Management of urban air logistics with unmanned aerial vehicles: The case of medicine supply in Aveiro, Portugal

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Abstract

**Purpose:** This research aims to investigate the relation between urban logistics and all delivery systems used. The unmanned aerial vehicle (UAV) and the unmanned aerial system (UAS) have been under investigation in the world of logistics, having been pointed as the next logistic technology. For that reason, this article proposes the use of UAV in urban logistics.

**Design/methodology:** We set for the methodology study the current state of this system and analyze what lies ahead soon. Based on this information, we intend to implement a scenario of deliveries in an urban environment. This scenario will be in the city of Aveiro and consists of the delivery of medicines into pharmacies located in an urban environment. With this study, we pretend to find the best current and future solution to operate in an urban environment, with the conventional vehicle or the UAV/UAS.

**Findings:** The legal implications for the use of UAV/UAS are one important factor that can set back the use of these technologies due to the lack of legislation. Although this technology has some limitations in endurance and payload, this investigation reached a consensus in the use of UAV for logistics in urban areas, in small payloads (around 15 kg), and low endurance (around 25 min). The UAV/UAS brings excellent advantages that the conventional vehicle cannot overcome: direct routes; traffic congestion; and environmental legislation.

**Practical implications:** This study brings an overview of a possible scenario for urban logistics. Although this is currently not possible, soon, this scenario could be implemented. This would bring a reduction in operation costs and reduce the congestion in the urban cores of the cities.
Originality/value: Based on this research, this delivery system could, in the future, help and be the starting point for UAV/UAS logistics, specifically in the delivery of medicines.

Keywords: Unmanned Aerial Vehicles (UAV), Unmanned Aerial Systems (UAS), urban logistics; route optimization, facilities location

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1. Introduction

The future of urban logistics is one of the most studied and researched areas in the current days due to the growth of the population and services provided. At the same time, there is an extensive increase in urban traffic due to the urgent need for mobility and accessibility into the cities. With it comes the need to control and improve urban traffic. Directly related is the urban logistic, that depends on the good flow and accessibility, for a fast and more profitable delivery (Geister & Korn, 2018). In the urban environment, there are several stages of the logistic system, the approach transportation, and the last-mile delivery. For the freight approach, the industry uses mainly utility vans, that are also used in the last-mile delivery (Gonzalez-Feliu et al., 2014). Although, for this delivery, there are several types of vehicles doing this service, since motorcycles to commercial cars (combustion or electric), or even by foot (Allen et al., 2018). Today's urban logistics rely on ground transports, but this does not ensure that in the near future, it will steal the same.

The last-mile service can improve with air transportation, where unmanned aerial vehicles (UAV) are purpose as a better solution. UAVs have a lot of applications, such as deliveries, infrastructure surveillance, search and rescue, agricultural monitoring, and other more services (Netto & Silva, 2018). So, for that reason, it is urgent to investigate if this solution can apply to more and more services, in this case, logistics companies, to optimize the services provided.

There was a necessity to optimize the complicated and crowded urban space that let to urban logistics or also known as “city logistics” (Crainic et al., 2009), (Ruske, 1994). They have been considered a new solution to solve urban problems. Taniguchi defined the concept of city logistics as “the process for totally optimizing the logistics and transport activities by private companies in urban areas while considering the traffic environment, the traffic congestion and energy consumption within the framework of a market economy” (Taniguchi & Thompson, 1999).

In European countries, there are the Urban Vehicle Access Regulations (UVAR) applied to some regions of the cities. They could be low emission zones (LEZ) or congestion charging (CC). Since its implementation, there was a reduction in the CO₂ emissions, and also, the congestions levels decreased (Van den Bossche et al., 2017). With the new regulations applied into the city centers, UAVs are an excellent solution that the urban environment can accommodate, this system does not need to use the roads located in the urban core, and the UAV/UAS can quickly be launched from a van, or a logistic center located in the peripheral area of the city. Logistics could and should integrate the urban airspace in the chain of transportation for a more balanced and distribute traffic (Neto & Miranda dos Reis, 2014). This idea has been the focus of several companies, for example, Amazon, DHL, and Google (Prime Air Na Amazon, 2020), (Heutger, 2014), (X - Wing, 2020). They aim to achieve the delivery by using the urban air space. As an example, in 2019, DHL and Ehang, a UAV company, made a partnership in China to innovate in smart logistics (Figures 1 and 2).

Already in Portugal, several projects have been captivating the interest of companies. An example of operation in an urban environment was executed by the company Connect Robotics, the first authorized UAV operator in Portugal, where it places a UAV in the city of Lisbon. The UAV, whose flight was authorized by the National
Civil Aviation Authority (ANAC), connected the post office (CTT) distribution center to the company’s headquarters, in “Parque das Nações”, in Lisbon. This route had 3 kilometers and took seven minutes to cover, at an altitude of 30 meters (as it is an area close to Lisbon airport) (Connect Robotics: Drone Delivery Operator, 2020). The CEO of Connect Robotics stated that “(…) we believe that this will be the most used method for the distribution of small goods in the future. Our service is undoubtedly an asset to the distribution of letters or orders. A drone is faster, quieter, less expensive, and nobody has to waste time to travel (…)” (CTT Testaram Drones Em Lisboa - Transportes & Negócios, 2017).

What characterizes a UAV is essentially its way to operate. A UAV has no pilot on board; instead, it has navigation and communication systems that capacitate the aircraft to be controlled from a ground station. In some cases, if the aircraft is fully autonomous, they navigate using all the information collected by his sensors (video, proximity alert, altimeter, and GPS). For Remoted Pilot Aircraft (RPA), the flight can be piloted by a visual line-of-sight (VLOS), or in beyond visual line-of-sight (BVLOS). For a better notion of how this technology evolves, there are some different types of aircraft, for example, fixed-wing; tilt-wing; unmanned helicopter; multi-copters; and hybrid UAV (a fixed-wing with vertical take-off and landing (VTOL)), (Custers B. H. M., 2016).

Even though analyzing today’s legislation, logistic companies using UAV for delivering goods in the cities would not be possible. The good news is that authorities are now studying and implementing new guidelines for the future legislation of UAV intending the population’s new needs and introducing the level of automation regulation. That until now, authorities only were concerning with the remoted pilot aircraft. For better integration of the future UAV/UAS laws, it would be further convincing with an international convention (Custers B., 2016). European Union Aviation Safety Agency (EASA) will implement new legislation during 2021. They release a new document with the objective of creating standard legislation for the use of UAV/UAS, with "applicable airworthiness codes, environmental protection certification specifications and acceptable means of compliance with Part 21, as well as important special conditions and equivalent safety findings" (EASA, 2020). As it was expected, the EASA new outline for controlled urban air mobility (UAM) will attend the new requirements for profitable use and operations.
2. Object and Objectives

We start by asking: how is it possible to use UAV/UAS in urban logistics, especially for the transport of goods and provision of services?

This study aims to answer this question as follows: the object of this investigation will be to study urban logistics, and in order to verify the current state of logistics in urban areas, we set as objectives:

- Analyze the current state, its evolution, and a possible future;
- Study a delivery scenario in an urban environment where we will apply a possible UAV/UAS system;
- Optimize the delivery system; and
- Intend to find the best solution for a new approach to urban logistics, either today or in the near future.

3. Methodology

The methodology pretended it is a conceptual approach of a possible scenario with the use of UAV and UAS for logistics in urban areas. This study will start with an overview of today’s urban logistic systems, as well as an introduction to UAV/UAS to be used in an urban logistic scenario. In a way to obtain several conclusions, this paper will compare, nowadays urban logistics system (e.g., vans delivery) with the application of UAV/UAS in the same system. The comparison starts with a SWOT analysis, where some parameters get evaluated, and the strengths, weaknesses, opportunities, and threats can be reached for each logistic system. The next phase of the methodology will be the case study with a possible scenario in the city of Aveiro with the delivery of medicines. The case study is divided into several parts. The first one will attend to all the requirements needed by the pharmaceutical companies, as well as all the limitations that the UAV/UAS and the typical logistic system (e.g., van delivery) can have. Then, we divide the delivery implementation in two phases. In phase 1, we implement a delivery route starting from the existing logistic facility, both for conventional vehicle and UAV/UAS delivery. The delivery must happen both for daily and emergency medicine delivery. For phase 2, it is pretended to create a delivery route for the UAV that will start in a new facility. This facility will be chosen from several possible locations in order to obtain the near optimal one. In conclusion, we intend to expose all the results and proposed some guidelines for possible urban logistics with the use of UAV/UAS. In the following scheme (Figure 3), there are some guidelines of the methodology pretended.
Figure 3. Methodology pretended for this study
4. Operation outline

The scenario chosen for the implementation of our case study is the city of Aveiro. It has many pros for the use of UAV/UAS, it is extremely flat, with an average height of 25 meters and a maximum height of 78 meters, and there is no buildings with more than 30 meters of high ("PORDATA - Ambiente de Consulta," 2020).

One crucial issue for the operation that follows is the analysis of weather conditions where the UAV will operate. For that, we resort to the "Instituto Português do Mar e da Atmofera" (IPMA), which shared all the weather information for the city of Aveiro in the year of 2019 ("Instituto Português do Mar e da Atmosfera," 2020).

From the weather conditions data, we can define the days that the UAV will be able to operate. Following the procedure, all the days with max wind per hour above 13.9 m/s (50km/h) and with precipitation above 2 mm/h will be considered unapproved for flying. These limitations left us with a total of 274 days per year with approved conditions for flying. All the other days did not meet acceptable conditions.

The demand required for each pharmacy will consider the population of each civil parish and be divided by the number of pharmacies existing in each parish. This data was collected from Infarmed (2018). We will also consider the information provided by "Associação Nacional de Farmácias" (ANF), that on average, a box of medicines weigh 50 g (0.050kg).

In the delivery operation, when the payload arrives at the pharmacy, the process can take some time to deliver. For that reason, we will add to the value of each trip, 2.5 minutes per stop, both to the van and UAV system.

The vehicles selected for the operation will be the Fiat Ducato (see figure 4) for the conventional delivery system, and the FB2 (see figure 5) for the UAV/UAS delivery system. The UAV has some limitations, the endurance of this aircraft will be 25 minutes, and the payload will be of 15 kilograms. All the safety factors were considered and applied to the original characteristics of the FB2 aircraft.

The operation for medicine delivery will consist of several objectives, separated into 2 phases. Tables 1 and 2 displays all the objectives for each phase and introduces an outline for all our investigation.

![Figure 4. Fiat Ducato](FiatDucato2020.png)

![Figure 5. UAV FB2](FlyingBasketDronesThatCanTransportHeavyLoadsToRemotePlaces2020.png)
3. Return to the logistic base;
4. Repeat if necessary, until all demand is delivered.

| Implementation | Implementation |
|----------------|----------------|
| It will be completed using a van in an optimized path with the TSP algorithm. | It will be completed with UAV/UAS delivery in an optimized path with the CW algorithm and TSP algorithm. |

Table 1. Implementation of the phase 1. This implementation will be the same both for daily and emergency delivery.

| Phase 2 |  |
|---------|---------|
| The conventional vehicle (e.g., van) will depart from the logistic base “L0” (see figure 9, and the UAV delivery system will require a departure from a mobile logistic base (L0, L1, L2, or L3). |  |
| **Daily delivery and emergency delivery** |  |
| **Conventional delivery** | **UAV/UAS delivery** |
| 1. Departure from the logistic base; | 1. Select the best location for the mobile facility base (L0, L1, L2 or L3); |
| 2. Delivery to each pharmacy their demand; | 2. Departure from the mobile logistic base; |
| 3. Return to the logistic base; | 3. Delivery to each pharmacy their demand; |
| 4. Repeat if necessary, until all demand is delivered. | 4. Return to the mobile logistic base; |
| | 5. Repeat if necessary, until all demand is delivered. |
| | The location of the mobile base will be chosen using the uncapacitated FLP. |
| | It will be completed with UAV/UAS delivery in an optimized path with the CW algorithm and TSP algorithm. |

Table 2. Implementation of the phase 2. This implementation will be the same both for daily and emergency delivery.

5. Results

5.1. Phase 1

Conventional delivery

With the data collected for vehicle routing generated automatically in Google Maps, we build a database where all distances between each pharmacy and the logistic facility are assembled.

The total demand is 150 kg for daily delivery and 15 kg for an emergency delivery. This value does not overcome the maximum payload capacity of the van. For that reason, the van will deliver all the medicine in one path.

The final values obtained with the TSP algorithm were done with 1000 iterations (Miller et al., 1960). This process was repeated several times to ensure that the results were the same. The results for the conventional route vehicle are shown in table 3 for daily delivery and for emergency delivery. These results will establish a new route that will be almost the minimal cost possible.

The time displayed in the last column in tables 3 was obtained from Google Maps. For that reason, all speed limitations and road regulations were respected. However, the time travel could suffer some changes due to traffic or road obstructions, increasing the final duration of the distribution. In addition to this time, was introduced a manual delivery time of 2,5 min, regarding the fact that the operator must initially park the vehicle and unload the medicines from the van and deliver them to the respective pharmacy.
Table 3. Data obtained from Office Excel using the TSP algorithm for daily and emergency van delivery

Table 3 (section 5.1.1) exhibits the daily medicines delivery and the emergency delivery, respectively, with a total distance traveled by the van of 35.88 km and a time travel of 2 hours and 21 minutes (141 minutes). The total payload transported was 150 kg for the daily delivery and 15 kg for the emergency delivery.

Figure 6 portrays the final TSP route for the van, where it is visible a sequential flow between delivery points, and it does not have any path different from the expected.

In figure 6, from point 18 to point 2, to better understand the path that the van must do, we took a picture from the Google Maps that generates the best road route. The projected route can exemplify that none of the routes displayed are in a direct path.

**UAV delivery**

For the UAV/UAS system, we will collect all the distances between pharmacies using Google Maps direct distance tool. To comply with the operation objectives, we need to consider all the constraints of the aircraft, the payload, and endurance. The UAV selected is limited to 15 kg of payload and 25 minutes of maximum endurance.

In the operation scenario, we will start with the construction of a delivery route using the Clarke and Wright Savings algorithm (CW) (Clarke & Wright, 1964). We start to apply the CW algorithm for all the distances between the facility and each pharmacy, applying this method both to daily and emergency delivery.

Following the steps of CW algorithm, the first step will consider all the possible direct routes to each pharmacy, for example: L0 to 1, and return to L0; L0 to 2, and return to L0; and so on until L0 to 22, and return to L0.
In step 2, we calculate all the savings from each group considered in step 1.

In step number 3, we organize by descending order all the savings between each route from step 2. According to the algorithm, the best route to rearrange will be where we can save more distance.

For that reason, in step 4, we assemble all the groups, always having to count the limitations of our operation outline (15kg of payload and 25 min of maximum endurance).

These routes achieved with the CW algorithm are not fully optimized. For that reason, we apply the TSP algorithm to each group with the objective to find an optimal route for our UAV operation (Miller, Zemlin & Tucker, 1960). According to the TSP algorithm, all locations were tested as starting points of the circuit, and the optimized solution is shown further ahead. From the TSP algorithm, the final solution to each group was found. On table 4 and table 5 (section 5.1.2), there are the final routes, each payload transported, the distance traveled, and the time delivery done by the UAV, both for daily delivery and emergency delivery, respectively.

| Routes   | Solution       | Payload [kg] | Distance [km] | Time [min] |
|----------|----------------|--------------|---------------|------------|
| Route A  | L0-13-14-15-L0 | 11,08        | 11,10         | 24,16      |
| Route B  | L0-8-10-12-L0  | 11,08        | 9,49          | 21,73      |
| Route C  | L0-11-9-7-L0   | 11,08        | 9,01          | 21,03      |
| Route D  | L0-20-19-18-L0| 14,71        | 10,99         | 23,97      |
| Route E  | L0-6-21-5-L0   | 11,08        | 8,13          | 19,70      |
| Route F  | L0-1-L0        | 9,26         | 3,38          | 7,57       |
| Route G  | L0-2-L0        | 9,26         | 5,26          | 10,39      |
| Route H  | L0-3-L0        | 9,26         | 5,24          | 10,36      |
| Route I  | L0-4-L0        | 9,26         | 5,06          | 10,09      |
| Route J  | L0-16-L0       | 12,63        | 10,40         | 18,10      |
| Route L  | L0-17-L0       | 13,68        | 10,50         | 18,25      |
| Route M  | L0-18-L0       | 15,00        | 8,08          | 14,62      |
| Route N  | L0-22-L0       | 12,63        | 13,64         | 22,96      |
| **Total**|                | **150,00**   | **110,28**    | **222,93** |

Table 4. Routes for phase 1 UAV daily delivery

| Routes   | Solution       | Payload [kg] | Distance [km] | Time [min] |
|----------|----------------|--------------|---------------|------------|
| Route A  | L0-15-16-L0   | 1,63         | 10,69         | 21,03      |
| Route B  | L0-12-14-13-L0| 1,11         | 10,36         | 23,04      |
| Route C  | L0-11-10-9-L0 | 1,11         | 9,40          | 21,60      |
| Route D  | L0-3-17-18-L0 | 4,53         | 10,59         | 23,39      |
| Route E  | L0-6-7-8-19-L0| 1,48         | 9,07          | 23,60      |
| Route F  | L0-4-5-21-20-L0| 2,03       | 8,76          | 23,14      |
| Route G  | L0-1-2-L0     | 1,85         | 5,43          | 13,15      |
| Route H  | L0-22-L0      | 1,26         | 13,64         | 22,97      |
| **Total**|                | **15,00**    | **77,93**     | **171,90** |

Table 5. Routes for phase 1 UAV emergency delivery

The system/solution used with UAV/UAS will carry 150 kg of daily medicines, go through 110,28 km in a time of 222,93 minutes (3 hours and 42 minutes). For emergency delivery, they will carry 15,00 kg go through 77,93 km in a time of 171,90 minutes (2 hours and 51 minutes).

The final operation scenario is presented in figures 7 and 8 with the routes displayed over the map of Aveiro, both for daily delivery and emergency delivery with the UAV/UAS system.
5.2. Phase 2

Conventional delivery

The first objective is to deliver medicines into the pharmacies from L0 using a van. This operation is the same presented in phase 1. Summing up, with the data collected for vehicle routing generated automatically in Google Maps. The lowest possible value of total distance computed with the TSP algorithm is presented in phase 1, on Table 3 and 4 (Miller, Zemlin & Tucker, 1960).

Facility location for the UAV

The operation for UAV/UAS starting from a new facility will initiate by selecting between 4 possible locations, with the purpose of optimizing the new route that we pretend to create.

We start by collecting all the distances between each pharmacy and each possible facility (L0, L1, L2, and L3), (Figure 9). The values are in kilometers as a referential to the dislocation of a mobile logistic base.

The algorithm of uncapacitated FLP has the objective to minimize the equation 1 (Conforti et al., 2014). This will be done to all the facilities, and the one with the lowest value of kilometers will be the optimal choice. First, we establish all the variables:

- $c_{ij}$ – travel costs in kilometers between the facility and the delivery point;
- $d_i$ – annual demand that leaves each facility;
- $y_{ij}$ – annual demand fraction of $d_i$ of each facility;
- $f_j$ – facility operating cost;
- $x_j$ – if the facility is open, the value is 1. If not, the value is 0.

Min \[ \sum_{i=1}^{M} \sum_{j=1}^{N} C_{ij}d_{ij} + \sum_{j=1}^{N} f_j x_j \] \quad i=1,\ldots,M \quad (1)

\[ \sum_{j=1}^{n} y_{ij} = 1 \] \quad i=1,\ldots,m \quad (2)

\[ \sum_{j=1}^{n} y_{ij} \leq mx_j \] \quad j=1,\ldots,n \quad (3)
\[ y \in \{0,1\}^m \times n, \quad x \in \{0,1\}^n \]  

Adapting to our operation scenario, we will consider \( c_{ij} \) as the distance between each possible facility and each pharmacy. For \( d_i \), this information is not possible to know. For that reason, we establish an annual demand equal to every facility with a value of 1, where \( y_{ij} \) will also be considered equal to each facility, with the value of 1. The value of operating cost is established as the implementation cost, \( f_j \), in kilometers, and the facility will be considered as open, taking the value of 1 for \( x_j \). Applying equation 1 to each facility, we conclude of an annual cost presented in Table 6.

On the development of the FLP algorithm, it was tested if there was any client that could compensate for reallocating anywhere. Pharmacy number 1 could be changed to facility L0, although, in order to simplify the model tested, it would not offset build another facility only for one client.

The solution from the implementation of the uncapacitated FLP algorithm concludes that the optimal location for the mobile logistic base will be L2 with an annual total of 29033.56 kilometers done (Figure 9).

| Location | Annual cost [km] |
|----------|------------------|
| L1       | 66006.60         |
| L2       | 44201.50         |
| L3       | 29033.56         |
| L4       | 39285.68         |

Table 6. Final annual cost in km for each facility location

Figure 9. Operation scenario for delivery. (Based on satellite view from “Direção Geral do Território” (DGT) (Direção Geral do Território, 2020)

UAV/UAS delivery

In this subchapter, we will implement an optimal route for the UAV using the CW algorithm and optimizing with the TSP algorithm, for that, we will use the new logistic base L2. The outcome of the new operation scenario is presented in figure 9.

For this new operation scenario, we will start with the construction of a delivery route using the CW algorithm (Clarke & Wright, 1964). We start to apply the CW algorithm for all the distances between each pharmacy and the logistic base. We apply this method both to daily and emergency delivery.

Following the steps of the CW algorithm, the first step considers all the possible direct routes to each pharmacy, for example, L2 to 1, and return to L2; L2 to 2, and return to L2; and so on until L2 to 22, and return to L2.

In step 2, we calculate all the savings from each group considered in step 1.

In step number 3, we organize by descending order all the savings between each route from step 2. According to the algorithm, the best route to rearrange will be where we can save more distance.
For that reason, in step 4, we assemble all the groups, always having to count the limitations of our operation outline (15 kg of payload and 25 min of maximum endurance). These routes achieved with the CW algorithm are not fully optimized. For that reason, we apply the TSP algorithm to each group intending to find a near optimal route for our UAV (Miller, Zemlin & Tucker, 1960).

From the TSP algorithm, the final solution to each group was found. In Table 7 and Table 8, we present the final routes, each payload transported, the distance traveled, and the time delivery done by the UAV, both for daily delivery and emergency delivery, respectively.

| Routes | Solution     | Payload [kg] | Distance [km] | Time [min] |
|--------|--------------|--------------|---------------|------------|
| Route A | 0-12-10-8-9-0 | 14,78        | 3,86          | 15,80      |
| Route B | 0-6-19-20-7-0 | 14,78        | 3,70          | 15,55      |
| Route C | 0-11-13-14-15-0 | 14,78   | 4,57          | 16,85      |
| Route D | 0-5-21-0     | 7,39         | 1,721         | 7,59       |
| Route E | 0-1-0        | 9,26         | 4,5           | 9,25       |
| Route F | 0-2-0        | 9,26         | 4,14          | 8,71       |
| Route G | 0-3-0        | 9,26         | 2,58          | 6,37       |
| Route H | 0-4-0        | 9,26         | 2,88          | 6,82       |
| Route I | 0-16-0       | 12,63        | 2,78          | 6,67       |
| Route J | 0-17-0       | 13,68        | 3,96          | 8,44       |
| Route L | 0-18-0       | 15           | 3,1           | 7,15       |
| Route M | 0-18-0       | 7,31         | 3,1           | 7,15       |
| Route N | 0-22-0       | 12,63        | 5,96          | 11,44      |
| **Total** |             | 150          | 46,85         | 127,78     |

Table 7. Daily delivery optimized with TSP optimization for UAV/UAS

| Routes | Solution     | Payload [kg] | Distance [km] | Time [min] |
|--------|--------------|--------------|---------------|------------|
| Route A | 0-11-9-8-10-12-14-0 | 2,22        | 4,62          | 24,43      |
| Route B | 0-15-16-22-17-0 | 4,26         | 7,70          | 24,04      |
| Route C | 0-13-7-20-19-6-21-5-0 | 2,59   | 4,61          | 24,41      |
| Route D | 0-4-3-1-2-18-0 | 5,94         | 7,50          | 23,76      |
| **Total** |             | 15,00        | 24,43         | 96,65      |

Table 8. Emergency delivery optimized with TSP for UAV/UAS
6. Comparative analysis

6.1. Phase 1: results analysis

We start by looking for the results of tables 3, 4, 5, 7 and 8 of chapter 5. These results will be compared separately by daily delivery and emergency delivery, wherein one side there is the Van delivery, and on the other side is the UAV/UAS delivery. The timeline for this comparison will be a full year of work (365 days). Remembering that, the UAV only will be able to operate on 274 days, as it was shown in chapter 3 of the operation outline. The other 91 days will be operated with the van.

The first data to be compared is the daily delivery from tables 3 and 4. In table 9, we proceed to assemble all the total values for all payload transported, the total distance, and the time travel of the full year.

The values of Table 9 show that the use of a van will bring less distance traveled and with less time travel than using the UAV/UAS and van system. This outcome can bring some questions about the UAV/UAS capabilities since the results show that this system does not have values close to the van system. The reason we encounter this to happen is due to the significant demand of the pharmacies compared to the UAV payload, forcing the aircraft to go through the same route twice, and also, this compels the UAV to return to the logistical base to replenish the payload. All these extra kilometers will have a large effect on time travel. Another concern is the volume that 15 kilograms can represent, for nowadays UAV technology, this might be nearly impossible. On the other hand, the van delivery system is completed in only one journey. This delivery is possible due to high payload capability and endurance.

Considering now the emergency delivery, the results from tables 3, and 5 are analyzed. The Table 10 gathers the total values of payload distance and time travel.

In this scenario, the van has less total distance traveled, as well as total delivery time. Although, there is one important thing to retain, the UAV/UAS and van system has more 11,522,25 km traveled than the van delivery, but only differentiate in 8,466,05 minutes in time traveled (141 hours). In a full year of work, this difference is almost as none. In this scenario, the maximum payload of the UAV is not considered a problem, but due to a long-distance traveled between the logistic base and the pharmacies, the maximum endurance of the UAV is reached. For example, the route H (see table 6, from subchapter 4.1.2) can only deliver to pharmacy 22 due to having a flight time of 22,97 minutes, being close to the endurance limit of 25 minutes.
6.2. Phase 2: results analysis

Going through the results shown on Tables 3, 4, 8, and 9, we compare both for the daily and emergency delivery, between the van delivery system and the UAV/UAS and van delivery system. To compare, we assume a full year of work (365 days), where due to weather conditions limitations, the UAV will operate for 274 days, and the van will complete the other 91 days.

The first data to be compared is the daily delivery from tables 3 and 8, wherein Table 11, we show all the total values for all payload transported, the total distance, and the time travel of an all year.

In this scenario, the system with UAV/UAS and van has the lowest accumulated time travel in comparison to the van system. The values of the distance traveled, the van does lower values, which could mean that the UAV/UAS and van system is faster, mostly due to direct paths that the UAV can do between delivery points. These results are very satisfying from the UAV/UAS system perspective, it shows a competitive performance. Although, theses payloads can be with enormous volumes, meaning an impossible task for nowadays UAV technology. For future UAV aircraft, this is one important limitation to study.

The second data to be compared is the emergency delivery, wherein Table 12, we gather all the values for all payload transported, the total distance, and the time travel of an all year.

In this scenario, the best system is undoubtedly the UAV/UAS and van distribution. The values from the operation implementation show, lower distance and time travel for the UAV/UAS and van, being the difference between systems of 202 hours and 12.153,27 kilometers. From these results, the UAV/UAS evidence that it would be the best choice to implement this delivery.
34-52

Table 11. Total for daily distribution performance of each delivery system

|                         | With van | With UAV and van |
|-------------------------|----------|------------------|
| Total payload [kg]      | 54,750,00| 54,750,00        |
| Total distance [km]     | 13,096,20| 16,102,52        |
| Total delivery time [min]| 51,465,00| 47,842,17        |

Table 12. Total for emergency distribution performance of each delivery system

|                         | With van | With UAV and van |
|-------------------------|----------|------------------|
| Total payload [kg]      | 5,475,00 | 5,475,00         |
| Total distance [km]     | 13,096,20| 9,958,9          |
| Total delivery time [min]| 51,465,00| 39,311,73        |

6.3. Associated costs

These systems, when implemented, will have associated costs of implementation and maintenance. For that reason, we try to foresee the cost of each system during 50,000 kilometers in a way to compare both systems, the conventional and the UAV/UAS. This comparison is based on the data collected from the UAV companies as also as from van companies, where is presented the implementation cost for both systems and an estimative for maintenance costs. We show in Table 13 all the information needed to compare total cost associated and the price per kilometer that each system will charge.

The difference between one vehicle and the other is not so great. Even though the UAV cost is more expensive than the van, there are several other UAVs in the market at a more affordable price, quickly becoming a chipper vehicle in terms of cost per kilometer. This UAV was chosen due to its endurance and payload capabilities. Another point to enhance is the fact that this technology is at the beginning of its evolution path, becoming an expensive acquisition. We can foresee that in the future of the UAV market, the competition between builders will increase, and the prices will decline into more attractive prices. The maintenance of a UAV is almost inexistence, and in this case, the cost of the UAV comes with all systems integrated and spare batteries.

The price per kilometer in 50,000 km will be used as a reference for the implementation costs of each delivery system. For this analysis, we take the information collected from our case study results together with the costs of implementation. The construction of this delivery system will depend on where it can be beneficial or not for the logistic company. For that reason, we assemble table 14, assuming the cost per kilometer and the travel distance done in one year.

For the UAV and van system, the solution comes from the equations 5 and 6.

\[
Total \ cost_{VAN} = (vankmcost) \times d1 \times d2 \tag{5}
\]

\[
Total \ cost_{UAV/VAN} = (UAVkmcost) \times d1 \times d2 + (vankmcost) \times d1 \times d2 \tag{6}
\]

Table 13. Implementation costs for each vehicle

| Associated costs | Van system | UAV/UAS system |
|------------------|------------|----------------|
| Vehicle cost     | 25160,00 € | 40000,00 €     |
| Fuel cost        | 5567,50 €  | 0 €            |
| Recurring costs  | 7500,00 €  | 0 €            |
| Cost per kilometer | 0,76 €/km | 0,80 €/km     |
| Total cost       | 38227,50 € | 40000,00 €     |
where:

- \(d_1\): distance per day
- \(d_2\): working days

| Phase 1 | Daily | Urgent |
|---------|-------|--------|
|         | Van   | UAV and Van | Van   | UAV and Van |
| Distance [km] | 13,096,20 | 33,482,90 | 13,096,20 | 24,618,45 |
| Cost per km [€] | 0,78 | UAV=0,80, VAN=0,78 | 0,78 | UAV=0,80, VAN=0,78 |
| Total cost [€] | 10,215,04 (2) | 26,721,02 (3) | 10,215,04 (2) | 19,629,46 (3) |

| Phase 2 | Daily | Urgent |
|---------|-------|--------|
|         | Van   | UAV and Van | Van   | UAV and Van |
| Distance [km] | 13,096,20 | 16,102,53 | 13,096,20 | 9,958,90 |
| Cost per km [€] | 0,78 | UAV=0,80, VAN=0,78 | 0,78 | UAV=0,80, VAN=0,78 |
| Total cost [€] | 10,215,04 (2) | 12,816,72 (3) | 10,215,04 (2) | 7,901,82 (3) |

Table 14. Total implementation costs for a full year

In all systems studied, the van remains the more affordable system to be implemented, even though for urgent delivery starting from facility L2, the use of a UAV will be the best option, that could save at the end of the year around 2313 €. For daily delivery, the UAV/UAS and van system are not yet the best option, even though in the near future, this technology will improve and allow a more competitive delivery system.

7. Conclusion

The initial process for this paper was to set the object and the objectives, where it was agreed to analyze the future of urban logistics. Based on this thought, we set the study of urban logistics as the object of this work to study this subject, we faced numerous solutions to improve urban logistics and study its viability. For that reason, the use of UAV in an urban environment was the optimal choice due to worldwide interest on this technology and the incredible progress that has been made in other projects and investigations. We set as objectives for this study to study the urban logistics; to study the possible future of urban logistics; implement and study an urban delivery scenario; optimize this scenario in order to make UAV more competitive; and find the best solution for the urban logistic system.

The importance of this work was shown in chapter 2, where we did a literature review of all concepts and all the urban logistic processes. The working chain of a city stands interconnected through the logistics industry. As it was showed, the urban environment depends on the logistic chain that supplies the city. This research found several limitations that could jeopardize the future of city logistics. For that reason, we went in search of new solutions, and among the several good ideas, one that stands out is the use of UAV/UAS for delivery and supply. To support this idea, we search for examples of implementation in the real world, having found several examples that can support the viability of this system.

To better understand the UAV/UAS, we introduce the concept of aircraft that it was possible to find and achieve the nest results for our purposes. Through this research, we found several advantages that could be in favor of our objectives, although the main problem was the lack of legislation to operate in the urban environment, which could explain why the examples shown were always prototypes and never daily deliver systems. The legislation is one crucial factor to the survival of this technology. At the same time, this technology evolves, the legislation needs to adapt and make sure that this industry will be as safe as the nowadays aeronautical industry.

The study case implementation was done successfully in the city of Aveiro. The research done on the topography and demography of the area enables a more sustained study. In the implementation, we create a network for each delivery system, both for daily and emergency delivery. For each distribution were created two
phases for the investigation. The first phase studied the delivery departing from the logistic base exiting in the industrial area. In the other way, phase 2 studied the delivery departing from a new logistic base. The algorithms brought in the literature review were possible to optimize the distribution and achieve plausible results according to the industry’s current analysis. In the implementation of phases 1 and 2 of the delivery systems for each vehicle, we were very successful, having found no problem in the implementation of the algorithms or the construction of the delivery paths. The operating limits were always respected, and the optimal routes were found.

The outcome from the analysis of all operations implemented reached a consensus. The use of nowadays conventional delivery system with a van it is still the best option for long distance, heavy payloads, and big volumes. The limitations of UAV/UAS were enhance on this study, where the vehicles were obligated to return the base several times due to payload and endurance limitations. Although the UAV/UAS won one delivery path, the emergency medicine delivery departed from L2. In this case, the best option, both for performance and implementation costs, the UAV had the lowest values, making it the ideal choice. Other routes also had better performance done by the UAV, although due to implementation costs, it is not viable to implement for now, according to our operation scenario.

In a future approach, this technology will have other attributes, making it possible to perform equal to a van or even better in any scenario. On the contrary, the use of van vehicles can decrease in the urban environment, as it was stated in the literature, urban areas are repelling road vehicles with new legislation and even more crowded spaces. There is expected that the conventional vehicle will adapt, changing to electric vehicles and maybe even autonomous (e.g., sidewalk Droids), as was demonstrated in the state of the art. For now, the technology that is most prepared to enter the world of logistics is that of UAV/UAS.

A limitation is the fact that we do not consider the volume of medication packages. For specific routes, a high payload would represent a volume too large to be incorporated in the UAV. However, our main objective was to devise a UAV route, so our type of payload is not our main concern.

We can also consider as a limitation the non-implementation of a test system, with platforms for landing and take-off, however again, we intended only to focus the study on a conceptual distribution with UAV and compare to the current system, trying to understand which would be the best option.

For future investigation, several studies can take this work as a starting point. This investigation limitation can be one critical study, for example, with the several distribution systems implemented, investigate the possibility of safe landing platforms near to each pharmacy or several pick-up points with an optimized location for several pharmacies.

Nevertheless, the objectives of this work were achieved. There was found a consensus in the use of UAV/UAS for the management of urban air logistics.

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