more ever-present, regulators worldwide are attempting to stay in contact with new usage, capabilities, and technological developments. Commercial UAV regulations vary from one place to another; as such, the changes in regulations around the world, along with technological developments and safety incidents over the upcoming few years should give key insights into whether slow-and-steady or extreme approaches prove to be more beneficial for technology adoption.

When it comes to dangers, encounters between drones and traditional aircraft have been on the uptick as the demand for UAVs has increased. Drone encounter reports have increased dramatically over the past two years, with the United State's Federal Aviation Agency receiving upwards of a hundred such instances for each month. (FAA, n.d.). It is amongst this backdrop that Europe is creating its very own U-Space legislation, a groundbreaking approach created with a view to the provision of safe access to common airspace for unmanned aerial vehicles (SESAR Joint Undertaking, 2017). Many stakeholders have been party to developing the concept: EASA (European Union Aviation Safety Agency), SESAR, member nations' aerial regulatory bodies, private technology firms, and most importantly of all, UAV users themselves. The U-space concept is based upon an ideal scenario where drone rules ''should be proportionate to the nature and risk of the operation or activity'' (EASA, n.d.). Yet there still lie roadblocks to its full and complete implementation.

5.1 Gaps in regulation

The first is how Europe, due to the rush to create legislation in a limited time span, left many gaps to be filled in their work. The regulation, for example, proposes the notion of dynamic airspace reconfiguration, defined as the temporary modification of the U-Space airspace by adjusting the airspace geographical limits; member nations are to decide on their own design for this space. This means that Europe will still be lacking a sensible and common approach for all members. As such, the lone viable stopgap is segregation of airspace – an answer which fails to satisfactorily address safety risks and its subsequent disruptive effect on those who want to operate UAVs. One answer to this issue is the potential introduction of human observers for drone routes outside the usual VLOS, as it allows traditional manned aircraft to enter U-Space, an approach is currently being implemented in the United States (FAA, 2020). The other alternative is to mandate that U-space surveillance systems be able to respond to conventional transponder signals, similar to traditional aircraft for safe and reliable collision avoidance. However, there are downsides to these two suggested approaches as well: Drones are not usually armed with radio equipment specifically for air traffic communication clearance and alerts. Yet if operators do manage this step, they then are faced with a choice between a license to for radio operations aboard the UAV or a ground station license to establish communications with fellow aircraft (EASA, 2017), neither of which are ideal. If drones reach altitudes beyond the primary radar's range, the secondary radar will be unable to spot drones unless without a transponder, which can be prohibitive in cost, at least 200 euros (unmannedtechshop.com, n.d.) and possibly ill-fitting, since their usual dimensions are for manned aircraft. With human observers, it could also be tough to differentiate a drone from a bird, which could lead to mishaps.

5.2 Perception of drones

The second question is how citizens perceive UAVs. A study by Munich Reinsurance, the global leader in reinsurance (Munich RE, 2017), identified invasion of privacy to be the main concern in the case of commercial use of UAVs. Drones within the last-mile result in further risks to privacy, fueling concerns from clients that commercial operators might have ulterior motives (Scharf, 2019). Tech firms' information collection approaches have caught the eye of regulators before (CBS, 2020), which portends adverse developments which could result in further loss of trust from clients regarding UAVs. Also present is the risk of annoyance, through the drone's signature buzzing noise or whether because of its exotic nature in everyday life (Christian & Cabell., 2017). Further examination of consumers' privacy risks and trust issues towards drone deliveries ought to be a priority for the Union as those two factors could prove massive hindrances to adaptation of drones; a failed drone delivery implementation can bring major consequences. Despite a study from the EU's Aviation Safety Agency, interviewing around 3000 citizens in 6 urban centers, finding that most have accepted the introduction of UAVs to their doorsteps, it is still believed that work is still needed so citizens can be trusting of the drone.

6 Greener last-mile delivery

Last-mile delivery can be defined as the concluding phase in the transportation and logistics process; this begins from the moment the product is moved from the final distribution point (a warehouse) up to its arrival at the correct address; it is the most important part in the delivery process and one that promises the most stumbling blocks.

A variety of factors contribute to its high costs; one is the heightened demand for fast and flexible delivery options, which could prove hard to maintain in the cramped confines of the modern city. Prohibitive costs in logistics and transporting of goods could prove a roadblock for last-mile delivery services, or more specifically, small businesses as well as mid-sized firms. Adverse weather events, road congestion and a variety of outside factors could affect how reliable and efficient last-mile deliveries can be. Furthermore, last-mile delivery services also need to adjust to evolving customer expectations, a major challenge in an ever-changing line of business.

Another sticking point in the last mile is the significant amount of emissions originating from traditional delivery methods; fossil fuels still remains the primary global energy source, at 82% (Ritchie et al., 2024), they contribute massively to air pollution and GHG emission that are hugely detrimental to the environment. Emissions from last-mile deliveries can worsen local air quality, especially so in population centers with existing congestion issues. Fuel consumption is yet another challenge, as the inherent instability of fuel prices mean that it is hard for delivery companies to foresee their expenses and allocate resources wisely.

Environmental concerns within the last-mile for drones is a key area of research as it is critical to devise eco-friendly methods for the preservation of existing natural resources; this can manifest in a number of ways, be it trimming emissions, lessening carbon footprint, making deliveries more energy-efficient as well as shifting to more sustainable green energy sources.

Trucks are currently needed to carry drones, supplies and packages to support drone delivery networks; they rely heavily on traditional fossil fuels, which emanate greenhouse gas (GHG). Edenhofer et al. (2015) stated that transportation accounts for 14% of global greenhouse emissions and that 95% of global transportation energy use can be attributed to non-renewable sources.

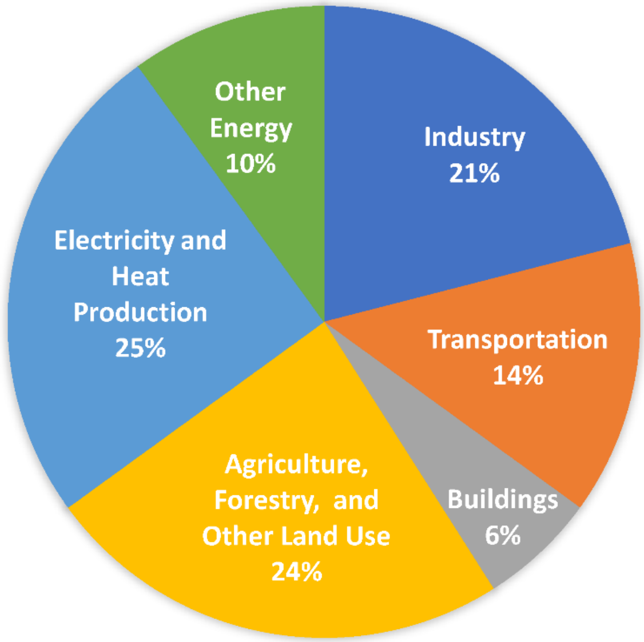


Fig 3. Greenhouse gas emissions for each economic sector. (Edenhofer et al., 2015)

Xiao et al. (2012) hypothesized that a given vehicle's fuel usage is contingent upon weight as well as distance traversed. The authors formulated a simulated-annealing algorithm and demonstrated through experiments that their approach could lessen fuel consumption by an average deviation of 5.35%, in certain cases up to 10% with on average of 1.94% uptick in average distance travelled. Kuo and Wang (2011) addressed The Green Vehicle Routing Problem, a problem that targets lower consumption of fossil fuels through the reduction of the travel distance, speed, and payload, presented a tabu-search algorithm to lower fuel use through the reduction of vehiclular weight. In this work, it was demonstrated that with extra weight inside a vehicle, correspondingly, the more energy, and fuel, is required for it to have movement; this is due to heavy vehicles inducing additional inertia and rolling resistance to be exerted upon them.

Bektaş and Laporte (2011) examined the connection between speeds of travel and fuel usage in the context of heavy-duty delivery vehicles. The pollution routing problem (PRP) in this work involves balancing the operational/monetary cost (driver salaries and fuel costs) with environmental costs of logistics businesses who still operate fossil fuel-powered vehicle fleets. The authors first adopted a discretization strategy for travel speeds, meaning that the vehicles were to be restricted to travelling at individually discrete speeds to be chosen from a predetermined speed set. Their conclusion was that velocities in excess of 40 km/h had an adverse impact on fuel efficiency. The time-dependent pollution routing problem, an extension of the PRP through the study of traffic congestion at its most intense, which puts a limit on the vehicular speeds and increases the level of greenhouse emissions, was first highlighted in the work of Franceschetti et al. (2013). The authors provided a MILP formulation to help reach the best answer to the single-arc version of this issue, before later presenting an optimization procedure for speeds as well as departing times for one vehicle arriving at client destinations in a certain order in congested conditions, which serves as consolidatory work to prior results. Koç et al. (2014) brought attention to yet another variant of the PRP, one termed the Fleet Size and Mix Pollution-Routing Problem, with a hypothetical scenario involving a heterogeneous fleet of vehicles; the authors presented a hybrid evolutionary metaheuristic model as the solution. They performed experiments to highlight the delicate give-and-take between a number of performance metrics, such as general emissions, fixed vehicular costs, distance, driver costs and total costs. The results of their work demonstrated how there are benefits gained from using a heterogeneous fleet as compared to one which is more homogenized.

Dukkanci et al. (2021) presented a with trucks in place as mobile launching pads of drones; it was termed the Energy-minimizing and Range-constrained Drone Delivery Problem. The proposed approach selects portable launch spots from a given list of locations, seeks out flight paths for UAVs to conduct their missions as well as making drone speeds more efficient so they are able to conduct additional deliveries after each charging cycle. The authors established the results of a drone fleet being in parallel operations with a truck lowers the distance to be covered for the truck, thus, reducing total costs by 30.08% (Dukkanci et al., 2021). What's more, in the scenario of a depot as launching pad, the results are not always beneficial for drones as compared to trucks. Chiang et al. (2019) provided research concerning the effect that drones have on greenhouse gas emissions along with the expenses involved in delivery operations. The figures calculated in the paper provide evidence for the assertion that delivery drones when used in the last mile are key to expenses saved via shorter delivery times and reduced fleets. Liu, et al. (2020) conducted a study measuring Hydrogen Fuel Cell Electric Vehicles against conventionally fueled vehicles; the results showed that a vehicle of said type, even with fossil fuel-based hydrogen as a fuel source, uses 5 to 33% lower fossil-fuel usage, whilst producing 15 to 45% less greenhouse gas emissions in comparison to traditional gas-fueled vehicles.

As the e-commerce industry is undergoing major expansion, both customers and retailers are now capable of mitigating the environmental impact that these orders generate. There are a number of things clients and businesses can do in order to lower these footprints; when it comes to clients, they can do an all-in-one shopping trip and get their buys shipped home accordingly, rather than plastic packaging for each item they purchase. As it concerns sellers, it is imperative upon these vendors to introduce vehicles which run on more renewable energy sources as a means to reducing their carbon footprint; generally, a vast majority of deliveries are suitable for drones to handle (Guglielmo, 2013). As such, drones can deliver such packages and lessen the need for trucks, delivering major benefits to the environment; after all, it has been shown that drone energy consumption is 94% lower than that of a delivery truck (Rodrigues et al., 2022).

7 Case studies

7.1 Hamburg's Medifly

One major metropolis seeking answers to their ongoing challenges with the help of UAVs is Hamburg, Germany; in a scenario familiar with urban centers the world over, Hamburg is coexisting with issues caused by growing urbanization based on automobile-centric planning: increasing volume of commercial traffic, gradually increasing demand for mobility, a scarcity of physical space to handle transportation flow, as well as an aging population which is causing extra strain on its healthcare system, but to name a few.

Still, Hamburg is home to the world's third largest civil aviation location (Hamburg-Aviation, n.d.); with its inner-city airport as well as a vast array of healthcare centers, this city is a highly important proving ground, an open-air laboratory for UAM technologies in cities.

The setting for this in Hamburg is as follows: Medical interventions usually demand extraction of samples, and, consequently, for these to be sent to outside laboratories for diagnosis. This logistical process usually lasts several hours; as such, what is of utmost importance in these pressing scenarios is to transport these samples to location at speed and in time. However, congestion hinders this process. Drones, in this specific example, can help contribute to bypassing the usual congestion that might be present with road vehicles, whilst enabling better flow of goods to customers (UAS Vision, n.d.).

Figure 4.

Medifly drone.

Note. [Medifly drone], by D. Reinhardt, 2020, (https://medifly.hamburg/en/test-flights/).

The “Medifly Hamburg” project utilized a specialized drone (weight of 10 kilos) to conduct flights between the German Armed Forces Hospital in Wandsbek-Gartenstadt and Saint Mary’s Hospital in Hohenfelde (Antunes, 2020). The drone traversed the five kilometres between the two places, carrying medical samples at an altitude of 75m, completing the trip in only 10 minutes, 5 minutes quicker than an ambulance. The drone reached speeds of 40 km/h during the session, with a capability to reach 80 km/h in real world operations. The energy needed for manufacturing of the device is equal to a one smaller-sized refrigerator’s usual consumption level, whilst the data processing equipment required the energy equivalent of a standard laptop (EU Urban Mobility Observatory, 2023).

7.2 France and TINDAir

Two more places that have also demonstrated a readiness to embrace the future of UAM are Bordeaux and Toulouse, home to TINDAiR, short for Tactical Instrumental Deconfliction and In-Flight Resolution, a project whose aim was to make sure that cohabitation with other users of airspace is achieved safely; it resulted in a number of major exhibition events of the capabilities of UAM, with special attention paid towards managing conflicts between a variety of flight platforms.

Tests were conducted in the period from December 2021 to January of the following year in Toulouse; their main objective was to make sure communications between aerial platforms and the ground station could be maintained in an actual flight scenario. Some more innovative aspects of the project in were to be put to the test prior to official demonstrations. The TINDAiR consortium held a number of tests in both French cities with a vast array of representative as well as operational usage scenarios, showcasing both manned and unmanned aircraft. (EU Urban Mobility Observatory, 2023)

The operating scenarios concerned all manner of urban demands from emergency medical transports to both cargo-only as well as passenger flights. Cases of emergency use were also tested, such as one of overload in air traffic, or an emergency landing in the instance a drone fails to respond correctly. There were also tests on a variety of aerial vehicles, all possessing distinct capabilities and automated degrees. (SESAR Joint Undertaking, 2022)

TindAIR's integration test sessions managed to demonstrate a good working connection between drone and ground station, which remained in excellent condition and proved capable of transferring critical data. As it concerns the radio link between the vehicles and their supervisors, the 9 km range was achieved almost flawlessly, and the overwhelming majority of the data sent was received and processed in no more than 2 seconds (TindAir, 2022).

Demonstration results mean that the TINDAiR system is able to spot and defuse conflicts both strategically and tactically, handle emergency situations through the detection of precarious scenarios and ability to command the appropriate emergency landing orders, and maintain key services (traffic control for drones, identifying of networks, weather updates as well as geo-awareness) (TindAir, 2022).

8 Conclusions

Ever since the dawn of the new millennium, commercial interest as well as the public gaze more and more focused on the drone in a civilian sense, rather than its defense roots. This has enabled the rapidly growing usage of drones, enabling whole drone-based economies to take shape and grow (Grand View Research, n.d). In that sense, drones have become an ancillary addition to logistics, performing tasks seen prior as 'dull, dirty, and dangerous' (Bartsch et al, 2016). This has helped fuel the emergence of the business model of delivery of consumer goods. From this review, it can be observed that UAVs could be the best choice for last-mile deliveries in cities, with significant gains from both an economic sense and environmental sense, as shown in Dukkanci et al. (2021), Rodrigues et al. (2022) and Chiang et al. (2019). The impact of UAVs within the supply chain is much less environmentally harmful than traditional fossil fuel vehicles, as they are usually operating on electricity. There remains significant opportunity for development in making drone delivery leaner still, as shown by the many solutions to the four main issues of efficiency stated above. As an example, the ideal number of drones to be located at each depot is one key part within the assignment issue which ought to gain additional attention from researchers in a theoretical framework. Additionally, most studies selected for review were conducted based on the condition of there being a limited set of drones as well as clients, whereas real-world rollouts would be magnitudes larger, thus, making it vastly more difficult to model and predict their behavior. What is more, most formulas and optimization techniques within the models in the literature were based on randomly generated data, as researchers have to overcome the difficulty in finding real numbers on UAV characteristics, and solid figures on customer location and demands in prior years. As a result, the introduction of real data (from model simulations) from manufacturers and logistical firms could result in major contributions as it concerns both industrial applications and academic ones. Finally, further research would greatly support strategic decisions, be it on the planning or engineering sector, including cost optimizations; charging hub location optimization; drone allocation strategies; scheduling optimization for deliveries. A number of challenges under the engineering umbrella could see resolution through further research, e.g., UAV tracking trajectory of mobile stations as well as identification and self-determined drone landings upon recharging hubs.

Sustainable practices in route planning, optimizing the distribution of goods, battery management will have pronounced effects on the environment at-large, yet they are mostly still hypothetical at this moment, due to difficulties in accessing real, hard data. Regardless, the prior bibliography concerning the pollution-routing problem (PRP) have shown the way for existing practices to be overhauled in a significant manner in order to protect our natural ecosystem.

What is also apparent is that the regulatory framework, in this case the EU's U-space concept, is still in a rather nascent stage, with constant changes being made, understandably, to keep pace with a rather new and always-evolving technology, creating some confusion among its members, which in turn has given way to a lack of harmony in implementation amongst member states. This indicates there is a ways to go before a fully harmonized approach is possible on the continent. In the interim, segregated airspace is the answer, which is not ideal as operators need to overcome bureaucratic and financial barriers and normal aircraft are now also restricted in their movements. Finally, despite public acceptance of drones being high in Europe, privacy and security remain major concerns. The registration process requires sensitive data like names, birthdates, addresses; as such, there ought to be safeguards in place to ensure this data stays protected. Despite the problems mentioned above, a common approach is possible to ensure Europe lives up to its pioneering role in regional drone regulation, in the process providing a blueprint for other regions in aiding and facilitating the foundations for the upcoming UAM revolution.

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