Last Mile Delivery by Drone: A Technoeconomic Approach

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Abstract. As consumers progressively turn to e-commerce for all their shopping needs, on time delivery is of major importance. Logistics companies struggle to find strategies that improve efficiency and reduce costs. Drone-based distribution is an alternative for last mile delivery, gaining popularity, as it can provide reliable and safe services. In this paper the severe challenges of last mile delivery are discussed and a techno economic analysis is presented, introducing and describing a drone distribution model. In addition the drone distribution model is compared with the classic two-wheeled motorcycle distribution model, highlighting the fundamental contribution drones can have in the supply chain.

Keywords: Last Mile Delivery · Drone · Capital Expenses· Operating Expenses · Techno-economic Analysis

1 Introduction

Last mile delivery refers to the last step of the delivery process when a parcel is moved from a transportation hub to its final destination, which usually, is a personal residence or retail store. Growth in Last Mile Delivery (LMD) had been strong for a number of years. Then came the COVID-19 pandemic and has created a spike in demand for delivery. The LMD market is constantly growing and is predicted that will record a Compound Annual Growth Rate (CAGR) of over 14% during 2020-2024 [2]. Therefore, it is not surprising that major Logistics providers, such as UPS, FedEx and XPO Logistics offer last mile delivery services to small and large retailers.

A large challenge when delivering products is the time frame upon which the product will be delivered. Several proposed strategies have studied the complex problem of packages distribution in last mile logistics chain. Based on literature the last mile delivery can be successful by combining drone with truck [2], or by using electric vehicles that are considered feasible solutions in reducing the carbon foot-print [11]. In addition, introduction of known distribution algorithms that resolve delivery problems such as the Vehicle Routing Problem with Time

Windows (VRPTW) and the classic version of Vehicle Routing Problem (VRP) are evolved by proposing a transport model and achieving the goal of successful deliveries [10] [8] [5] [12].

Companies need to explore and adopt innovative technologies to enhance their LMD services. Into this context, businesses can gain a competitive edge by adopting drones for last mile delivery optimization. A delivery drone is an autonomous vehicle that transports packages, food or other products.

Drone technology is a rapidly evolving research area, focusing on the technical improvement of air crafts, their operation through a combination of technologies, including computer vision, artificial intelligence and other similar aspects [17]. However, so far the contribution to the literature, related the techno-economic assessment of the drone technology is relatively limited, despite the fact that the economic standpoint of a corresponding investment of paramount importance. Established commercial companies and transportation service companies integrate their distribution systems services by using drones. Amazon, Google, UPS and DHL are some of these companies developing pilot drone projects for the last mile delivery of their products [17].

Towards this direction a techno-economic analysis is introduced, examining the employment of drones in the LMD service. The analysis introduces a case study that compares and evaluates the drone and the traditional motorcycle-based delivery approaches. In addition, the work performed in this paper and the derived results can also serve as a valuable input for potential investors and provide a roadmap to the drone technology business.

The rest of the paper is organized as follows: Section 2 introduces the case study, where a motorcycle and a drone last mile delivery service are compared. Section 3 discusses the results and finally Section 4 presents the conclusions, the limitations of the paper, together with future research.

2 Last Mile delivery- Case Study

In the proposed scenario, a hypothetical local courier distribution center handles the last mile delivery services, named HuaLmd. The proposed case study is initially implemented by a motorcycle-based last mile delivery model and then a drone last mile delivery model is adopted. The scenario of using an electric motorcycle was initially considered, but this technology has not been adopted by Greek distribution companies yet.

Capital Expenses (Capex) and Operating Expenses (Opex) are estimated for each individual model. Capex correspond to the money an organization or corporate entity spends, in order to buy, maintain, or improve its fixed assets, such as buildings, vehicles, equipment [9] where as Opex are the ongoing costs for running a product, business, or system [14]. The following delivery details describe the specifications of each delivery model:

- Transport box dimensions.
- Parcel characteristics, such as the dimensions and the weight of the parcel. Without loss of generality, an average parcel was chosen.

- Delivery Points: The end point where the user receives the parcel.
- Package Delivery: In the current work each delivery consists of only one parcel.
- Estimated Time: The time required from the departure of the parcel from the distribution center to its final recipient.
- Completed Routes: Number of successful deliveries in a prearranged time frame.

2.1 Last Mile Delivery by motorcycle

The delivery details for the LMD motorcycle model are based on data collected by courier companies [4] [15] [16] and are presented in Table 1. A Greek urban area was chosen for the implementation of the model (Egaleo, Greece). In Egaleo the longest delivery route is 6 kilometers while the shortest route is set to zero (0). Therefore, the average distance equals to 3 km.

Table 1. Motorcycle LMD details

Transport Box Dimensions	L0,57cm X W0,52cm X H0,54cm
Parcel Dimensions and Weight	L0.20cm X W0.10cm X H0.05cm and 1,5 kg
Delivery Points	48
Delivery Packages	48
Completed Routes	2
Estimated Time	8 Hours

In the motorcycle distribution model, the Capex includes the cost of purchasing the motorcycle (2200.00 €) which is an average price of a motorcycle model for deliveries and the shipping box (170.00 €). Thus the estimated total amount equals to 2370.00 €. The operating expenses of this case are presented in Table 2.

Table 2. Total Operating Expenditure Cost of Motorcycle on an annual basis

Salary	9100.00€
Fuel consumption	1576.80€
Vehicle tax fees	22.00€
Insurance premiums	190.00€
Motorcycle maintenance costs	450.00€
Total	11338.80 €

2.2 Last Mile Delivery by drone

The delivery details for the LMD drone model are based on drone specifications.The specific drone [13] can fly in moderate weather conditions with temperatures between -10 °C and 40 °C. The climate of Greece is Mediterranean with low possibility of rain and snow, thus drone can fly without weather many interruptions. For comparative reasons the characteristics of the transport box and parcel are similar to the corresponding characteristics of motorcycle model. The details of the drone model are presented in Table 3.

Table 3. Drone LMD details

Transport Box Dimensions	L0,57cm X W0,52cm X H0,54cm
Parcel Dimensions and Weight	L0.20cm X W0.10cm X H0.05cm and 1,5 kg
Delivery Points	61
Delivery Packages	61
Completed Routes	61
Estimated Time	8 Hours
Flight Time [13]	32 min

For comparative reasons, the selected urban area where the last mile delivery takes place remains the same. The longest distance that drone will need to cover from the starting point (HuaLmd's distribution center) is 1.93 kilometers, The shortest route is set to zero as in the motorcycle delivery model. Thus, the average distance is defined almost at 1 kilometer. Based on drone's specifications [13] the autonomy of the drone with a load of 1,5 kg is 32 minutes, thus the drone is capable of four completed flights with a full charge. Aiming to avoid delivery interruption due to battery recharging, four DJI TB48S flight batteries and the corresponding DJI hex charger model are purchased [7]. The required time for a full charge is set at 110 minutes [13]. After four completed routes the first battery will be replaced by the second fully charged and the first one will begin charging. Then having completed four more flights, the second battery will be replaced by the third one while the second will also begin charging.

In the drone distribution model, the drone purchase considers to be the main capital cost (4.300,00 €) [13]. As mentioned above, the company purchases four back-up batteries (768,00 €), thus the distribution will not be interrupted by the re-charging of the battery. Finally, for charging simultaneously up to four batteries a specific charger was bought (333,00 €). Capital expenditure of drone case study equals to 5401,00 €.

The operating expenses of this model includes the cost for purchasing routing platform software [13] and power consumption cost during batteries charging. Finally, insurance premiums [1] and maintenance cost service are taken into account. The insurance covers compensation for personal injury, material damage to third parties, replacement of the drone, ground navigation system coverage and payload coverage. The maintenance cost includes occasional changes of spare parts like propellers of the drone. In addition, the operator of the routing platform is one of the existing employees of the company. The depreciation period of the drone is 3 years while the depreciation period of batteries is 4 years, so the batteries are not replaced prior to the deprecation of the drone. Table 4 presents the operating costs.

Table 4. Total Operating Expenditure Cost of Drone on an annual basis

Routing platform software	6.360,00 €
Electricity consumption	1211,80 €
Insurance premiums	300,00 €
Maintenance cost	190,00 €
Total	8061,80 €

In order to set the best possible prices for the last mile service provided by HuaLmd, the following framework is formed:

- The company already owns a fleet of motorcycles for the distribution. In the existing fleet a drone is added in order to cover the needs of its customers that arising during the day.
- Motorcycle driver completes two routes within an 8-hour period. The first route refers to orders that have been placed the previous days, whereas the second route includes deliveries from same day orders.
- The success of drone LMD service is related to the lead time, which is limited to 10 minutes per order. Lead time is the time from the moment the customer places an order to the moment it is ready for delivery.
- The arrival of orders follows a Poisson distribution, with mean value and standard deviation, deriving from the available courier data. Poisson distribution is a discrete distribution that measures the probability of a given number of events happening in a specified time period [3].
- The distributions serviced by drone, will execute the same day orders. Services with a short lead time delivery will be offered with additional charge.
- In the motorcycle distribution model, orders are grouped twice a day and the loading is scheduled every four hours at the distribution center.
- In motorcycle scenario 50% of the deliveries have lead time same day delivery and the remaining 50% of deliveries have lead time next day deliveries.
- In drone model, the number of delivered packets are estimated by Poisson distribution based on the lead time. Therefore, drone carries out 65% of deliveries within 8 hours, 25% of deliveries within 4 hours and 10% of deliveries within 1 hour.

Pricing is based on the lead time and it is derived from the average market prices [15] [16] [4]. Therefore, HuaLmd offers next day delivery at 6.00€ and same day deliveries at 13.00€. Regarding the drone distribution service, the proposed pricing scheme includes three different prices for the same day deliveries based on the lead time of the delivery, in particular the shorter the lead-time implies the higher the price. More specific, the price for 8, 4 and 1 hour lead time equals to 13€, 18€ and 35€ respectively.

2.3 Application Scenario

The techno-economic analysis presents the investment process of the case study for the following three years. Delivery service pricing, initial cost investment and the monthly operating expenses are taken into account through the analysis. Furthermore, the most important assessment indices, the Net Present Value is calculated [30]. NPV is the sum of the present values of incoming and outgoing cash flows over a period of time, as presented in Equation 1.

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

where R_t represents net cash flow at time t, i denotes discount rate and t defines time of the cash flow [6].

Motorcycle Last Mile Delivery Scenario In the current scenario the two-wheeled motorcycle, based on lead time, the 50% of the deliveries are served the same day and the remaining 50% are delivered the next day. Based on the above assumption, Table 5 presents the parameters that are taken into account for the calculation of the NPV. By setting the annual discount rate to 10%, the calculated NPV for the first three years of operation is: 270088,37€.

Table 5. NPV parameters

Lead Time	Price per delivery	Deliveries	Revenue/year
Next day	6€	8760	52.5606€
Same day	13€	8760	113.880€

Drone scenario In the drone scenario, the drone serve orders of the same day. The number of delivered packets are estimated by Poisson distribution based on the lead time. Therefore, drone carries out 65% of deliveries within 8 hours, 25% of deliveries within 4 hours and 10% of deliveries within 1 hour. Table 6 presents the overall number of deliveries. Taking into account the Capex and Opex, the calculated NPV for the first three years equals to 62.1180,05€.

3 Results and Discussion

In both models, the motorcycle and drone purchase constitute the main factor of the Capex, since the cost of acquiring the appropriate transportation mean

Table 6. NPV parameters

Lead Time	**Rate of deliveries packets**	**Revenue/year**
8 hours	65%	189800.00€
4 hours	25%	98550.00€
1 hour	10%	76650.00 €

contributes up to 93% and 80% of the total capital cost, respectively. As shown in Figure 1, the total Capex of the drone model is twice the cost of the motorcycle model. The annualized Capex for motorcycle and drone equipment is depreciated over 8 and 4 years respectively.

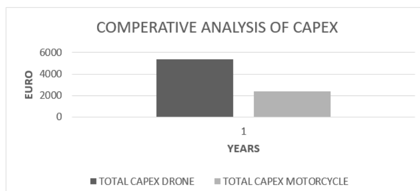

Fig. 1. Comparative analysis of motorcycle and drone Capex

The average depreciation period of a motorcycle, provided that it is used only for product distribution, is estimated and equals to 8 years, and the annual rate equals to 13%. Regarding the drone distribution model, the average depreciation period is estimated and equals to 4 years and the annual rate is set at 25%. Drones' depreciation estimations are based on data derived by distribution models in Canada, Australia and new Zealand where drone delivery service is already applied [18].

In the motorcycle distribution model, the driver's salary and the annual consumed fuel contribute highly to the operating costs. These two individual costs represent the 94% of the total operation expenses. In the drone distribution model the software platform that replaces the driver of the motorcycle contributes up to 82% of total expenses.

Electricity consumption follows with an estimated contribution up to 16% in the Opex. Even though the cost for drone purchase is twice as much as the motorcycle purchase, the corresponding annual operating costs of the motorcycle are 1.5 times higher than the drone and is equal to 3577.00€. he project is scheduled to be carried out for the following three years, therefore, the difference at the end of the three year is equal to 10731,00 €. Figure 2 presents a comparative illustration between motorcycle and drone Opex.

Summarizing the two different models, it is evident that the drone last mile deliver service is more profitable than the classic two-wheeled motorcycle deliv-

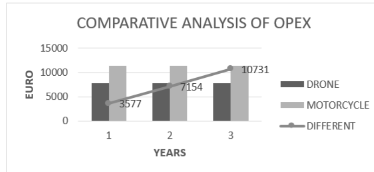

Fig. 2. Comparative analysis of motorcycle and drone operating expenses

ery. Comparing motorcycle and drone-based scenario an increase in the number of the deliveries is highlighted. Replacing the motorcycle by a drone, 13 more deliveries are made per day. The growth rate is 27%. The growth of services in combination with the new price in the price list, increase revenues in the realistic scenario with a drone by 117% compared to the scenario of motorcycle. Over the three-year period, the differences widen even more for the drone distribution scenario, as compared to the two-wheeler motorcycle scenario. The comparison between the two distribution models is illustrated in Figure 3

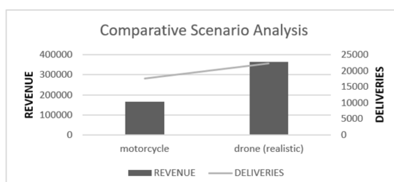

Fig. 3. Comparative scenario analysis

4 Conclusions

The proposed techno-economic analysis focused on the last mile delivery, thus a case study was introduced that proposed HuaLmd, a hypothetical established distribution company, which added a drone to its of already owned fleet of motorcycles.

According to the results, it is evident that the required Capex for the drone adoption for the last mile delivery service is rather high, however the corresponding annual operating costs of the motorcycle are 1.5 times higher than the drone costs. The results indicate that the drone approach is more profitable than the classic two-wheeled motorcycle distribution service, maintaining a substantially higher level of revenues.

The current techno-economic analysis is subject to some limitations. Initially, HuaLmd is assumed to be active in the Greek market for several years, therefore it has already a pool of customers who will try the drone delivery. The offered pricing list service was also based on popular transportation companies of the Greek market. The application cost of the drone distribution model in a startup transportation company with a limited clientele is expected to be higher. Thus, a techno-economic analysis based on a startup company would be an interesting future research direction. In addition, a comparison between a drone and an electric car or motor-cycle distribution model would be challenging.

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