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Drone-as-a-Service for last-mile delivery: Evidence of economic viability

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ABSTRACT

An economic viability of last-mile delivery via drones is assessed, offering an investment model comparing traditional motorcycle delivery to drone-based alternatives. Two drone investment options — purchase or lease (Drone-as-a-Service) — were introduced. The proposed last-mile delivery model considers capital and operational costs, calculating Net Present Value(NPV) and Return of Investment (ROI) per investment scenario. For the operational expenses, the energy consumption model for the motorcycle and the drone is formulated. Furthermore, three wind settings — low, medium, and high wind — were examined to account for environmental factors impacting drone performance. The investment model has been formulated and then validated considering the relevant literature as well as realistic information collected during a semi-structured interview with industry experts The findings affirm the financial feasibility of adopting drones for last-mile delivery. Drone-as-a-Service emerged as a more profitable choice, exhibiting improved NPV and ROI over owned drones or motorcycle delivery. Emphasizing DaaS in the investment model presents a probable scenario for the logistics industry, easing their transition to drone technology. Evidence of DaaS viability is of value since it could convince risk-averse distribution vendors to adopt drone delivery.

1. Introduction

Business-to-consumer (B2C) e-commerce refers to the process of selling goods and services between a business and end-users over the Internet (Zhou et al., 2022). B2C e-commerce is becoming popular in many markets and the global market size reached US$ 4.4 Trillion in 2022 and is expected to expand at a CAGR of 18.95% by 2028. Selling products online raises noteworthy supply chain issues related to traditional commerce; one that has attracted the focus of both academics and practitioners is last mile delivery (LMD) (Zhou et al., 2022). Last-mile logistics, also known as last-mile delivery (LMD), focuses on the final leg of the delivery process, which occurs when the parcel is handed off to the customer (Mangiaracina et al., 2019). It is often the most expensive and time-consuming part of the delivery process and it can be challenging due to a variety of factors, such as traffic congestion, narrow streets, lack of parking, and delivery restrictions in certain areas (Lim et al., 2018).

Drone delivery is on the verge of becoming a viable option on a worldwide scale. This technology has grown in prominence in recent years because to its potential to transform the logistics business by delivering quicker, cheaper, and more efficient delivery alternatives. Drone delivery is especially beneficial in situations where traditional modes of transportation, such as vehicles or trucks, are limited, such as in rural or isolated areas, or where traffic congestion is a big issue. It can also be used to bring medical supplies to disaster-stricken communities (Alwateer and Loke, 2020). It is predicted that, in 2026, more than one million drones will be carrying out retail deliveries, up from 20,000 today (Gartner, 2020). Several businesses are already making use of this growing sector, such as Amazon (Department, 2023), Flytrex (Flytrex, 2024), UPS Flight (UPS, 2024) and DHL (DHL, 2024).

Apparently, distribution stakeholders have started to explore drone delivery since it appears to have many benefits. However, many logistics companies are skeptical of the technology because they are hesitant about the upfront investment of purchasing the drone itself, as well as of the hidden costs it may bear. They consider it as a new innovative delivery means for which there is not extensive, valid evidence of its capability to serve last-mile deliveries in realistic conditions of urban areas. Hence, it is no surprise that, in recent years, Drone-as-a-Service is introduced and increasingly been used in various sectors, and the supply chain is one of them.

D*rone-****as****-****a****-****S****ervice (DaaS) is a financial leasing model that has been introduced in the market (Alwateer and Loke, 2020), which enables businesses to avoid investing in drone equipment and paying for training their own employees. It offers cost-effectiveness since DaaS providers offer flexible pricing models and enable businesses to pay for services according to their requirements. DaaS providers are third-parties companies that can provide drone services for logistics

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companies, leasing technical infrastructure such as the drone itself, drone stations, power stations, and pilots. It also comes with all the software frameworks and services that are installed on the infrastructure's parts, such as functions and certificates that are specific to each application (Alwateer and Loke, 2020). Commercial Daas providers are Zendrone (skroutz, 2023c) and Exabotix (skroutz, 2023a). This research emphasizes on the viability of drone-as-a-service in last-mile delivery and proposes an investment model that assesses traditional delivery (with motorcycle) and modern delivery with drone. There are two options of drone investment evaluated, that is to purchase a drone or lease one (Drone-as-a-Service). Acknowledging that energy consumption is an important operational cost in drone delivery service, we formulate a last-mile delivery drone energy consumption model based on the literature. The proposed investment model considers the capital and operational expenses of each delivery investment (motorcycle, owned drone, DaaS) and assesses its viability in terms of Net Present Value (NPV), Return of Investment (ROI), and also calculates the break-up point. We also examined three wind conditions-low, medium and high wind-to account for environmental factors affecting drone energy consumption. Finally, we apply the proposed model and, thus, validate it. The parameters of the model are populated based on the relevant literature and an interview with a drone pilot and trainer and a courier employee.

The findings when applying the model showed that adopting drones for last-mile is a financially viable investment. For both delivery options with drone (owned and as-a-service), the NPV and ROI values reveal that, in 5-year period, the investment in drones is promising and more advantageous than in motorcycles. DaaS is better than investing in owned drones; NPV and ROI values are improved and reaching the break-even point earlier than when we invest in owned-drone or motorcycle investment. Such evidence can encourage distribution companies (even small-medium ones) to adopt drones. They will minimize the risk by outsourcing the drone delivery and select Drone-as-a-Service. Alike, DaaS providers can utilize such results to grow their market share and convince skeptical delivery stakeholders that DaaS is feasible and does not carry the risk of drone purchase.

The rest of the paper is structured as follows: Section 2 presents related work, whereas Section 3 summarizes this study's approach. Section 4 describes the last-mile delivery energy consumption model for drone and motorcycle, whereas Section 5 introduces the last-mile delivery investment model. Section 6 presents last-mile delivery investment model application and validation, and finally, Section 7 discusses the findings and concludes this research.

2. Related work

Over the last few years, the last-mile delivery industry has experienced tremendous growth. According to Gartner, the global last-mile delivery market size was valued at $40.5 billion in 2021 and is anticipated to generate $123.7 billion in 2030 (Gartner, 2022). To a great extent, consumers use computers and smart devices to place their orders for delivery to the residence. Furthermore, COVID-19 has reshaped last-mile logistics and created new trends in the industry (Lindqvist et al., 2022). Drone technology is considered a disruptive last-mile delivery option, and even though its commercial use is currently limited, a continuous increase in the near future is anticipated, and it has found new momentum since the COVID-19 pandemic and lockdowns (Kiani Mavi et al., 2022). Globally, e-commerce giants like Amazon and Walmart have already been experimenting in using drones to access rural and isolated areas.

Researchers have discussed how technology can improve supply chain efficiency (Dong et al., 2021), consumer acceptance (Osakwe et al., 2022) and environmental sustainability (Figliozzi, 2020). Several works have presented last-mile delivery models implemented by parcel lockers (Peppel and Spinler, 2022), electric vehicles (Muñoz-Villamizar et al., 2019) and drones. The current work studies drone last-mile delivery and emphasizes on drone-as-a-service meaning that logistics companies outsource delivery in drone vendors and do not have their own drone fleet.

Drones are applied to a wide range of businesses serving different purposes, including agricultural (Ahirwar et al., 2019), law enforcement (Barrows, 2021), surveillance (Gohari et al., 2022), and emergency response (Wankmüller et al., 2021). However, they are considered to be a challenging option for delivering products to consumers, particularly in the last-mile of the supply chain. As a result, scholars have been exploring drone last-mile delivery through multiple research lenses.

Consumers' perceptions of and intentions to adopt drones for last-mile delivery (Merkert et al., 2022; Chen et al., 2022; Hinzmann and Bogatzki, 2020), drone routing problems (Rojas Viloria et al., 2021; Poikonen and Campbell, 2021) and impact of drone delivery on sustainability (Rashidzadeh et al., 2021), are the main research topics scholars have been interested in. This research considers the investment in drones for last-mile delivery and assesses the economic viability of such investments. This is a vital question for logistics industry, since investment assessment is a prerequisite for any investment, especially when new innovative means are explored.

In Borghetti et al. (2022), authors explored the viability of drones for last-mile delivery in the city of Milan in Italy. A survey was conducted to assess consumer attitude towards drones in last-mile delivery. Based on the survey results, a last-mile delivery service was proposed and, also, a financial analysis was carried out to evaluate the costs and the benefits for a firm that would adopt the proposed service. Results suggested that drone last-mile delivery could be profitable for the firm. Moreover, scholars in Sudbury and Hutchinson (2016) introduced a cost–benefit analysis of the Amazon Prime Air drone delivery system. Prime Air system was modeled for Chattanooga, TN. The model took into consideration FAA regulations, logistics, drone specifications, and attempted to predict how would Amazon perform drone delivery. According to the paper findings, the benefits and possible revenues would outweigh the operational cost of the system, since a third in cost per package delivered was saved compared to ground delivery. In addition, in D'Andrea (2014), the operational costs of a drone were examined, calculating the average energy cost per kilometer and comparing with a vehicle delivery, and it seemed that drone solution was more advantageous.

Moreover, in Kostrzewski et al. (2022), they compared modern (civil drones, or smart bikes) with conventional last-mile delivery options. Multi-criteria decision analysis (MCDA) was implemented to develop a comparison model that rated last-mile delivery options from the most important to least important. Based on the results and multiple criteria, such as safety, economy, laws and regulations and operation time during delivery, payload civil drones or smart bicycles were ranked higher than conventional options. In addition, the modern delivery options appeared to contribute to the operational expenses reduction. In Baldisseri et al. (2022), authors introduced a truck-drone joint delivery model, discussing a economic analysis based on the total cost of ownership methodology. Based on the results, truck-drone option offered significant emissions reductions, whereas its cost is highly influenced by the drone automation.

Finally, in Aurambout et al. (2019), researchers proposed a modeling approach that uses high-resolution population and land-use data from throughout the EU to determine the probable ideal site of drone-beehives based on the economic viability criteria. Four different scenarios were conducted, estimating the number of Eu28 citizens that could benefit from the drone last-mile delivery service and presenting the economic viability threshold for each scenario.

This study introduces a last-mile delivery investment model that assesses traditional delivery (with motorcycle) and modern delivery with drone. This model evaluates the economic viability of the investment including capital and operational expenses. The model considers the expenses of drone operations, i.e. mainly the amount of energy they

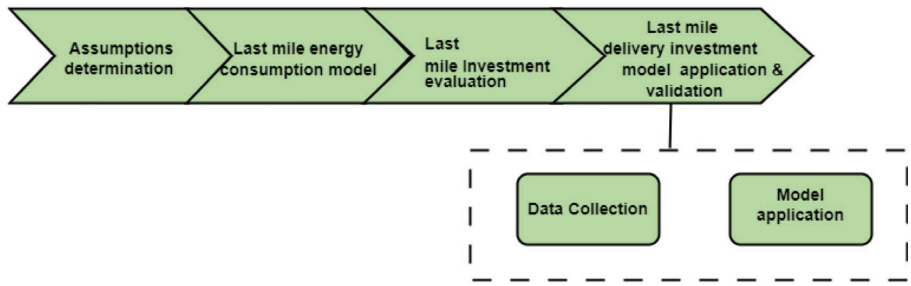


Fig. 1. Research approach overview.

consume during delivery. We highlight that our investment feasibility model investigates drone delivery in two alternatives, that is to purchase a drone or lease one (Drone-as-a-Service). DaaS has been already studied in other fields, such as agricultural (Baimukhamedov et al., 2021), surveillance (Loukinas, 2022), and healthcare (Liu et al., 2019), but, has not been explored for last-mile delivery purposes. We chose to include the DaaS option in our model since we believe that logistics organizations would be risk-averse to purchase their own drones, but it is realistic to lease drone delivery services.

To sum up, we intend to answer the following research questions:

RQ1 How can we formulate a last-mile delivery investment model that assesses the economic viability of drone delivery versus the traditional one (with motorcycle)?

RQ1.1 How can we formulate a last-mile drone delivery investment model that assesses the economic viability of two alternatives of drone delivery — with owned drones or leased ones (Drone-as-a-Service)?

RQ2 Is drone last-mile delivery investment more economically viable than motorcycle last-mile delivery?

RQ2.1 Is Drone-as-a-Service last-mile delivery investment the most economically viable?

3. Research approach

To answer the above research questions, we followed the next research steps:

- **Assumptions determination**: Based on studies of the literature (Kirschstein, 2020; Rashidzadeh et al., 2021; Zhang et al., 2021), we form the key assumptions behind the proposed last-mile delivery energy consumption model, as well as the investment model.
- **Last-mile delivery energy consumption model**: Based on the available literature, we propose a last-mile delivery energy consumption model for drones; and the respective model for motorcycles where we calculate fuel consumption.
- **Last-mile delivery investment model:** We formulate the investment model for: drone that a logistics company has bought (owned-drone) or lease from Drone-as-a-Service providers (DaaS); and motorcycle delivery. The model considers the monetarized expenses (CapEx, OpEx) and positive cash flows, and, then, calculates Net Present Value (NPV), Return of Investment (ROI) and break-up point per investment.
- **Last-mile delivery investment model application and validation:** We apply the investment model and simultaneously we validate it.
  - **Data Collection:** Data collection in order to assign values to the predefined parameters of the model.
  - **Model application:** Model application and calculation of NPV, ROI and break-up points for the three delivery alternatives.

The following sections detail our research approach that Fig. 1 depicts.

4. Last-mile delivery energy consumption model

Here, we present the last-mile delivery model that considers the number of the delivery points, the delivery distance, energy specifications for the delivery means, and provides the energy consumption of the delivery mean and the corresponding cost. We need to formulate energy consumption per delivery means (drone and motorcycle) towards proposing the last-mile delivery investment model.

More specifically, the proposed model is for an urban city, assuming that we have a delivery zone of radius r and the depot is located in the center of the delivery area. Drones and motorcycles are the distribution means as presented in Fig. 2.

The proposed model has been formulated based on the following assumptions:

- Drone performs one-to-one delivery. Namely, it travels to each delivery location, drops the parcel and, then, returns empty to the depot.
- Shipping operations between the depot and the final destination have been only taken into account.
- The drone's flight distance is the Euclidean distance between the depot and the delivery point and the maximum euclidean distance equals to radius r.
- For motorcycle delivery, the network distance is adopted, which indicates the actual distance between the depot and the delivery points.
- Depending on the battery range, drone is capable of doing several one-on-one deliveries (Rashidzadeh et al., 2021).
- Drones' energy consumption is independent of altitude, but the amount of carried cargo influences energy consumption (D'Andrea, 2014).
- All delivery points are inside the predetermined delivery zone.
- Drone delivery would concern mostly low weight payloads, approximately 2 k (Aurambout et al., 2019).
- The utilized usable drones use cutting-edge control technology, GPS and cameras and can fly in the sky with full network connectivity capabilities.
- Drones can fly over buildings and mountains so, the impact of obstacles is not taken into consideration (Aurambout et al., 2019; Rashidzadeh et al., 2021).
- The selected drone is equipped with LiPo batteries, which are the most often used drone power source. The advantages of this power source are their small weight and the ability to store large amounts of energy (Baronti et al., 2011).
- Motorcycle performs one-to-many deliveries. It travels to each delivery location, leaves the payload and then continue its route.
- Motorcycles deliver half of the deliveries in the first four hours, returns to the depot and delivers the remaining ones in the following four hours (Seghezzi et al., 2022).
- For comparative reasons, the motorcycle will also deliver low weight payloads.
- Drone and motorcycle routing is not performed.

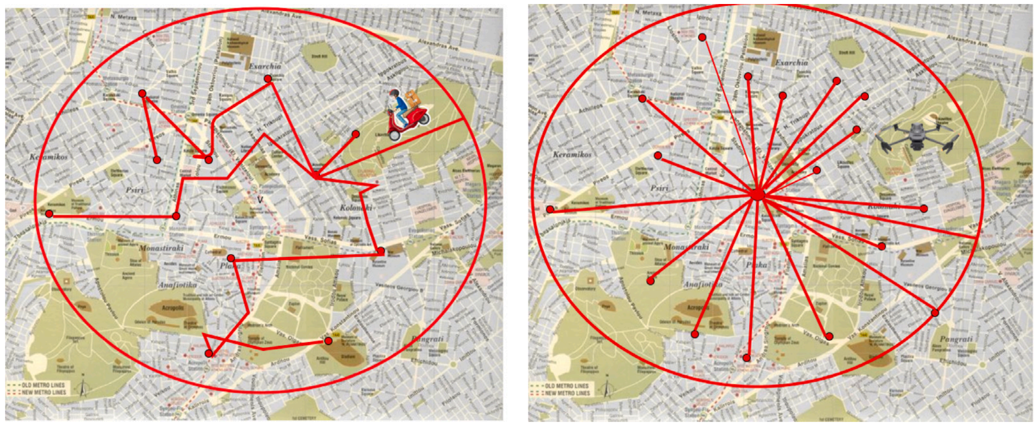


Fig. 2. Motorcycle and drone delivery zones.

Fig. 3. Schematic description of and head/tail wind setting.

- Delivery routes are served only by drone or by motorcycle. Mixed distributions from both drone and motorbike are outside the scope of this study.
- Wind and traffic conditions do not change during a trip (Kirschstein, 2020)
- The drone flights towards the delivery point facing head wind and returns with tail wind. Kirschstein (2020) and D'Andrea (2014)

4.1. Drone last-mile delivery model energy consumption model

The primary factors influencing drone energy consumption can be grouped into four categories: drone design, environmental conditions, drone dynamics, and delivery operations. Drone design factors include the weight and size of the drone, battery attributes such as weight, size, and energy capacity, power transfer efficiency, maximum speed, and payload capacity. Environmental factors encompass elements like wind conditions and gravitational force. Moreover, drone dynamics factors involve travel speed, motion, acceleration and deceleration, angle of attack, and flight altitude. Lastly, delivery operations factors cover the weight and size of the payload, "empty returns" (i.e., returning without the payload after a successful delivery), the number of deliveries per trip, the delivery mode, and the size of the service area (Zhang et al., 2021).

Our proposed energy consumption model incorporates the factors mentioned above. Specifically, the drone flights towards the delivery point, drops the parcel and, then, returns empty (without the mass of the carried payload) to the depot. A head/ tail wind setting is selected, as shown in Fig. 3, where tail wind supports the drone on one leg which reduces energy demand, while head wind increases the drone's energy demand on the other leg. Head wind is assumed on the first leg, whereas tail wind is considered on second one (Kirschstein, 2020; D'Andrea, 2014).

Below, we outline the key parameters of the model and present the formulation of the final model.

- m_d :drone mass(kg) including battery, Figliozzi (2017)
- payload mass $M_l = [m_{l_1}, m_{l_2}, m_{l_3}, \ldots, m_{l_n}]$: mass of each $1..n$ payload carried.
- $D = [d_1, d_2, d_3, \ldots, d_n]$: euclidean distance of each $1..n$ delivery location from the depot, assuming that drones conduct one-to-one delivery to n delivery locations in a 8-h shift.
- u : constant velocity travel speed [m/s]
- $\theta(s)$: lift-to-drag ratio of drones
- $u_{air} > 0$: head wind air speed [m/s]
- $u_{air} < 0$: tail wind air speed [m/s]
- v: ratio of air wind to airspeed
- η: battery's total power efficiency (unit-less)
- p: power consumption of electronics
- E_d : Cumulative drone energy consumption for n one-to-one deliveries (joules)

Based on D'Andrea (2014), Eq. (1) provides the drone's total required power to serve all n delivery points. It estimates the actual cumulative power E_d consumed when a drone performs n one-to-one deliveries

$$E_d = \sum_{i=1}^{n} [\frac{d_i}{1-|v|}(\frac{m_d + m_{l_i}}{370 * \theta(s) * \eta} + \frac{p}{u}) + \frac{d_i}{1+|v|}\frac{m_d}{370 * \theta(s) * \eta} + \frac{p}{u}] \tag{1}$$

We assume all payloads share the same weight $m_{l_1} = m_{l_2} = \ldots = m_{l_n} = m_l$ and all delivery locations are sample from a normal distribution with $\bar{d}_{mean}$ and a standard deviation of 2 km. Therefore we have Eq. (2)

$$E_d = \sum_{i=1}^{n} [\frac{d_i}{1-|v|}(\frac{m_d + m_l}{370 * \theta(s) * \eta} + \frac{p}{u}) + \frac{d_i}{1+|v|}\frac{m_d}{370 * \theta(s) * \eta} + \frac{p}{u}] \tag{2}$$

Depending on the battery range, the drone can make multiple one-to-one deliveries. When the capacity of the battery is inadequate for providing the needed power, the battery is swapped and drone distribution continues, while the drained battery is recharged. Fig. 4 illustrates a general overview of battery swapping.

4.2. Motorcycle last-mile delivery fuel consumption model

Here, we describe how we formulate the model that calculates the fuel consumption when a motorcycle is the delivery means. Essentially, here the energy is provided by the fuel whereas in the drone by the battery.

In a 8-h shift, motorcycle serves n delivery locations and delivers one parcel in each location. We consider that motorcycle's travel distance is the network distance. Network distance is the shortest distance between two points using a transportation network (Kim et al., 2013). Fig. 5 highlights the difference between the network and Euclidean distance.

The ratio of network to Euclidean distance, known as circuity factor (Kim et al., 2013), is presented in Eq. (3) and approximates actual travel distances. For motorcycle delivery, the network distance between the delivery locations is estimated by multiplying Euclidean distance to a typical circuity factor of a urban city (Park et al., 2018).

$$cf = \frac{NetworkDistance}{EuclideanDistance} \tag{3}$$

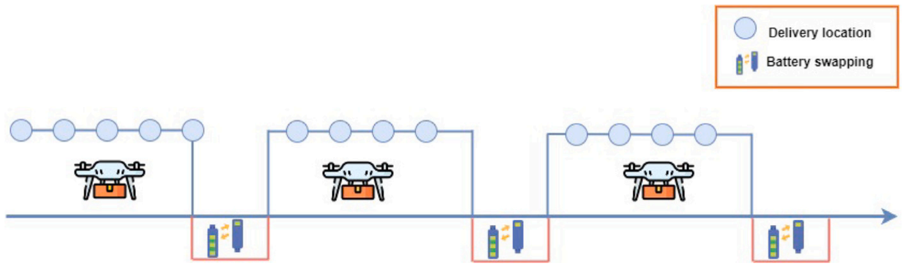


Fig. 4. Battery swapping.

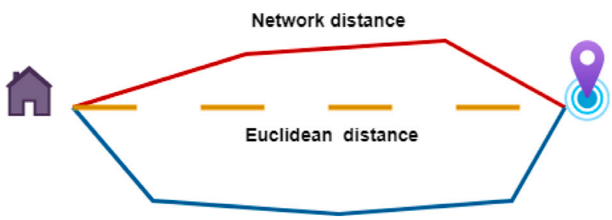


Fig. 5. Euclidean distance vs. Network distance.

The main parameters of the motorcycle last-mile delivery model are presented below.

- cf : circuity factor of an urban city.
- $ND = [nd_1 = cf * d_1, nd_2 = cf * d_2, \dots, nd_n = cf * d_n]$: network distance between deliveries points, assuming that motorcycle conduct one-to-many deliveries to n delivery locations in a 8-h shift.
- c_{fuel}: fuel consumption [lt/km]
- Em: the total required fuel consumption of the motorcycle to supply all delivery points (lt).

Based on Chen et al. (2003), the total required fuel consumption of the motorcycle to supply all delivery points is denoted by Eq. (4). For comparative reasons, the motorcycle fuel consumption model follows the specs of the drone model. Specifically, All delivery locations are sample from a normal distribution with $\bar{d}_{mean}$ and a standard deviation of 2 km.

$$E_m = c_{fuel} * \sum_{i=1}^{n} nd_i \tag{4}$$

5. Last-mile delivery investment model

The ultimate goal of this study is to formulate an investment model and, then, assess the economic viability of last-mile delivery done with drones. The model evaluates an investment in traditional means (motorcycle) or drones. Specifically, for drone delivery, the model conducts investment appraisal for two options: a delivery stakeholder buys drones or pays for drone delivery service (DaaS).

According to investment evaluation studies, first we determine the monetarized expenses of an investment, as well as the monetarized benefits (i.e. the positive cash flows). The monetarized expenses include the cost of the initial investment in capital, i.e. the capital expenses (CapEx), and the operational expenses (OpEx) of the investment starting from Year 1.

Then, we assess the Net Present Value (NPV) (Woods and Randall, 1989) and Return on Investment (ROI) (Friedlob and Plewa, 1996), and break-even points (Powers, 1987) which are established metrics for assessing the viability of investments. NPV of an investment is used to assess whether or not it will be profitable in the long run (Woods and Randall, 1989), and ROI is a performance metric that is used to assess the efficiency or profitability of an investment or to compare the efficiency of many projects (Friedlob and Plewa, 1996). Essentially, ROI shows the percent of the investment cost that is covered by its net cash flows in a specific year. The higher the ratio, the better for the investment. Finally, the break-even point marks the point where total cost and total income are equal, implying that the investment has no loss or benefit (Powers, 1987).

Next, we first present the cost parameters that compose the capital and operational expenses for the three last-mile delivery services (owned-drone, Drone-as-a-Service, owned-motorcycle) that we assess and compare. Then, we provide the positive cash flows gained through the price charged for the delivery. Finally, we model the NPV and the ROI per delivery service.

5.1. Drone last-mile delivery CapEx and OpEx

The following cost parameters compose CapEx when we decide to buy (own-drone service) or lease (DaaS) a drone.

1. **Owned-Drone investment — CapEx**
   - p_d: drone purchase cost [€];
   - p_{bat}: cost of extra drone batteries [€];
   - p_{charg}: cost of battery charger [€];
2. **DaaS investment — CapEx** There are no capital expenses, since the user company will not invest in drone infrastructure; instead it will lease it.

Thus, Eq. (5) calculates CapEx for the owned-drone investment model, while Eq. (6) refers to CapEx for DaaS.

$$CapEx_{od} = p_d + p_{bat} + p_{charg} \tag{5}$$

$$CapEx_{daas} = 0 \tag{6}$$

Respectively, the following cost parameters compose OpEx for own-drone and DaaS investment model.

1. **Owned-Drone investment — OpEx**
   - y: 365 [days];
   - p^a_{sal}: drone pilot salary per year [€];
   - c_{kw}: cost of electricity [€/kwh];
   - t_{charge}: time for battery full charge[min];
   - e_{ch}: battery efficiency;
   - C_{nb}: number of daily battery full charges;
   - P_{nb}: daily battery charge cost [€];
   - C_s: annual service maintenance cost [€];
   - $C_i ns$: drone insurance cost[€];
   - P_c: drone power consumption cost per distance d[€];
   - P_{bcc}: drone battery cycle cost per distance d [€];
   - p_{bc}: battery cost per KWh [€/kwh]
   - l: battery life, in cycles
   - Pd_{total}: Total drone flight cost per distance d [€]

- U_c: Unpredictable maintenance cost: it includes the annual cost of possible damage, for example propeller's damage. Based on the drone pilot interview, it is considered to be equal to the annual service maintenance cost increased by 10%.

2. **DaaS investment — OpEx**

- C_{dl}: Drone leasing cost per month [€];
- C^a_{dl}: Drone leasing cost per year [€];
- All the aforementioned cost parameters of OpEx for owned-drone investment, apart from drone insurance cost C_ins and annual service maintenance cost C_s. According to the pilot interview, such costs are included in the drone leasing cost.

Thus, Eq. (7) calculates OpEx for the owned-drone investment model, while Eq. (8) refers to OpEx for DaaS.

$$OpEx_{od} = p^a_{sal} + C^a_{nb} + Pd_{total} + U_c + C_{ins} \tag{7}$$

$$OpEx_{daas} = C^a_{dl} + p^a_{sal} + Pd_{total} + C^a_{nb} \tag{8}$$

Here, we explain how Pd_{total} annual drone flight cost per distance d for a payload m_l is calculated. Essentially, Pd_{total} includes the respective drone power consumption cost, as well as the cost of drone battery cycle cost; and depends on E_d, the drone energy consumption per one-to-one delivery of distance d aforedescribed by Eq. (2). In turn, according to D'Andrea (2014), the cost of battery cycle per distance d and for customer i can be calculated by Eq. (10).

$$P_c = \frac{c_{kw}}{e_{ch}} E_d \tag{9}$$

$$P_{bcc} = \frac{p_{bc}}{l} E_d \tag{10}$$

$$Pd_{total} = y * \sum_{i=1}^{i=n} (P_{c_i} + P_{bcc_i}) = (\frac{kw}{e_{ch}} + \frac{p_{bc}}{l})[\frac{2gd}{\theta(s)\eta_p}(M + 0.5m_l)] \tag{11}$$

5.2. Motorcycle last-mile delivery CapEx and OpEx

The following cost parameters compose CapEx and OpEx , when we decide to purchase a motorcycle for last mile delivery.

- p_m: the purchase cost of a motorcycle [€];
- p_{box}: shipping box cost [€]

Therefore Eq. (12) calculates CapEx for the motorcycle delivery model.

$$CapEx_m = p_m + p_{box} \tag{12}$$

Additionally, the following cost parameters calculate OpEx for motorcycle delivery.

- y: 365 [days];
- p^a_{dsal}: driver's salary per year [€];
- p_{fuel}: fuel price per lt[€/lt];
- d_n: network distance[meter];
- T_m: annual motorcycle tax fee [€];
- P_{insm}: motorcycle insurance cost [€];
- S^a_c: annual total motorcycle maintenance service cost [€];
- C^a_{cm}:annual total motorcycle fuel consumption [€]

Eq. (13) calculates OpEx for motorcycle delivery.

$$OpEx_m = p^a_{dsal} + C^a_{cm} + T_m + P_{insm} + S^a_c \tag{13}$$

where the C^a_{cm} is calculated in Eq. (14)

$$C^a_{cm} = y * p_{fuel} * E_m = y * p_{fuel} * n * c_{fuel} * nd \tag{14}$$

5.3. Last mile delivery model - Monetarized benefits

Respectively, the monetarized benefits in the last-mile delivery investment model are the positive cash flows created based on the price pr charged per delivery. Thus, Eq. (15) calculates the annual earnings for n deliveries per day.

$$income = y * \sum_{i=1}^{i=n} (pr) \tag{15}$$

5.4. NPV and ROI

Finally, the investment model assesses Net Present Value (NPV) and Return on Investment (ROI) over a period of five years. Additionally, break-even points per delivery investment are also calculated.

Hence, the following two equations assess NPV and ROI per delivery investment.

$$NPV = \sum_{t=0}^{t=4} \frac{R_t}{(1+i)^t} \tag{16}$$

$$NPV1 = -CapEx + \sum_{t=1}^{t=4} \frac{income_t - OpEx_t}{(1+i)^t} \tag{17}$$

where, t denotes the life of investment in years, R_t is the net cash inflow-outflows during year t, namely the earnings minus OpEx in year t; and i represents the discount rate or return that could be earned in alternative investments.

$$ROI = \frac{\sum_{t=0}^{t=4} income_t - (CapEx + \sum_{t=0}^{t=4} OpEx)}{CapEx + \sum_{t=0}^{t=4} OpEx}, \tag{18}$$

6. Last-mile delivery investment model application

Here, we describe how we applied and validated the formulated investment model; and, we conclude the section with the results.

6.1. Data collection

First, we collected data from different trusted sources in order to assign values to the predefined parameters of the model. We utilized the following means to populate the investment model. The next table includes the sources we utilized.

- Values utilized in relevant, recent academic literature studying drone last-mile delivery.
- Interviews with experts, that is a drone pilot and trainer for drone flights and a courier employee in order to capture realistic information about flight ranges, potential costs and motorcycle delivery parameters based on their experience in the actual market. More information on the interview protocol and the discussion are summarized in Appendix.
- Delivery charges were decided based on the delivery charge used when buying online.

The wind speeds on each UAV trip are sampled from a normal distribution with mean $\bar{v}_{wind}$ and standard deviation of 5 km/h, as displayed in Table 2.

6.2. Application of last mile delivery investment model

We applied the investment model considering last-mile deliveries taking place in Athens, a Greek metropolitan city, where motorcycles are the main transportation means for last-mile deliveries. We consider a delivery zone with a maximum radius of 10 km, n = 65 delivery locations and the deliveries are performed during an 8-h shift (Seghezzi et al., 2022), whereas the payload per delivery weighs approximately 2 kg (Aurambout et al., 2019). It is assumed that the drone travels distances are sample from a normal distribution with $\bar{d}_{mean}$ and a standard

Table 1
Input data for Last-mile delivery investment model.

Parameters	Values	Literature	Interviews	websites
n	65	Seghezzi et al. (2022)		
y	365			
r	10 km	Aurambout et al. (2019)	Drone pilot	
m_l	2 kg	Aurambout et al. (2019)		
m_d	10.1 kg	Rashidzadeh et al. (2021)	Drone pilot	
$\theta(s)$	3.5	Rashidzadeh et al. (2021)		
η	0.66	Rashidzadeh et al. (2021)		
p	0.1 kW	D'Andrea (2014)		
cf	1.34	Merchan et al. (2020)		
d	d_{mean} = 10 km, σ = 2 km	Aurambout et al. (2019)	Drone pilot	
p_d	17 000 €		Drone pilot	microdrones (2023)
p_{bat}	1000 €			microdrones (2023)
p_{charg}	650 €			microdrones (2023)
p_{sal}	800 €		Drone pilot	
e_{ch}	0.85	D'Andrea (2014)		
P_{nb}	0.18 €			rae (2023)
P_{bcc}	300 €/Kwh	D'Andrea (2014)		
C_{ins}	500 €		Drone pilot	Droneinsurance (2023)
pr(for drone)	3.85 €	Borghetti et al. (2022)		skroutz (2023b)
pr (for motorcycle)	3.0 €			skroutz (2023b)
Uc	550 €		Drone pilot	
C_{dl}	500 €		Drone pilot	
p_m	2970 €		Courier	car (2023)
p^a_{dsal}	7800 €		Courier	
p_{box}	230 €		Courier	skroutz (2023b)
c_{fuel}	0.02 lt/km			
p_{fuel}	2 €			
T_m	22 €			aade (2023)
P_{insm}	210 €			hellas direct (2023)
S^a_c	200 €		Courier	

Table 2
Parameter settings in experimental design for wind conditions.

Level	Mean wind speed ($\bar{v}_{mean}$)
Low	0 km/h
Medium	25 km/h
High	45 km/h

deviation of 2 km, whereas the motorcycle travels the corresponding network distance. The circuity factor denoted as cf, is 1.34 (Merchan et al., 2020).

We selected a MD4-3000 drone (microdrones, 2023) for drone delivery, with a battery capacity of 777 Wh (Aurambout et al., 2019). According to the information collected during the interview with a drone pilot (see in Appendix), it is necessary to obtain two additional batteries in order to replace the discharged batteries and, thus, allow the drone to fly continually. Settings with low, medium and high expected wind speeds are generated based on Table 2. For each parcel the head/tail setting is assumed.

Hence, the battery swapping may be foreseen by estimating the energy consumption using Eq. (2), as shown in Fig. 6. It is obvious that wind intensity appears to influence the frequency of battery recharges and overall energy consumption. Specifically, under low wind conditions, a single battery replacement is required, while in medium wind conditions, the batteries need to be replaced twice. Finally, in the case of high wind the batteries need to be replaced six times.

Based on the values assigned to the parameters of the model, as seen in Table 1, we calculate the capital and operational expenses for the three last-mile delivery services (owned-drone, Drone-as-a-Service, owned-motorcycle) under various wind conditions, as shown in Table 3

In motorcycle scenario, CapEx is significantly lower at 3193.00 €, reflecting the lower initial investment required to acquire motorcycles compared to drone systems. In owned-drone scenario, CapEx is much higher at 19,650.00 €, whereas in DaaS scenario CapEx is 0 € as this scenario relies in outsourcing the drone service, offering an attractive option for business aiming to avoid high upfront costs.

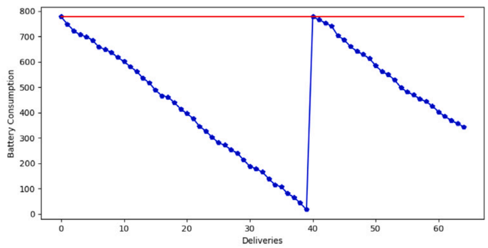
Table 3
Capex and Opex per scenario.

		CapEx (€)	OpEx (€)
Motorcycle		3193.00	17,652.00
Low wind (Drone)	Owned drone	19,650.00	10,788.64
	DaaS	0.00	16,233.64
Medium wind (Drone)	Owned drone	19,650.00	11,079.18
	DaaS	0.00	16,524.18
High wind (Drone)	Owned drone	19,650.00	12,608.53
	DaaS	0.00	18,053.53

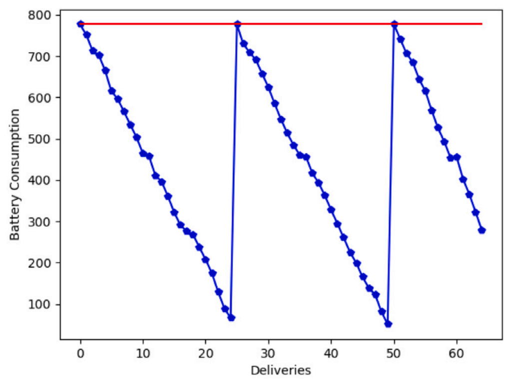
Regarding OpEx, in motorcycle scenario OpEx is consistently high at 17,652.00 €. Moreover, in owned-drone scenario OpEx is lower than the motorcycle scenario, ranging from 10,788.64 € (low Wind) to 12,608.53 € (high wind). This increase with wind intensity reflects higher energy usage or maintenance requirements under more challenging conditions. In DaaS scenario, OpEx integrate the cost of outsourcing drone services and wind-related operational adjustments, thus it is comparable to the motorcycle scenario, ranging from 16,233.64 € (low Wind) to 18,053.53 € (high wind).

Motorcycle delivery corresponds to the next day's delivery, while drone delivery ensures same-day service. Therefore, as shown in Table 1, the price for delivery via motorcycle is set at 3 € based on the usual delivery fee in Greece, which also charges the most popular e-commerce platform in Greece (skroutz, 2023b). Respectively, we assume that the price for drone delivery is 3.85 € based also in the same e-commerce platform (skroutz, 2023b) that charges this fee when a customer wants next day delivery served by van or motorcycle. Additional, a similar delivery fee price was also used in Borghetti et al. (2022).

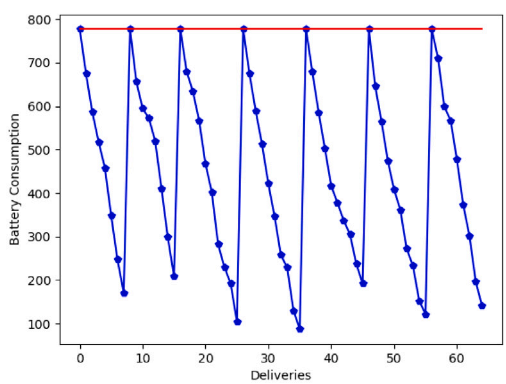
The total income for 2024–2028 is shown in Table 4. It is evident that motorcycle scenario has the lowest income among the three scenarios, while owned-drone and DaaS scenarios represent a significant increase (28.4%) over the motorcycle scenario.



(a) Low wind



(b) Medium Wind



(c) High Wind

Fig. 6. Drone energy consumption categorized by wind conditions.

Table 4
Incomes.

Scenario	Total income
Motorcycle scenario	355,875.00 €
Owned-drone scenario	456,706.25 €
DaaS	456,706.25 €

6.3. Results

After calculating CapEx, OpEx and positive cash flows per each last-mile delivery service (owned-drone, Drone-as-a-Service, owned-motorcycle), here we present the results of NPV, ROI and the respective break-even points in order to realize in practice the economic viability of each of the three alternative delivery services.

Table 5
Net Present Value (NPV) and Return on Investment (ROI) for delivery services under wind conditions.

	Motorcycle	Owned drone		DaaS	
		Low wind	Medium wind	Low wind	Medium wind
NPV (€)	89,550	113,406	112,880	136,955	136,429
ROI (%)	106	150	149	239	232

We calculated NPV for each delivery alternative over a period of 5-years and the results are presented in Table 5.

Based on Table 5 the motorcycle scenario appears to hold the lowest NP and ROI values, indicating a less profitable option compared to drone-based services. Regarding owned-drone scenario, NPV shows a slight decline as wind intensity increases. For instance, it drops from 113,406.27 € (Low Wind) to 110,180.07 € (High Wind), highlighting the wind impact on operational expenses. Additionally, the estimated ROI of owned — drone scenario starts at 150% in low wind and decreases to 106% in high wind, suggesting reduced profitability in harsher weather conditions. Finally, DaaS scenario has the highest NPV across all wind conditions, starting at 136,954.88 € in low wind and slightly decreasing to 133,728.68 € in high wind. The corresponding ROI appears to be higher compared to other options, especially under low wind (239%) and medium wind (23%). Even in high Wind, it retains a competitive 198% ROI, demonstrating robust profitability.

Finally, we calculated the break-even point for each delivery service to find the point in time at which the incoming revenue exactly covers the investment expenses. Fig. 7 demonstrates that across all scenarios the breakeven point in the owned-drone scenario is delayed due to the high upfront capital expenditure. DaaS option exhibits a quicker breakeven point compared to owned drones across all wind conditions. This is because DaaS eliminates the need for large upfront investments, spreading costs over time. Moreover, in owned-drone and DaaS scenarios and breakeven is slightly delayed as wind conditions intensify, nevertheless, DaaS remains more favorable.

6.4. Sensitivity analysis

We also performed sensitivity analysis to check whether and how changes in significant input parameters of our investment model affect the economic viability of each investment scenario, namely how NPV is altered. For drone scenarios we conducted sensitivity analysis for medium wind setting, since it represents a balanced and realistic operating condition, capturing neither the idealized efficiency of low wind nor the more challenging and energy-intensive conditions of high wind. Considering that the number of deliveries and the price per delivery are fundamental parameters of the model since they are directly connected with the operational expenses and the positive cash flows, respectively, we decided to perturb them approximately $\pm$20%.

Fig. 8 shows that, even with perturbed values, the investment results are not significantly affected. Regarding owned-drone delivery service, a 20% increase in delivery price and number of deliveries results in about 23% increase in net present value, whereas in the DaaS scenario it causes a 19% increase in net present value. Finally, when we assess the motorcycle service, the sensitivity analysis shows that a 20% increase in the delivery price and in the number of deliveries brings out approximately 17% increase in NPV.

7. Discussion and conclusions

The application of the proposed last-mile delivery investment model shows that adopting drones for last-mile is a financially viable investment. For both delivery options with drone (owned and as-a-service), the NPV and ROI values reveal that, in 5-year period, the investment in drones is promising and more advantageous than in motorcycles. Break-even point is reached earlier when a motorcycle is adopted, but this is

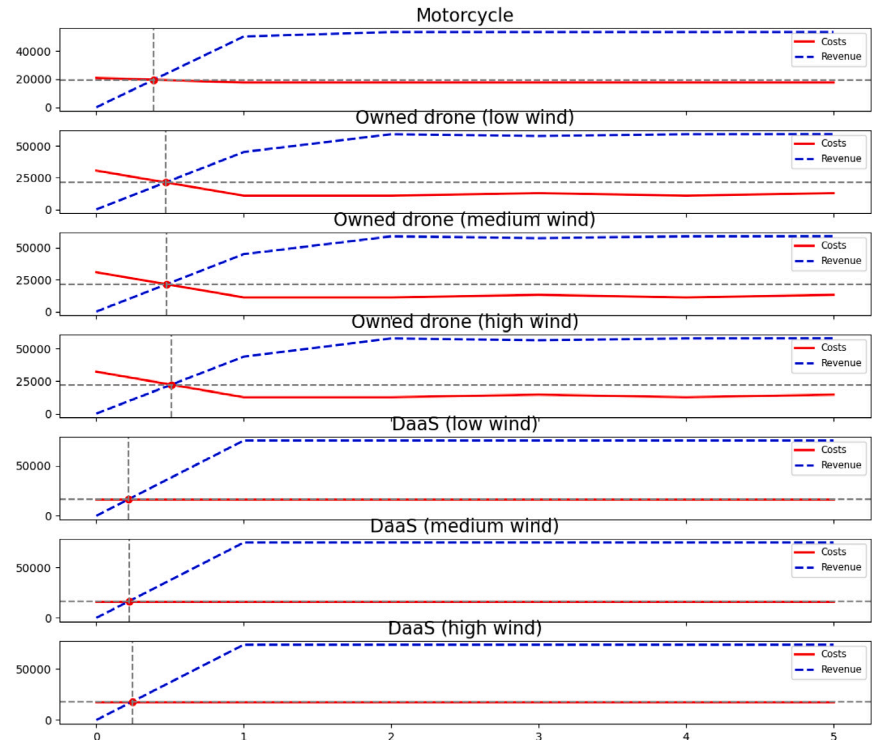
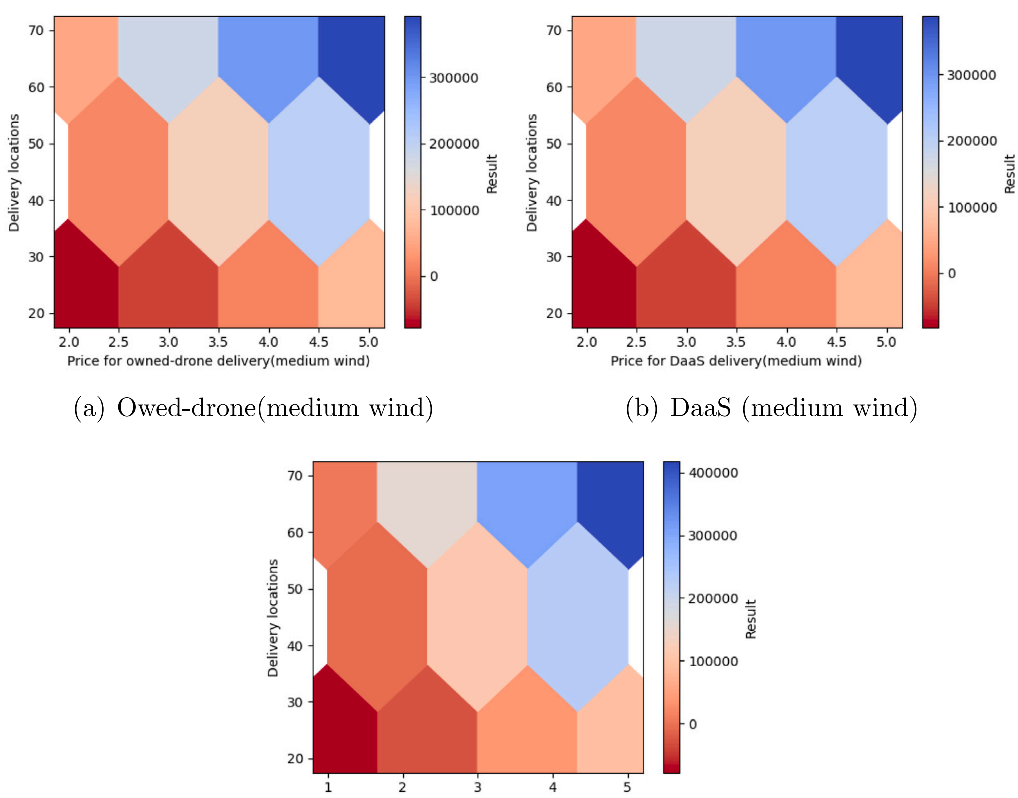


Fig. 7. Breakeven points for the last-mile delivery services.



(a) Owed-drone(medium wind)

(b) DaaS (medium wind)

(c) motorcycle

Fig. 8. Sensitivity analysis per last-mile delivery service.

expected since the initial motorcycle investment is significantly smaller than the drone one. In the same spirit, the drone-as-a-service option is better than investing in owned drones since it is a financial leasing model that shifts capital expenses to operational expenses, improving the profit of the investment. It is the most advantageous solution with NPV and ROI values improved and reaching the break-even point earlier than the owned-drone and motorcycle investment.

When considering different wind settings (low, medium, and high), the results remain consistent in highlighting the financial advantages of drone investments. Under low-wind conditions, drones perform with higher efficiency due to reduced energy consumption, improving both NPV and ROI values. In medium-wind settings, the energy consumption increases moderately, slightly impacting the operational costs but still maintaining the financial feasibility of the drone investment. High-wind conditions represent the most challenging scenario due to significantly higher energy demands, which marginally reduce profitability; however, drones remain a viable option even under these conditions.

Specifically, we show that, for a delivery/ logistics company, the DaaS delivery service is economically viable and more than double (2.24 specifically) positive flows of the initial cash investment will be returned in a period of five years. In other words, the findings suggest to logistics providers to adopt drones as a delivery means and gain all the benefits of fast delivery, without the risk of investing in fleet of drones as they have already done with motorcycles and vans. This way, the organizations, which are usually risk-averse in new technologies, can rip the benefits of a new, innovative, technology (i.e. a drone) without investing directly in the new technology.

Overall, the current study introduced a last-mile delivery investment model that assesses three different last-mile delivery means; that is traditional delivery with motorcycle; delivery with drone that has been bought (owned-drone) and delivery with leased drone (drone-as-a-service). Acknowledging that organizations are used to outsource certain operations that do not belong to their expertise and, thus, lease respective services, we decided to model and assess a last-mile delivery investment with leased drones and not purchased. We highlight that this alternative was recommended by the drone expert and pilot we had an interview with, since it is his belief that this investment scenario is more probable considering that logistics industry is not familiar yet with drone technology and would be reluctant to invest directly to it.

Moreover, the proposed investment model, as well as the drone energy consumption model, have been formulated based on available, relevant studies (Figliozzi, 2020; D'Andrea, 2014). The same holds for the values utilized when applying and validating the investment model. In other words, the current work draws on related studies; however, it puts the Drone-as-a-Dervice investment in the spotlight, as well as the corresponding cost. Even though, in Rashidzadeh et al. (2021), authors have also calculated the corresponding costs of drone delivery, they mainly focused on the achievement degree of drone sustainability. They compare drone-versus traditional vehicle-delivery mainly in terms of sustainability metrics such as CO2 emissions. In contrast, we focus on the economical aspect of last-mile delivery and the investment cost in drones versus traditional vehicles. We believe that providing to logistics/ delivery stakeholders evidence on the viability of investments in drone can be prioritized in order to foster the adoption of such investments.

Moreover, in Borghetti et al. (2022), authors conducted a users' survey and, based on the responses, a drone service was designed. They proposed a model that calculates the operational expenses and revenue. This model differs from the one we propose since they do not include capital expenses. Moreover, our model includes also the DaaS delivery scenario.

Considering the managerial implications of our research, this paper can support stakeholders in the logistics/ supply chain industry in their decision to adopt drones as a new innovative delivery means. More specifically, it can inspire and guide small-medium sized distribution companies that are sceptical towards drone adoption due to financial constrains. The proposed investment model and its application calculates all the potential operational and capital expenses and prompts them to adopt drones; however, they will not buy them, they will minimize the risk by outsourcing the delivery and selecting Drone-as-a-Service. This research's results can also be utilized by DaaS providers who need more evidence to convince future customers (delivery stakeholders) that they offerings are viable.

Finally, this research paper presents some limitations that point to future research directions. For example, delivery routes are served only by drone or motorcycle. A mixed distribution delivery model can be explored in the future, including vans or trucks and drones. Moreover, automatic delivery routing was not taken into consideration in the current work. Numerous algorithms could be adopted for optimizing the delivery routes in terms of a variety of criteria.

CRediT authorship contribution statement

Evangelia Filiopoulou: Writing – original draft, Visualization, Resources, Investigation, Conceptualization. **Cleopatra Bardaki:** Visualization, Project administration, Methodology, Conceptualization. **Mara Nikolaidou:** Project administration, Conceptualization. **Christos Michalakelis:** Project administration.

Appendix

We conducted a semi-structured interview with a drone pilot and trainer and a courier in order to collect realistic information for building the investment model and, then, validate it.

Specifically, the authors conducted a semi-structured interview with a drone pilot and trainer in June 2023. He is the main instructor of an educational program about drone technology and how to fly drones in the Center of Continuing Education and Lifelong Learning in our University. We asked him about the challenges when utilizing drones for one-to-one delivery and he underlined the limitations of drone battery; therefore, he suggested the battery replacement model in order to achieve non-stop deliveries in an 8-h shift. We also asked for his opinion on the technical parameters of the model, such as delivery distance, payload weight, and drone type selection. The specific parameters were also confirmed by the relevant, recent literature. Respectively, we reviewed with him the values we assigned to the model parameters when validating the model in order to ensure they are realistic. We highlight that during the discussion, the pilot insisted that we should focus on the Drone-as-a-Service investment alternative since he finds it more appealing to distribution companies. Further, we asked him about the operational expenses of drone delivery and the corresponding values. More specifically, he proposed values for drone pilot salary, drone insurance cost, unpredictable maintenance cost and drone leasing cost based on his expertise.

Regarding the motorcycle last-mile delivery model, we interviewed an experienced courier of a well-established distribution company in Greece. To be more specific, a postgraduate student, who also worked as Distribution Supervisor in a pharmaceutical company and, thus, had expertise in the logistics field, conducted the interview for his Master thesis. The courier was mainly asked about the parameters of the model and the values we should assign to them in order to ensure validity. The interviewee provided his opinion on the salary, annual total motorcycle maintenance service cost, the selected motorcycle type and the shipping box.

Data availability

Data will be made available on request.

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