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Management of Urban Air Logistics with Unmanned Aerial Vehicles.

The Case of Medicine Supply in Aveiro, Portugal

(Versão corrigida após defesa de dissertação)

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Dedication

To Madalena.

"Success is not final; failure is not fatal: It is the courage to continue that counts."

Winston S. Churchill

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A special blessing to my girlfriend for all the patience and help given, without her, I would not be able to accomplish this thesis. *Thank you* for the motivation!

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Resumo

O meio urbano tem evoluído durante os últimos 50 anos, onde se verificou uma enorme aposta na logística urbana, por forma a tornar as tarefas urbanas mais eficientes e económicas. Esta investigação tem como objeto o estudo da logística urbana e tem como objetivo, aprofundar e estudar a estrutura atual dos sistemas de logística e analisar o que poderá ser o futuro próximo. Atualmente, a maior aposta tecnológica no mundo da logística é a aeronave não tripulada (UAV). Posto isto, tem-se também como objetivo analisar o funcionamento destas aeronaves, nomeadamente, as suas capacidades e limitações. Partindo de um cenário de logística urbana com recurso a UAV's, pretendemos estudar e comparar o processo de entregas nesse mesmo meio urbano.

A implementação do teatro de operações será na cidade de Aveiro e consiste na entrega de medicamentos às farmácias localizadas no meio urbano. Com este estudo tencionasse encontrar a melhor solução atual e prever uma futura que se adeque à operação apresentada.

O estudo está dividido em várias partes. Primeiramente, começamos por uma análise da literatura e seguido uma análise SWOT. Por fim, no caso de estudo são implementadas várias rotas de entregas a farmácias, quer para medicamentos de entrega diária, quer de emergência. O sistema de entregas está dividido em duas fases, uma onde inicialmente a partida dos veículos seria feita na atual base de logística e outra onde o veículo parte de uma base logística proposta, que estará otimizada ao percurso de entrega que se pretende realizar.

Das várias análises realizadas obtivemos resultados muito conclusivos. Para rotas de grande carga e distância, o UAV não consegue ter grandes desempenhos, sendo ainda preferencial a utilização da uma carrinha. Contudo, verificamos que para entregas de emergência, o UAV teria um melhor desempenho a partir da nova base de logística, e para além disso, o sistema de implementação seria mais barato. Numa análise futura, prevemos uma concorrência muito forte por parte do UAV, visto que em alguns resultados a performance deste é próxima ou melhor do que a carrinha. Sendo uma tecnologia emergente, em breve terá melhores capacidades e preços mais concorrentes. As reduções de custos deste tipo de entregas poderão em breve ser possíveis com a utilização de um UAV.

Palavras-chave

Veículos aéreos não tripulados (UAV); Sistemas aéreos não tripulados (UAS); Acessibilidade; Espaço aéreo urbano; Logística urbana; Otimização de rota; Localização das instalações;

Resumo Alargado

Motivação

O futuro da logística urbana é uma das áreas mais estudadas e investigadas nos dias atuais. Devido ao crescimento da população e dos serviços prestados, existe atualmente um grande aumento do tráfego urbano. Isto, promove uma maior necessidade de mobilidade e acessibilidade nas cidades. Surge assim, uma carência no controlo e otimização do tráfego urbano. Diretamente relacionada está a logística urbana, que depende das condições de acessibilidade e capacidade de escoamento do tráfego, o que permite uma entrega mais rápida e por sua vez, mais rentável [1]. No ambiente urbano existem várias etapas dos sistemas de logística, desde do transporte de mercadorias até à entrega ao cliente final. Numa abordagem aos transportes de mercadorias, a indústria usa principalmente carrinhas utilitárias, que também são usadas nas entregas ao cliente final [2]. Porém, para esta entrega, existem diversos veículos que executam esta tarefa, desde motociclos até carros comerciais (a combustão ou elétricos) ou ainda a pé [3]. A logística urbana de hoje depende de transportes terrestres, mas isso não significa que se mantenha igual num futuro próximo.

O serviço de entrega ao cliente final pode melhorar com o transporte aéreo, onde veículos aéreos não tripulados (UAV) são propostos como uma nova solução. Os UAV's têm muitas aplicações, como entregas, vigilância de infraestrutura, busca e salvamento, monitoramento agrícola e outros serviços [4]. Por isso, é urgente investigar se esta solução se adequa a mais serviços, neste caso, empresas de logística, para otimizar os serviços prestados. Nas figuras 1 e 2, encontram-se alguns exemplos de UAV's propostos para entregas de mercadorias.

Figure 1 - Amazon prime air UAV. Fonte: [5].

Figure 2 - Google X. Fonte: [6].

Objeto e Objetivo

Começamos por questionar, será possível usar UAV/UAS na logística urbana especialmente para o transporte de mercadorias e prestação de serviços?

Este estudo pretende responder a esta pergunta da seguinte forma. O objeto desta investigação focasse na logística urbana e terá como objetivo verificar o estado atual da logística em meio urbano, nomeadamente, a sua evolução e um possível futuro. Para além disso, pretende-se estudar um cenário de entregas no meio urbano, onde iremos aplicar este possível sistema UAV/UAS, que será otimizado e em concordância com os fatores e limitações propostos pela operação.

Por fim, como objetivo final, pretendemos encontrar a melhor solução para uma abordagem à logística urbana, quer para os dias de hoje, quer futuramente.

Metodologia

A metodologia prende-se numa abordagem conceptual de um cenário de operação com o uso de UAV/UAS na logística urbana. Este estudo iniciará com uma visão geral dos sistemas de logística urbana de hoje, bem como uma introdução ao UAV/UAS para melhor compreensão desta tecnologia. Também iremos abordar quais os algoritmos que melhor se adequam na procura da rota ótima para entregas. Por forma a obter várias conclusões, esta tese irá comparar, o sistema de logística urbana (por exemplo, entrega com carrinhas) com a aplicação de UAV/UAS no mesmo sistema de entregas. A comparação começa com uma análise SWOT, que consta na avaliação dos pontos fortes, fracos, oportunidades e ameaças, descritos para cada um dos sistemas de logística. A próxima fase da metodologia centra-se na implementação do caso de estudo com um possível cenário de entregas de medicamentos na cidade de Aveiro. O caso de estudo está dividido em várias partes. O primeiro atenderá todos os requisitos exigidos pelas empresas farmacêuticas, bem como todas as limitações que o UAV/UAS e o sistema de logística convencional (por exemplo, entregas com carrinha) possam ter. Para tal, construímos um cenário de operação (ver figura 3). Em seguida, dividimos a implementação das entregas em duas fases. Na fase 1, implementamos uma rota de entrega a partir da base de logística atualmente existente, tanto para entrega com carrinha, como também de UAV/UAS. As entregas devem ser realizadas diariamente e em caso de emergência. Para a fase 2, pretende-se criar uma rota de entrega para o UAV/UAS que terá início numa nova base logística. Esta base será escolhida entre vários locais possíveis a fim de obter o mais próximo do ideal (L0, L1, L2 ou L3). Partindo do mesmo princípio, iremos obter as rotas finais para o percurso do UAV/UAS e comparar com a rota do veículo convencional. Também para este sistema se aplica a entrega de medicamentos diários e em caso de emergência.

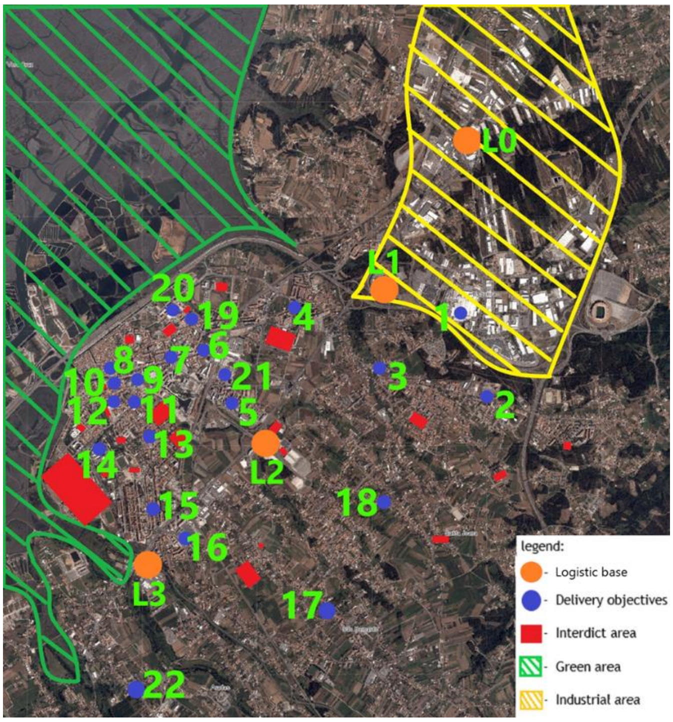

Figure 3 - Cenário de operação na cidade de Aveiro. Fonte: Elaboração do autor baseado em imagens satélite da Direção Geral do Território (DGT) [7].

Análise e Resultados

O estudo obteve diversos resultados importantes. A análise SWOT foi essencial para a conclusão desta dissertação e permitiu-nos responder alguns dos nossos objetivos iniciais. Concluímos que para a logística urbana atual, o uso de um sistema de entrega convencional é a escolha óbvia para operar. Porém, o que o futuro reserva para este sistema poderá não ser tão agradável. Além do tamanho superior do veículo e das futuras legislações de trânsito, os núcleos urbanos das cidades poderão tornar-se inacessíveis. Para o UAV/UAS como uma tecnologia que ainda se encontra em desenvolvimento inicial, apresenta muitas limitações. Contudo, esta tecnologia verifica muitas oportunidades que em breve poderão superar o veículo convencional. Existem alguns problemas que um sistema de entregas convencional nunca irá superar, como por exemplo, uma rota direta de entregas e acesso a locais onde é proibido para veículos rodoviários. Esta desvantagem, torna-se a principal vantagem do UAV/UAS. Além disso, é um sistema ecológico de baixo consumo de materiais na sua construção e funciona com energia elétrica, que pode ser facilmente gerada através de fontes renováveis. Por estes motivos, o UAV/UAS foi considerado na análise VRIO (Value, Rarity, Imitability and Organization) uma tecnologia competitiva que não pode ser utilizada devido a fatores legislativos.

O resultado das análises de todas as operações implementadas chegou a um consenso. A utilização do sistema de entregas convencional atual com uma carrinha, continua a ser a melhor opção para longas distâncias, cargas úteis elevadas e grandes volumes. As limitações do UAV/UAS foram realçadas neste estudo, onde este foi obrigado a retornar à base logística várias vezes devido a limitações da carga útil e autonomia. Embora tenhamos chegado a essa conclusão, foi realizada uma rota de entregas pelo UAV/UAS de medicamentos de emergência partindo de L2, onde se verificou ser o veículo preferencial, quer em performance e custos de implementação. A base logística L2 foi considerada pelo estudo como sendo a melhor localização para uma entrega mais eficiente. Em outras rotas o UAV também obteve melhor desempenho, embora devido aos custos de implementação não seja ainda viável, segundo o nosso cenário de operação.

Numa abordagem futura esta tecnologia terá outros atributos, sendo possível ter um desempenho igual ou até superior aos veículos convencionais. Pelo contrário, o uso de carrinhas pode diminuir no meio urbano, como já foi afirmado por inúmeros autores da literatura. Assim sendo, a tecnologia com maior potencial e que está mais bem preparada para entrar no mundo da logística é o UAV/UAS.

Os objetivos desta dissertação foram alcançados, tendo sido encontrado um consenso na utilização de UAV/UAS para a gestão da logística aérea urbana.

Abstract

The evolution of the urban environment has changed significantly in the last 50 years, and we see considerable investments in urban logistics in order to make urban processes more efficient. This investigation intends to study the situation of urban logistics with the objective to study the current state of this system and analyze what lies ahead in the near future. The unmanned aerial vehicle (UAV) has been under investigation in the world of logistics, having been pointed has the next logistic technology. For that reason, we set as an objective, analyze the working process of this aircraft, its capabilities, and its limitations. 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 on 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.

The study is divided into several studies, starting with an analysis of the literature, and then we carry out the SWOT analysis. Then we implement a delivery route to pharmacies, both for daily delivery and emergency medicines. The analysis is divided into two phases, one where the vehicles would initially start from the current logistical base and another phase, where the logistical base is proposed for a new location, that has been optimized to the delivery route to be carried out.

From the various analyzes carried out, we obtain very conclusive results. For routes of significant payload and distance, the UAV is still not able to have great performances, being still preferential the use of a van. However, we verified that for emergency deliveries, the UAV from the new logistics base (L2) would have the best performance, as well as it would be a low cost of implementation. In some results, the performance was close to the van or even better, although it would not be cost effective. For that reason, we foresee a robust competition from the UAV as an emerging technology. It will soon have better capabilities and more competitive prices. The cost reduction of this type of deliveries may soon be possible with the use of UAVs.

Keywords

Unmanned aerial vehicles (UAV);Unmanned aerial systems (UAS);Accessibility;Urban airspace;Urban logistics;Route optimization;Facilities location.

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List of Acronyms

ANF – Associação Nacional de Farmácias

APL – Automated Parcel Lockers

BVLOS- Beyond Visual Line of Site

CC – Congestion Charging

CW – Clarke and Wright

DETR – Department of the Environment, Transport and the Regions

DGT – Direção Geral do Território

EASA – European Union Aviation Safety Agency

FAA – Federal Aviation Administration

FLP – Facilities Location Problem

GPS - Global Positioning System

ICAO – International Civil Aviation Organization

LEZ – Low Emission Zones

NHS – National Health System

ODD – On Demand Delivery

OECD – Organization for Economic Co-operation and Development

PANS – Procedures for Air Navigation Services

RPA – Remote pilot aircraft

SARP's – Standards and Recommended Practices

SPB – Smart Parcel Box

SWOT – Strengths, weakness, opportunities and threats

TSP – Traveler Salesman Problem

UAS - Unmanned Aerial System

UAV - Unmanned Aerial Vehicle

UVAR- Urban Vehicle Access Regulations

VLOS – Vertical Line of Sight

VLOS – Visual Line of Site

VRIO – Value, Rarity, Imitability and Organization

VRP – Vehicle Routing Problem

VTOL – Vertical Take-off and Landing

Chapter 1

Introduction

1.1 Motivation

The future of urban logistics[1] 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 right flow and accessibility, for a fast and more profitable delivery [1]. There are several stages of the logistic system in the urban environment, 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 [2]. 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 [3]. 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 [4]. 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. In figures 4 and 5, there are some examples of UAV proposed for the delivery of goods.

Figure 4 - Amazon prime air UAV. Source: [5]

Figure 5 - Google X. Source: [6]

[1] For the purpose of this work we use Urban Logistics and City Logistics as the same concept.

For a logistics case, UAV could be a solution in urban center logistics, such as inspection, mapping, disaster response, delivery. At the same time, we have an extensive industry trying to make this solution profitable [8].

Although we must ask: is it possible to use UAV in urban logistics, especially for the transport of goods and provide services?

The first answer that comes up to our head would be, yes, and it is possible, although with many constraints. Transportation of goods and city logistics will always try to improve and optimize, to become more sustainable and, at the same time, satisfy the final customer. With the recent events of Amazon drones' trials, the use of UAV and unmanned aerial systems[2] (UAS) technologies have demonstrated that they can be part of this chain [9].

Pharmacies are an example of urban logistics chains. The goal of delivering medicines must be fast and efficient in a way to never create a stock failure that could jeopardize human lives. Margaret Eichleay, with a master in public health, stated that the "interest in using UAVs to transport medical goods is currently high, but the health sector lacks structured guidance to systematically consider the feasibility, utility, and impact of using UAV transport and evidence regarding implementation" [10][3]. This statement emphasizes that there is a need to compare and study the best logistic system to be applied in the delivery of the medicines because the use of UAV could be the next solution.

More than never, there is a need to increase the level of effectiveness in the use of UAVs. For that reason, we propose this thesis on the management of urban air logistics with unmanned aerial vehicles.

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[2] Unmanned Aircraft System (UAS) means an unmanned aircraft and the equipment to control it remotely.

[3] [10], pp 504.

1.2 Object

The object of this thesis is urban logistics that has been one of the most important chains of a city. The Organization for Economic Co-operation and Development (OECD) stated that "(…) freight transport is a fundamental component of urban life. Globalization of economic activities, changes in consumer behavior, and developments in advanced technologies have led to many developments (…)"[4], such as a worldwide chain of transportation between the manufacture and the seller. This procedure led to a reduced inventory and a more just-in-time business. With the improvement of the transportation systems, customers become part of this supply chain, also, due to the rapid development of electronic commerce (e-commerce) [11].

1.3 Objective

This thesis aims to firstly study today's network of logistics in urban areas and then to approach and study a possible tomorrow's network.

The next focal point is a possible scenario for the future of logistics in urban areas. The study case proposed is in the city of Aveiro, where the topography is preferential for a first approach to the UAV/UAS delivery concept. Aveiro has a significant industrial area in the north peripheral side and by the west and northwest side, a natural reserve and protected area of "Ria de Aveiro". Besides that, Aveiro is relatively flat, being the only existing immobile obstacles, buildings, electrical poles, or trees [12].

In the city, this thesis will propose the location of the distribution points, as well as a mobile logistic base, with the final purpose of optimizing the location of the mobile base according to the better distribution network for UAV/UAS delivery.

In figure 3, there is a satellite image of the city of Aveiro. In blue are the pharmacies that we consider as delivery points; inside the yellow area, we have the industrial area; in red, all the interdict infrastructures, due to privacy legalities; and in green, the natural reserve of "Ria de Aveiro".

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[4] [11], pp 8.

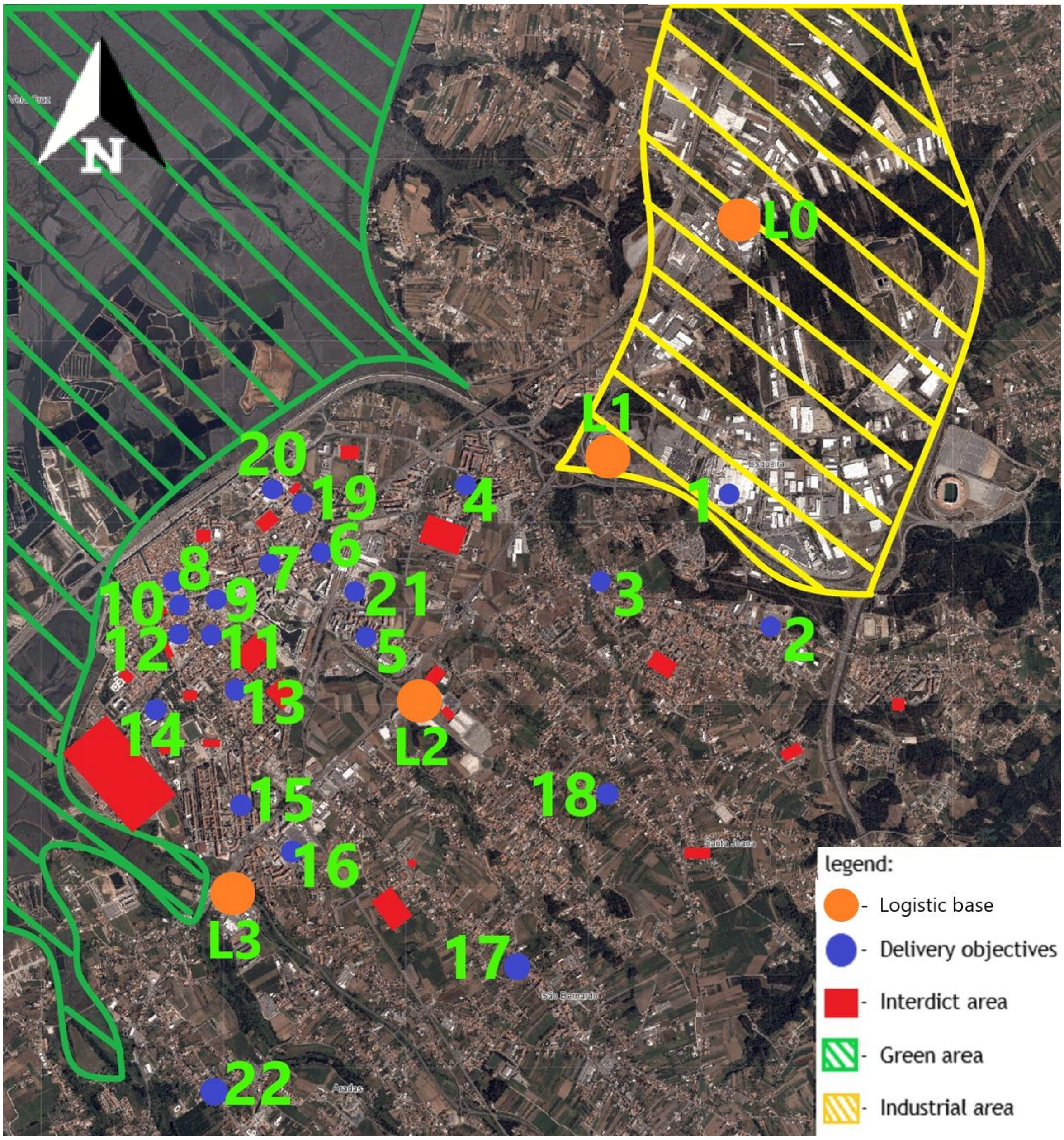


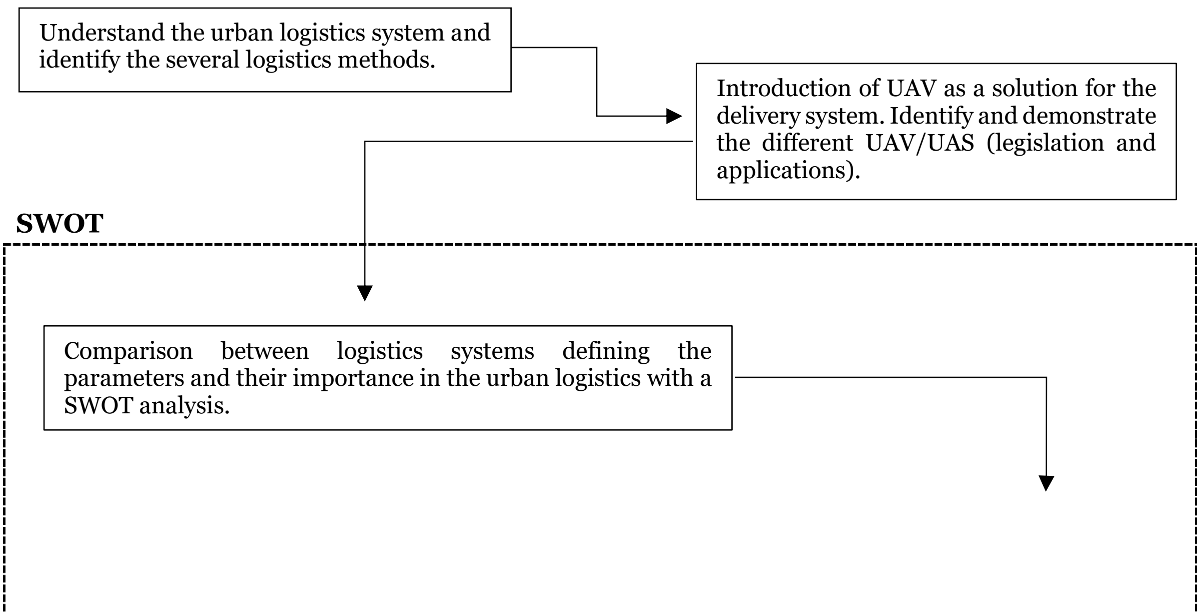
Figure 6 - Aveiro map with the operation scenario. Source: Own elaboration based on satellite view from “Direção geral do território” (DGT) [7].

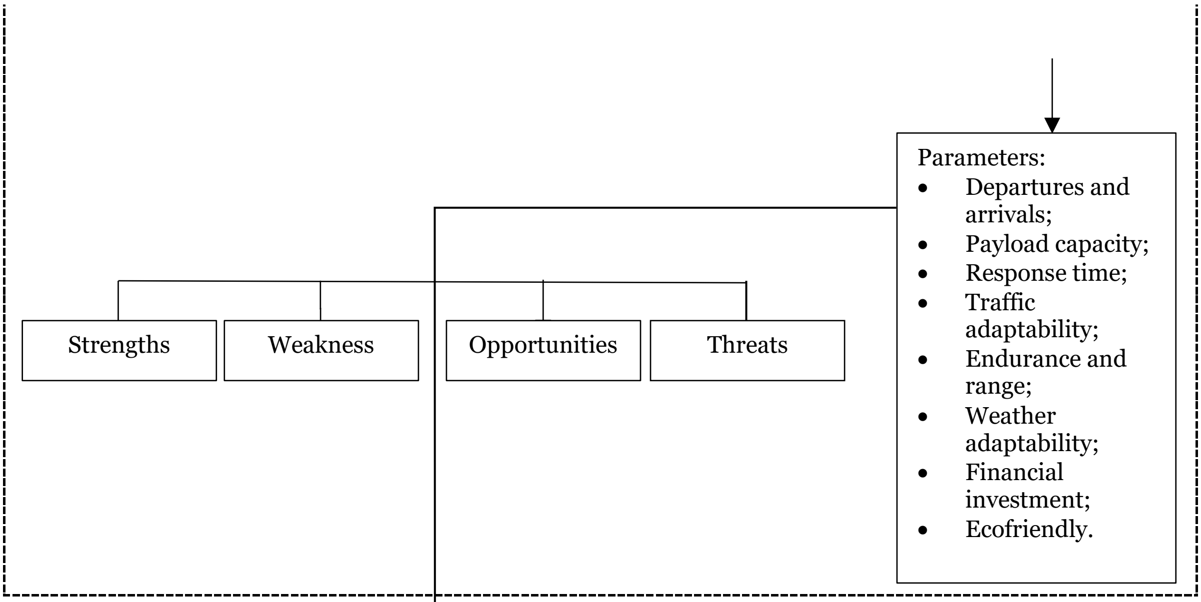
1.4 Keywords

Unmanned aerial vehicles (UAV); Unmanned aerial systems (UAS); Accessibility; Urban airspace; Urban logistics; Route optimization; Facilities location.

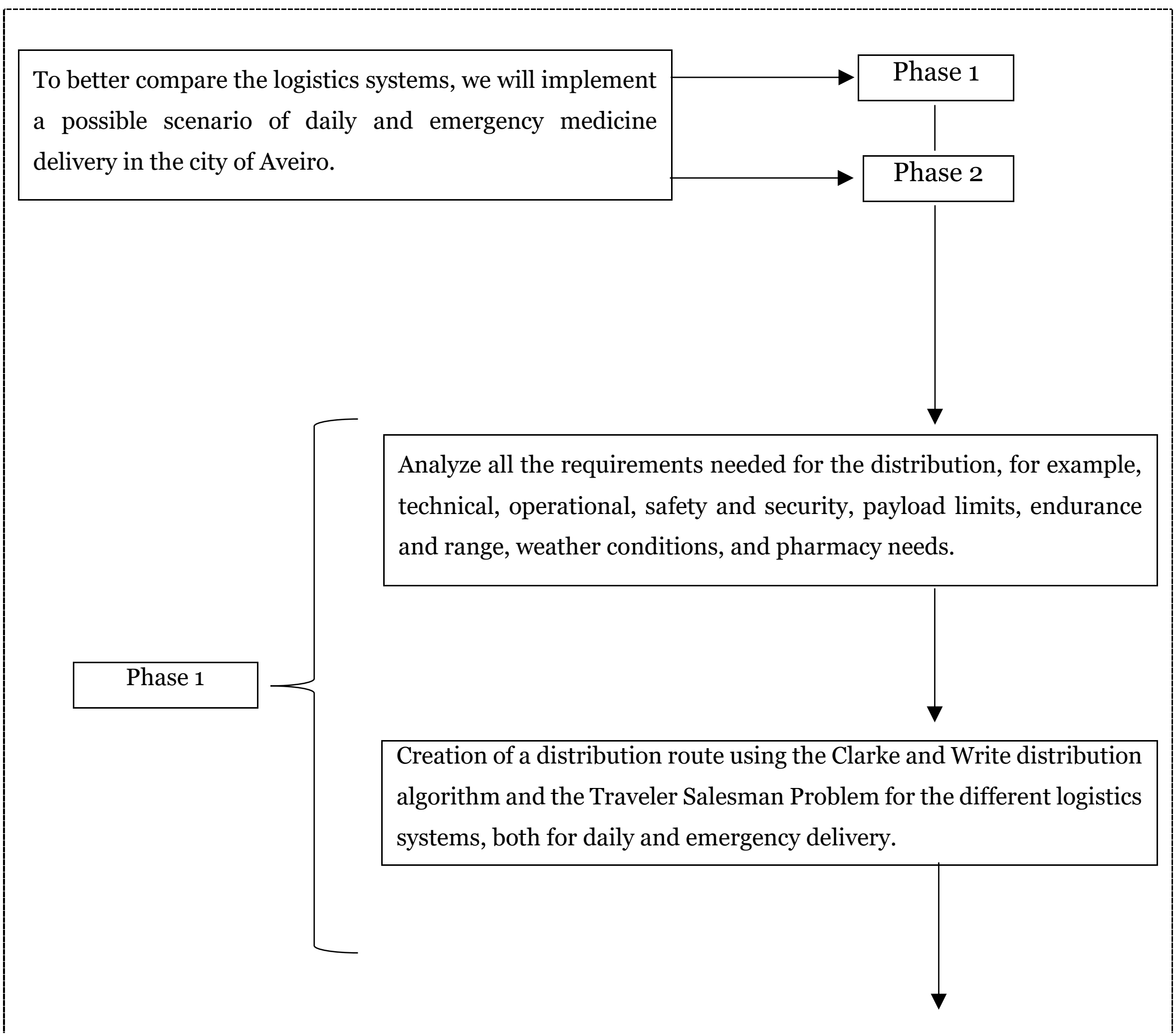
1.5 Methodology

The methodology pretended it is a conceptual approach of a possible scenario with the use of UAV/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 thesis 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 4), there are some guidelines of the methodology pretended.





Case of Study



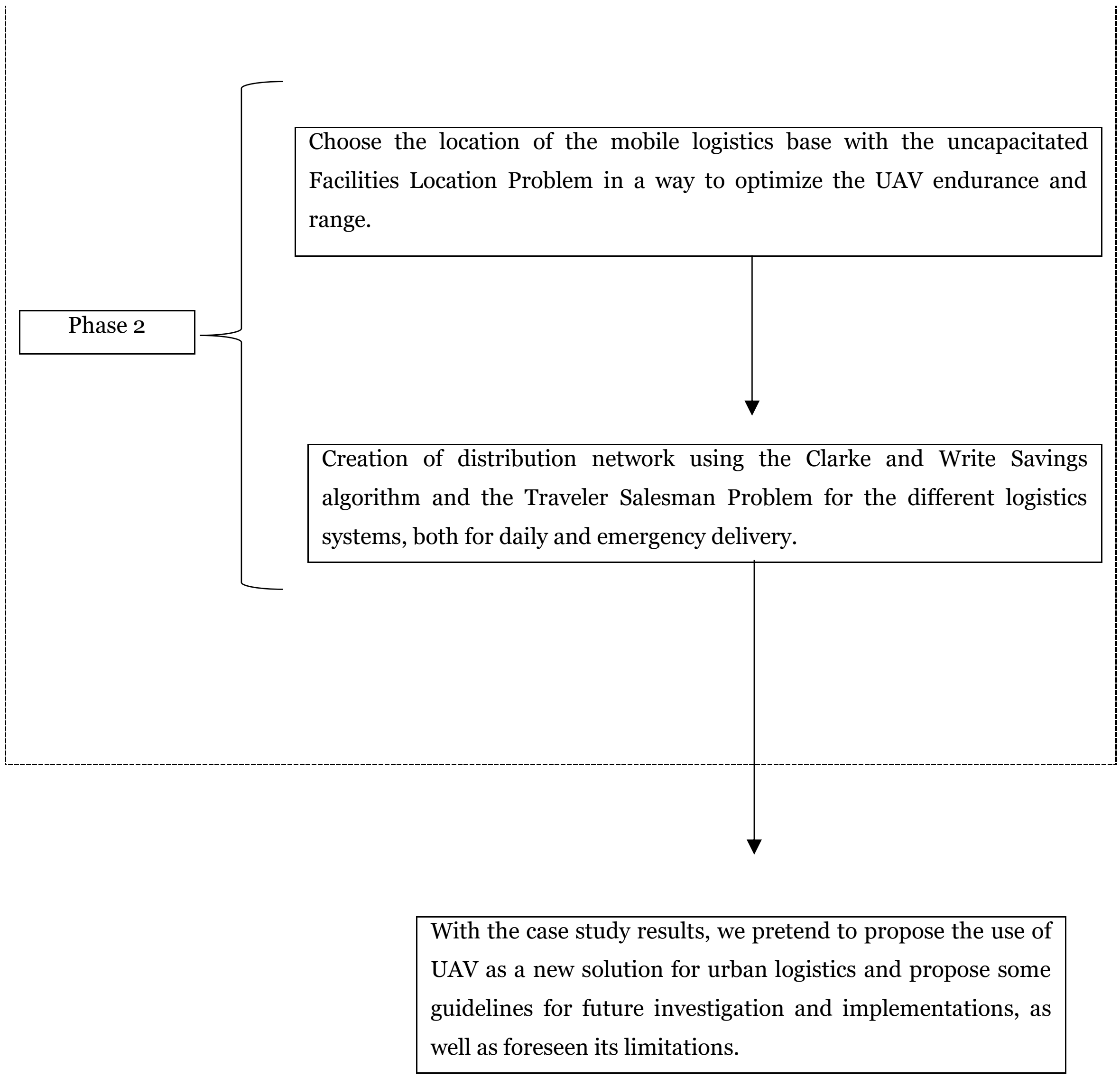


Figure 7 - Scheme of the methodology proposed. Source: Own elaboration.

1.6 Thesis structure

The structure of this thesis will take into account the methodology proposed. The first chapter is the introduction, where it has exposed the methodology used in the study. This chapter is divided into five subchapters: the motivation, object, objective, methodology, and the thesis structure.

Chapter 2 is the literature review, where it will be analyzed all the background of logistics in urban areas, as well as UAS/UAV examples and legislation to be considered.

Chapter 3 will incorporate the SWOT analysis on the urban logistics systems, both traditional and possible UAV/UASs, as well as all the essential parameters to be considered.

Chapter 4 will define the study implementation, where all operations will be detailed and described, and all parameters and factors are analyzed. We will use the algorithms for the better location of the mobile logistic base, as well as for implementing optimal routes with the UAV/UAS distribution system. The scenario where this study will take part, is going to be described, as well as the methods and operational rules in use. The results of the study implementation are displayed.

Chapter 5 will analyze all the results obtained in chapter 4.

Chapter 6 is the conclusion, where all significant results are exposed, as well as some concluding remarks and limitations, and future works.

In the next page it follows a scheme of the thesis structure.

- **Chapter 1 - Introduction**
    - Motivation
    - Object
    - Objective
    - Methodology
    - Thesis Structure

- **Chapter 2 – literature review**
    - Literature review
        - Urban logistics
        - UAV/UAS in city logistics
        - Logistic management algorithms

- **Chapter 3 – SWOT analysis**
    - Parameters
    - SWOT analysis
    - VRIO analysis

- **Chapter 4 – Case study**
    - Scenario description
    - Case Study Implementation
    - Results

- **Chapter 5 – Analysis of the case study**
    - Analyze of the results
    - Implementation fundaments

- **Chapter 6 – Conclusion**
    - Conclusions
    - Concluding Remarks and Limitations
    - Future works

Chapter 2

State of the art

2.1 Introduction

Chapter 2 will help understand the urban logistics process, as well as the current state in which it relies on, the mechanism beyond, and all the stakeholders that benefit from it. We will explore what the future of urban logistics can hold for us, and we will investigate what a UAV is, its history, potential, and limits. We intend to collect as much information as possible in order to enable a complete and sustained study in the literature review.

2.2 Urban logistics

2.2.1 What is Logistics?

The goods transported into the cities are fundamental for the economics and the social life of modern society. This movement can challenge at high levels the limits of the urban transport network, congestion, gas pollution, crashes, noise pollution. They all appose to a good and friendly urban environment [13].

The chain of transportation aims to be optimized, with the same objective, we apply logistic systems to these chains. Crainic states that "(...) in contemporaneous scope, "logistics" targets the analysis, planning, and management of the integrated and coordinated physical (e.g., materials, products, and money) and electronic (e.g., information and decisions) flows within a potentially multi-partner value network (...)" [14] [5]. For that reason, a fundamental task in logistics will always be the optimization, which could be economic, environmental, and time.

Afterward, there was a necessity to optimize the complicated and crowded urban space that let to urban logistics or also known as "city logistics" [14], [15]. 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

[5] [14], pp 433.

companies in urban areas while considering the traffic environment, the traffic congestion and energy consumption within the framework of a market economy (…)" [16] [6].

Inside the sphere of urban logistics, there is the last-mile logistics. Tom Cherret and Julian Allen define last-mile logistics as the "(…) term for the final stage of the delivery process when goods are sent from a transportation hub, such as a distribution center or warehouse, to an end-user, customer, shop or business, to achieve this as quickly and efficiently as possible. It can also refer to same-day point-to-point deliveries (…)" [17] [7]. The last-mile delivery has a significant weight in freight transport, it has increased in the last few years, and it will escalate in the near future. On the one hand, they are essential for a sustainable economy. On the other hand, the urban environment has become more and more crowded due to the increased urbanization; more frequent just-in-time business; an increase of e-commerce; high competitivity; and more complex multidisciplinary issues [18].

2.2.2 Urban Logistics and Its Constraints

To optimize the logistic system, we must clarify the importance of the stakeholders. These stakeholders are the following: the shippers and receivers; the residents; the freight carriers; and the administrators. In way to an optimal and balance system, these stakeholders need to be well integrated, and each role, problem, and objective could be solved with the same solution [13]. For example, the public sphere is responsible for the road network, legislation, and security. On the other side, the private sphere is responsible for creating logistic systems and the transport of goods. Figure 8 depicts an example of an urban logistics platform between the public and the private parties.

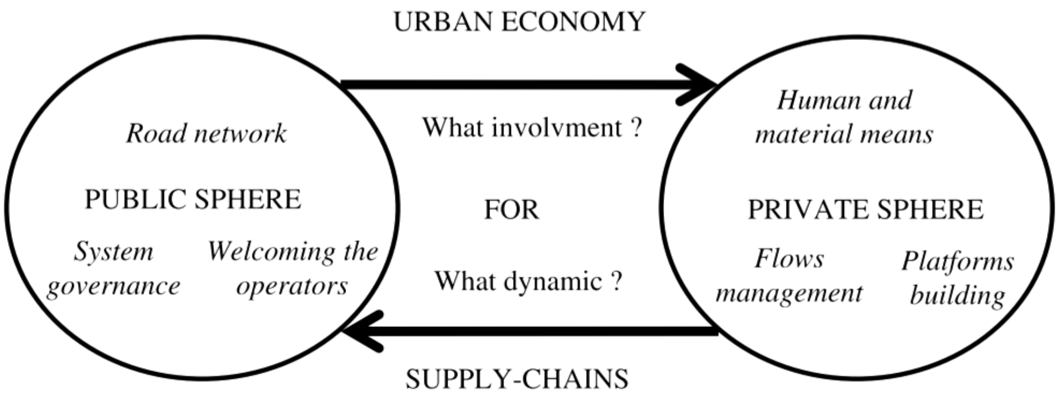


Figure 8 - Urban system from the point of view of logistic systems. Source: adapted from [2], [19].

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[6] [16], pp 5.

[7] [17], pp 3.

Inside this dynamic, between the private and public sphere, supply-chains must have good accessibility. In the literature, we find accessibility defined as a quality of the transport infrastructure in terms of capacity, connectivity, travel speeds, and determines the quality of locations relative to other locations [20]. There are accessibility problems due to the transportation infrastructures, insufficient infrastructure, access restrictions, or congestion that can cause problems, for example, disruption of traffic and further congestion [11], [21].

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 CO_2 emissions, and also, the congestions levels decreased. London started the implementation of LEZ and CC in 2003, and since then to 2007, they achieve reduced pollution and lower congestion (see table 1), [21].

Table 1 - Impacts of LEZ and CC in London from 2003 to 2007, source:[21][8].

Impacts	LEZ	CC
CO_2	-19%	-
NO_x	-12%	-
Road congestion	-	-39%

More, some European cities have old urban plans, creating a logistic nightmare for the distribution companies. For example, Barcelona is known for the big blocks, and parallel road design, a good factor for logistics companies. Although, the heart of the city, where roads are with medieval design, makes this a logical nightmare. This forces logistics companies to have two different models of approach. So, since 1998 the city council, in association with private companies, started a new program to improve mobility and accessibility into the urban core of Barcelona. They introduce a new access system for loading and unloading areas that started as a pilot test in a specific area in the heart of the city [22], [23].

2.2.3 Urban Logistics Solutions

With all urban constraints mentioned before, logistics companies have been trying different options to improve their logistic system, making it more efficient and more profitable. Nowadays, the urban logistic environment is composed mostly of:

- Trucks or vans over 3.5 tons gross vehicle weight;
- Trucks or vans less than 3.5 tons gross vehicle weight;

[8] [21], pp 15.

- Car;
- Motorcycle;
- Bus;
- Rail vehicles;
- Foot.

A study realized by the Department of the Environment, Transport and the Regions (DETR) states that in the UK, urban logistics are done mostly by lightweight vehicles. The goods transported tend to be done by light vans with gross weight below 3.5 tons. Generally, by the consumer's vehicles (e.g., supermarket buys); home deliveries by motorcycle or bicycle (e.g., food delivery, mail delivery); equipment transported by logistic companies (e.g., spare parts, electronics); and by services provided into our homes (e.g., plumbers, electricians, salesman's) [24].

The methods more common in urban logistics for delivering goods are:

- Home deliveries;
- Pickup points;
- Automated parcel lockers (APL);
- Smart parcel box (SPB);
- On-demand delivery (ODD);
- E-groceries (supermarket shops delivered into our homes).

All these methods are becoming more and more automated. For example, Amazon or UPS has a system for delivering goods that it is almost entirely automated since we click on the buy button to receive it into our homes. The system automatically prepares the package inside the warehouse into the delivery truck and then to our homes. The companies are using APL systems, as well as pickup points to deliver goods more efficiently. With this system, they do not need to make a new path each day to deliver the goods. It is possible to optimize the location of these delivery points to make everything more profitable. Moreover, it is possible to make these systems more automated using underground pipeline delivery systems, automated sidewalk vehicles, or unmanned aerial vehicles (UAVs). Through a fully automated system, this could be achieved with the use of UAVs, adapting the existing logistics system.

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. This idea has been the focus of several companies, for example, Amazon, DHL, and Google [5], , [6], [25]. They aim to achieve the delivery by using the urban air space.

2.2.4 Example of a Logistic System

As an example of a logistical supply chain, pharmacies are a great choice to be considered. The deliveries must be rapid and efficient, with high-security levels due to the payload they carry [26]. In figure 9, there is a representation of a pharmacy supply chain, studied by Westminster University, where it was adapted from a standard shop supply chain in London high street [11], [24]. This following example will show how urban logistics operate and who the stakeholders are.

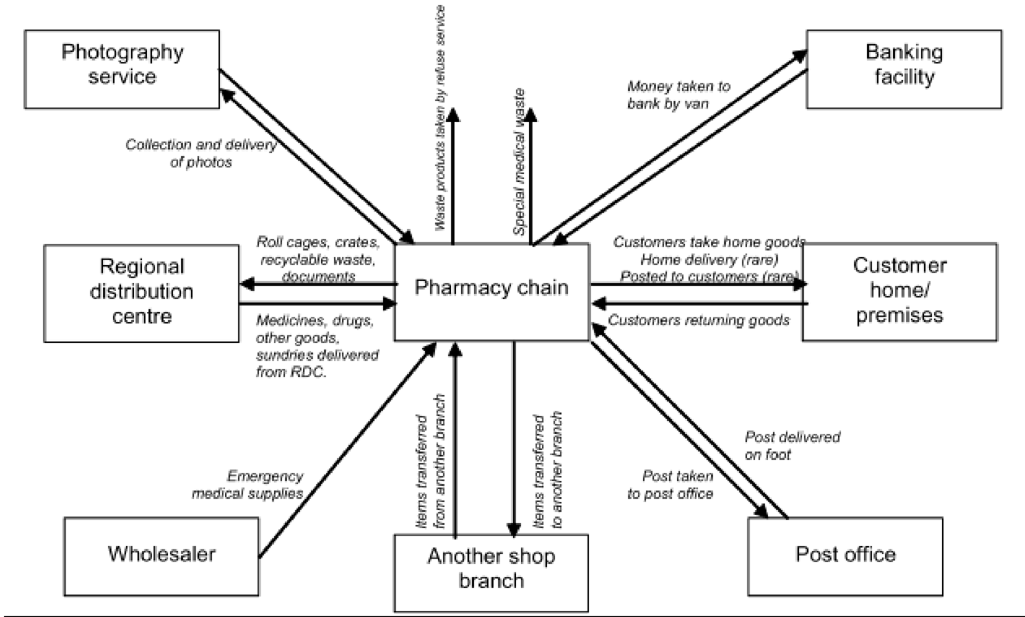


Figure 9 - Pharmacy chain logistics in the center of London. Source: adapted from [11], [27].

The example represented in figure 9 shows the tasks needed for that the pharmacy chain works between every party. In the pharmaceutical area, there are essential tasks, such as emergency medical supply or regular medical supply, special medical waste, money taken to the bank, exchange of medicines with other pharmacies, etc. These tasks involve other companies that provide this type of service, the transportation, and management of the goods provided. In this example, the transportation of medicines is made by small vehicles (e. g. vans) from a regional big distribution center, doing a day by day distribution, keeping the big stocks always in the wholesaler, and not in the pharmacy warehouse. From the viewpoint of the pharmacy, transportation only needs to be fast, secure, and with no stock failures [28].

2.3 The use of UAV/UAS in city logistics

2.3.1 Unmanned Aerial Vehicles

The unmanned aviation is not a recent event. The first appearance of an unmanned aerial vehicle (UAV) was during an attack in Venice when Austria used incendiary balloons to set fire to the city. Although, the aviation world might not consider a balloon as an unmanned aerial vehicle because it cannot be controlled.

The first approach to a most commonly known as a UAV was during World War I. The first flight of the Hewitt-Sperry Automatic Airplane was in 1917, using the latest radio techniques at the time, it was the first remote pilot aircraft (RPA). Then, with the development of the DH.82B Queen Bee, the word "drone" started to be used to identify a pilotless aircraft. The term refers to a male bee, as a reference to the Queen Bee [29].

Nowadays, Drones are available everywhere, in a toy store, electronics store, online, but of course, for non-military purposes, as a civilian drone.

There are several names given to this type of aircraft. In a way to better comprehend, there is a need to establish and define what is an unmanned aircraft. Innumerous authors can define the unmanned aerial vehicle (UAV), the international civil aviation organization (ICAO) standardized that a UAV is, by definition, a pilotless aircraft. Although there are innumerous types of pilotless aircraft: it can be a remotely piloted aircraft, autonomous aircraft, or a hybrid aircraft that can work in RPA mode or autonomous mode. Besides, the word "drone" is not considered an official definition of this type of aircraft. For that reason, it will not appear in official documents or citations, although it can be acceptable in informal communication [30].

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 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 it can look like a UAV, 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)) [29]. In table 2 evidences the advantages and disadvantages of the different types of UAVs.

Table 2 -Examples of UAV. Source: [24].

Build Types of UAV	**Advantages**	**Disadvantages**	**Visual**
Fixed-wing	• Long range; • Endurance[9].	• Horizontal take-off, requiring substantial space (or support, e.g., catapult); • Low maneuverability compared to VTOL (Vertical Take-Off and Landing).	 Source: BAAM tech [31].
Tilt-wing	• Combination of fixed-wing and VTOL advantages.	• Technologically complex; • Expensive.	 Source: Barnard Microsystems [32].
Unmanned helicopter	• VTOL; • Maneuverability; • High payloads are possible.	• Expensive; • Comparably high maintenance requirements.	 Source: Unmanned Systems Technology [33].
Multi-copter	• Inexpensive; • Easy to launch; • Low weight.	• Limited payloads; • Susceptible to wind due to low weight.	 Source: DJI [34].
Hybrid VTOL [35]	• Controllability and stability; • VTOL takeoff; • Long range; • Endurance[9]	• Extra weight; • Bigger drag coefficient.	 Source: Amazon [36].

[9] Endurance is the maximum length of time that an aircraft can remain in the air.

2.3.2 UAV/UAS delivers

The logistic companies are investing even more in the automation of the delivering process, reducing the human error, and trying to execute it faster. UAV/UAS are pointed as the next solution for this type of business. They enable new challenges for safety and security, although they can bring many benefits for the stakeholders. The urban cores of our cities are becoming crowded with traffic and people. As it was mentioned before, some cities in Europe are making new access rules for road traffic. Where the use of UAV/UAS can be the solution that everyone needs, reducing the movement, and, of course, everything negative that ground vehicles bring, for example, gas pollution, noise, traffic jams, etc.

DHL is one of the companies that believe in urban air delivery. They initiated the investigation with a remote delivering UAV/UAS. The mission was to transport medicines into a remote area in Tanzania. Furthermore, DHL, being a logistics company, begun to adopt this system in their core business, and create a UAV/UAS that could transport goods into our homes. So, in 2019 DHL and Ehang, a UAS company, made a partnership in China to innovate in smart logistics (see figure 10). Their project included a fully autonomous loading and offloading UAV, in the customer home or APL´s (see figure 11), that will increase efficiency and cost-effectiveness with less energy consumption. The plan is to further develop and upgrade smart drone delivery solutions for last-mile delivery. The first test was in the city of Bonn/Guangzhou (China) on 16 May 2019. The first fully autonomous delivering route was from the DHL service center in Liaobu, Dongguan, Guangdong Province, and it could cover an 8 kilometers range distribution. From this test, they conclude that the UAV/UAS deliver could "(...) reduce one-way delivery time from 40 minutes to only 8 minutes and can save costs of up to 80% per delivery, with reduced energy consumption and carbon footprint compared with road transportation (...)" [29] [10]. They used the new EHang Falcon smart drone (see figures 10 and 11), that incorporates [37]:

- Eight propellers on four arms;
- Multiple redundant systems for full backup;
- Smart and secure flight control modules;
- Vertical take-off and landing;
- High accuracy GPS and visual identification;
- Smart flight path planning;
- Fully automated flight and real-time network connection and scheduling;
- Payload up to 5kg of cargo per flight;
- Fully autonomous loading and offloading of the shipment.

[10] [29], pp 2.

Figure 10 -EHang Falcon smart drone flying over skies with delivery on board. Source: [38].

Figure 11 - EHang Falcon smart drone making a drop in an APL station. Source: [38].

Recently, the company Skyports was responsible for implementing hospital-to-hospital medical drone deliveries to assist the National Health System (NHS) of the United Kingdom in the battle against COVID-19. Under a special authorization, they use UAVs to delivery COVID-19 tests and medical supplies over an urban area. The company already said that this type of supply chain could generate high benefits [39] [11]:

- "(…) Increase frequency and speed of transport of medical products such as pathology samples;
- Transport high-value/perishable cargo such as vaccines, medicine, and organs through an on-demand service;
- Bring high quality healthcare to more communities (…)".

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

[11] [39], pp 1.

Robotics, the first authorized UAV/UAS 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) [40]. 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 (...)" [41][12].

These exceptions demonstrated that the UAV/UAS paradigm is changing from year over year, making this research of enormous importance to prove the viability of this technology.

2.3.3 UAV/UAS Legislation

Everything in the world of aviation is highly legislated and controlled by the national aviation authorities. Since the invention of the airplane, the whole world has tried to universalize the aviation rules and premises in a way to create a universal law for airplanes. This legislation allowed airplanes to fly to any part of the planet. The first convention in civil aviation took place in Chicago at 7th of December of 1944. Already then, the aviation entities had concerns about the pilotless aircraft. For that reason, the article 8 stated that "(...) no aircraft capable of being flown without a pilot shall be flown without a pilot over the territory of a contracting State without special authorization by that State and in accordance with the terms of such authorization. Each contracting State undertakes to ensure that the flight of such aircraft without a pilot in regions open to civil aircraft shall be so controlled as to obviate danger to civil aircraft (...)" [42] [13]. This convention has been followed for decades until the use of UAV became more common, and each state started to create their own rules, which forced ICAO and other aviation authorities to rethink the original article. So, in 2005 ICAO started the meetings about UAV/UAS that lead to a final document, CIR 328, with the goal to "(...) provide the fundamental international regulatory framework through Standards and Recommended Practices (SARPs), with supporting Procedures for Air Navigation Services (PANS) and guidance material, to underpin the routine operation of UAS throughout the world in a safe, harmonized, and seamless manner comparable to that of manned operations. This circular is the first step in reaching that goal (...)" [29] [14]. The

[12] [41], web page: accessed on 26-Aug-2020.

[13] [42], pp 8.

[14] [29], pp 3.

outcome of this document established new universal legislation for UAV/UASs, which become to be the new legislation applied by each national aviation authority [30].

Nowadays, UAV/UAS legislation used it is still the same that came from CIR 328 guidelines, although each national aviation authority adapted and established their own rules. In table 3, there are some of the main guidelines of ICAO, the Federal Aviation Administration (FAA), and the European Aviation Safety Agency (EASA) legislation.

Table 3 - Guidelines of the laws applied by each organization, ICAO [30], EASA [43], FAA [44].

ICAO	**EASA**	**FAA**
	Operation Limitations	
Low risk category guidelines: • Low fly operations (maximum altitude specified); • UAV must remain in visual line of sight (VLOS) of the remote pilot; • The UAV must remain at a specified distance from people; • The UAV must remain at a specified distance from buildings; • The UAV must remain at a specified distance from airports or non-segregated airspace; • Only day-light flights with optimal weather conditions.	Open category: • In the open category operations can take place that are considered low risk and do not require prior authorization; • The aircraft must weigh less than 25kg; • Visual line-of-sight (VLOS) only, the aircraft must remain in VLOS of the pilot or observer; • A maximum distance of 120m; • No carriage of hazardous materials; • No flyover airports or any non-segregated airspace; • No fly over crowds. Specific category: • In the specific category, operations take place that considering the risks do require authorization by a competent authority before the operation takes place. Certified category:	Operational guidelines: • Unmanned aircraft must weigh less than 55 lbs. (25 kg); • Visual line-of-sight (VLOS) only, the unmanned aircraft must remain within VLOS of the remote pilot or the observer; • Small unmanned aircraft may not operate over any persons not directly participating in the operation, not under a covered structure, and not inside a covered stationary vehicle; • Daylight-only operations, or civil twilight (30 minutes before official sunrise to 30 minutes after official sunset, local time) with appropriate anti-collision lighting; • Maximum groundspeed of 100 mph (87 knots); • Maximum altitude of 400 feet (122m) above ground level; • Minimum weather visibility of 3 miles (4,83 km) from control station;

	• In the certified category, operations can take place requiring a certified drone, a licensed pilot and, an organization approved by a competent authority to ensure an appropriate level of safety.	• No carriage of hazardous materials. Certificates and responsibilities: • A person operating a small UAS must either hold a remote pilot airman certificate with a small UAS rating or be under the direct supervision of a person who does hold a remote pilot certificate (remote pilot in command); • To qualify for a remote pilot certificate, a person must pass an initial aeronautical knowledge test at an FAA-approved knowledge testing center; or hold a part 61 pilot certificate other than student pilot, complete a flight review within the previous 24 months, and complete a small UAS online training course provided by the FAA and be at least 16 years old; • The remote pilot in command must make available to the FAA, upon request, the small UAS for inspection or testing, and any associated documents/records required to be kept under the rule. Report to the FAA within ten days of any operation that results in at least serious injury, loss of consciousness, or property damage. Conduct a preflight inspection and may deviate from the requirements of this rule in response to an in-flight emergency.

Even so, according to current legislation, it would not be possible for current logistics companies to use UAV/UASs for the delivery of goods. The good news is that authorities are now studying and implementing new guidelines for the future legislation of UAV/UAS 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 [45].

EASA will implement new legislation this year of 2020. Thus, the "(...) conditions have been classified as an important Special Condition (SC) and as such shall be subject to public consultation, following EASA Management Board Decision on 12/2007 dated 11 September 2007 (...)" [46][15].

This new document has the objective of creating standard legislation for the use of UAV/UAS, with "(...) applicable airworthiness codes, environmental protection certification specifications and/or acceptable means of compliance with Part 21, as well as important special conditions and equivalent safety findings (...)" [46][16]. As it was expected, the EASA new outline for controlled urban air mobility (UAM) will attend the new requirements for profitable use and operations.

This SC applies to UAV/UAS ([46][17]):

- "(...) Not intended to transport Humans;
- Operated with intervention of the remote pilot or autonomous;
- With MTOM up to 600 kg;
- Operated in the specific category of operations, medium and high risk, or in the certified category of operations (...)".

"(...) EASA has considered it appropriate to determine MOC to high risk safety objectives based on an assessment of a probable urban scenario projected in 2035 (...)" [46][18]. This vision will assume the already existing operation study by Single European Sky ATM Research (SESAR). It has also been considered that the safety objectives of UAV/UAS for the urban environment should undertake low risks for UAM operations.

[15] [46], pp i.

[16] [46], pp i.

[17] [46], pp iv.

[18] [46], pp v.

A methodology also used in SC for VTOL is considered for this case. Thereby, EASA synthesis is based on ([46][19]):

- "(…) the calculated number of flight hours (FH) flown by drones in the generic / average European city in 2035;
- a representative urban population density;
- representative products and operational assumptions (…)".

With this stated, EASA introduces new objectives for Continuous Airworthiness Standards (ICA), creating a type certificate for these aircraft under high levels of compliance, and also the creation of maintenance manuals and flight manuals for each aircraft. More, with the introduction of MOCs, several levels of risks must guarantee a low probability of failure.

EASA establish a new MOC for UAV/UAS, where the levels of risks are the following ([46][20]):

- "(…) No safety effect: Failure conditions that would have no effect on safety. For example, failure conditions that would not affect the operational capability of the UAS or increase the remote crew workload.
- Minor: Failure conditions that would not significantly reduce UAS safety and that involve remote crew actions that are well within their capabilities. Minor failure conditions may include a slight reduction in safety margins or functional capabilities, a slight increase in remote crew workload, such as flight plan changes.
- Major: Failure conditions that would reduce the capability of the UAS or the ability of the remote crew to cope with adverse operating conditions to the extent that there would be a significant reduction in safety margins, functional capabilities or separation assurance. Besides, the failure condition has a significant increase in remote crew workload or impairs remote crew efficiency.
- Hazardous: Failure conditions that would reduce the capability of the UAS or the ability of the remote crew to cope with adverse operating conditions to the extent that there would be the following:
    - Loss of the RPA where it can be reasonably expected that one or more fatalities will not occur, or;

[19] [46], pp v.

[20] [46], pp 21-22.

  - A large reduction in safety margins or functional capabilities or separation assurance, or;
  - Excessive workload such that the remote crew cannot be relied upon to perform their tasks accurately or completely;

- Catastrophic: Failure conditions that are expected to result in one or more fatalities. (…)"

The level of risk is considered to prevent any failure or accident that can lead to property damage or fatalities. The table 4 is the first guideline from EASA to all UAV/UAS industry, creating new standards that may save lives [46].

Table 4 - Relationship between the classification of failure conditions and probabilities for UAV/UAS. Source:[46][21]

Classification of Failure Conditions				
No Safety Effect	Minor	Major	Hazardous	Catastrophic
Allowable Qualitative Probability				
Not applicable	Probable	Remote	Extremely Remote	Extremely Improbable
Allowable Quantitative Probabilities				
Maximum dimension [2] < 8 m AND MTOM < 600 Kg (1200 m^2 worst crash area)	**<1.10^{-2}**	**<1.10^{-4}**	**<1.10^{-6}**	**<1.10^{-8}**
Maximum dimension < 3 m AND MTOM < 200 Kg (400 m^2 worst crash area)	**<1.10^{-2}**	**<1.10^{-3}**	**<1.10^{-5}**	**<1.10^{-7}**

These guidelines already can tell that the law for UAV/UAS is adapting according to the needs of the population, and one significant step for logistic companies would be a standard and controlled industry. This document has several similarities with international aviation legislation for airplanes, which could imply that both industries will work side by side for continuous improvement of safety and security of the aviation world. This document is published on the EASA web site for consultation [47].

ICAO is currently studying new guidelines for global standardization of the UAV/UAS law, this way, it will enable that a company operating in China can operate in Portugal using the same system [4], [30].

[21] [46], pp 22.

2.4 Route delivery and facilities location algorithms

2.4.1 What is an algorithm?

Logistic companies have been responsible for creating a network of goods and services. Even more, they are responsible for today´s highly competitive logistic market, where companies are always trying to improve their system and make it more profitable.

The management process begins in the factories, passing by warehouses, and ending at the retailer or the final consumer. All this process is controlled and managed by logistic companies. The goal is to plan, implement, and control the efficiency of the network of goods and services. The way to plan, implement, and control can be achieved using algorithms to optimize what the companies pretend [48].

Algorithms have been part of our life has human beans since ever, and we use them unconsciously, well before the word to describe them appeared. In the literature, numerous authors are defining the word algorithm. For a better notion, we choose a simple definition from Jean-Luc Chabertal, that states, an "(…) Algorithm are simply a set of step-by-step instructions, to be carried out quite mechanically, to achieve some desired result (…)"[49][22]. This definition seems a lit bit simple, but the better way to compare an algorithm would be with a recipe passed through generations, has mechanically step by step instructions for always get the same result.

From a point view of logistic management, investigators and companies are trying to create the perfect recipe that better accommodates their proposes for a logistic system. For that reason, algorithms are being used for logistic management due to the urgency to optimize networks of distribution and, to better choose the location of the company facilities. There are innumerous optimization algorithms in the literature [48], [50], [51]. For our case study, we pretend to use the Heuristic of Clarke and Wright algorithm in the distribution network, the traveling sales problem, for optimizing the Clark and Wright algorithm and for better choose the location of the mobile logistic base we will apply the facilities location problem with multiple choice [52], [50].

[22] [49], pp 1.

2.4.2 Heuristic Algorithms

Several heuristics algorithms have been proposed to solve the Vehicle Routing Problem (VRP) as those that generate approximate or sub-optimal solutions, reaching a solution in less time and requiring less computational effort. The classic heuristics introduced many of the concepts incorporated into modern algorithms, such as construction and improvement procedures.

However, a simple heuristic has the disadvantage of exploring only a subset of the totality of possible solutions. Heuristic algorithms perform local searches, creating optimal points, and then starting from there the optimized vehicle route. The selection of an initial optimal point will deteriorate the final objective once that all solutions will depart from that initial optimal point [53].

The following classification is based on Laporte et al (2000) for classical heuristics [54]:

- Construction solutions - merging existing routes using a savings criterion, and gradually assigning vertices to vehicle routes using an insertion cost.
- 2-phase methods - the problem is broken down into two distinct components: the grouping of points to be interconnected in a feasible route and the construction itself (that is, the order in which the group of points must be covered) and, finally;
- Sequential improvement methods - try to improve a given solution by carrying out a sequence of exchanges between points within a route or between routes.

For a final approach, the choice for this thesis was to firstly, construct and solve a vehicle routing problem using Clarke and Wright Savings Algorithm and secondly, using the traveler salesman problem, to improve the routes and lower the costs. With the facilities location problem, we also use a constructive solution method with an improving method to lower the costs of the initial outcome.

2.4.3 Clarke and Wright Savings Algorithm

The Clarke and Wright savings algorithm (CW) has the purpose of enabling iterative process for an optimum or near-optimum delivery route. The problem stated was "(…) the optimum routing of a fleet of trucks of varying capacities used for delivery from a central depot to a large number of delivery points (…)"[52][23]. This statement will mean that the routes to be taken by vehicles that, starting from a single location, the warehouse, will serve other locations, the customers, with the required quantities of a good and so that the total cost to be minimal. The capacity limitations of each vehicle will have to be respected, and it is assumed that each location is served only once by a single vehicle. For a visual example figure 12, shows two different delivery points (*i* and *j*) and the facilities from where the delivery starts the 0.

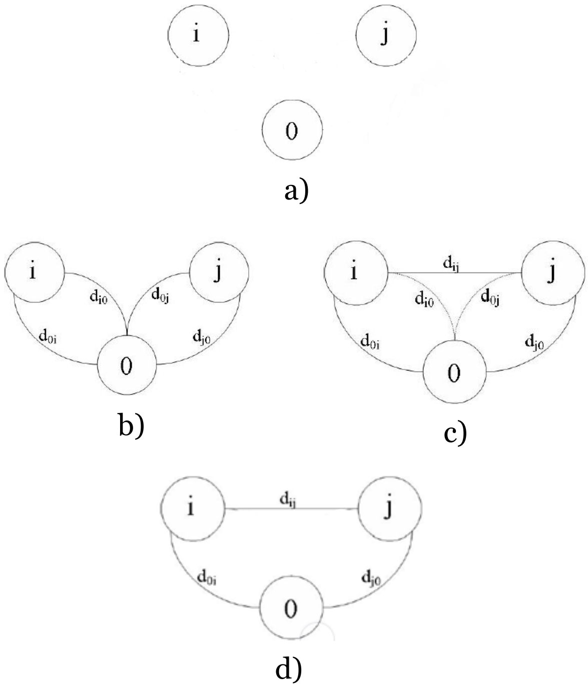


Figure 12 - Example of routes optimization using Clarke and Wright Algorithm. Source: Own elaboration based on [55].

All possible combinations between two routes are made (see figure 12, b) so that a vehicle can be eliminated, and the travel distance is reduced. The savings must be calculated between all pairs *i* and *j* (see figure 12, c) delivery points where *i* is a customer at the end of a route and *j* one in the end of another route, creating a near optimal route considering all the limitations (see figure 12, d). The formulation for this problem is present in appendix 1, a), where the algorithm used is explained.

[23] [52], pp 568.

2.4.4 Traveling Salesman Problem

Given a set of delivery points and an array of distances between them, the Traveling Salesman Problem (TSP) consists of establishing a route for a distributor, starting his way in the main facilities, going through all the “n-1” delivery points only once and return to the main facility. We need the distances between the main facility and all delivery points, and the distances between each delivery point. The TSP algorithm will encounter all the distances, choosing the combination that produces the lowest total distance possible. According to the TSP algorithm, all locations are tested as starting points of the circuit, and the optimized solution will comply with the lowest value [55], [56], [57]. The algorithm was implemented in the Office Excel program, using the solver tool to create circular optimization, taking into account the restrictions of this algorithm. The formulation for this problem is an integer linear programming formulation by Miller, C. E. et al. present in appendix 1, b), where the algorithm used is explained [57].

2.4.5 Uncapacitated Facilities Location Problem

In a Facilities Location Problem (FLP) is intended to install a certain number of facilities to serve in the best possible way a set of communities/customers whose location is known. For that to occur, we choose the potential locations for installing the facilities, and then we associate the cost of that installation to each one. Adding to this decision is the fact that all communities/customer’s travel with each facility must be calculated. The facility admitted for construction will be the lowest cost in terms of facilities implementation, as well as the lowest cost for travel to the delivery point. After this decision, starts a comparison to the cost of serving each customer for the previously selected equipment, with the cost of addressing each of the other potential equipment. If the change is worthwhile, we admit building this new equipment as well [58]. The FPL algorithm was implemented in the Office Excel program using summation functions. The algorithm used is expressed in appendix 1, c).

2.5 Conclusion

Chapter 2 has a crucial role in understanding the object and objectives of this thesis. We study how the current logistics system works and how it has evolved. We verify how essential it is for the functioning of a city, and the constant struggle to overcome its limitations and difficulties that are imposed on it. Thus, we find some current solutions that may come to help urban logistics, mainly in the fact that access to urban centers in a fast, ecological, and safe way.

From the viewpoint of a logistics company, the delivery can always be improved. With this stated, one way to improve the delivery could be recurring to new logistics systems, such as UAV delivery. We study UAV history and how they were important in many different times, and in the future, they may also reach their state of the art. This aircraft has enormous potential, as it has been verified in several prototype tests of the logistic systems. When analyzing those that were included in this work, we found that there are not yet enough conclusions to understand its operation in the long term. However, in the short term, the results are encouraging because there are substantial cost reductions, as well as almost total reductions in pollutant emissions.

When analyzing the limitations of this aircraft, we are immediately overwhelmed by the lack of legislation. We analyzed the current legislation, where we verified that there are significant gaps in terms of operation in an urban environment. However, recent EASA documents see changes in the state of legislative stagnation and bring the discussion of UAV back to the table in an operational environment.

In order to carry out this thesis, it was essential to analyze algorithms that enable us to optimize distribution networks and massively reduce costs without losing human resources. This analysis enhances the difference of UAVs compared to current systems, with an optimized network and with direct routes, it can make this system much more competitive.

Chapter 3

SWOT Analysis

3.1 Introduction

In this chapter it is pretended to analyze and compare both logistic systems, the conventional and used today (e. g. van, motorcycle, bicycle delivery), with the possible use of UAV/UAS delivery. This analysis will place in two independent SWOT processes, as it was for two different companies.

This investigation will undertake all the issues concerned with the delivery of goods and services in urban areas. With these premises, we can build a SWOT analysis for the solution proposed [24].

After the SWOT analysis, we pretend to compare the results and introduce a competitive comparative analysis, where both logistic systems are competitors.

3.2 SWOT Analysis

An analysis of strengths, weaknesses, opportunities, and threats (SWOTs) is a tool used by companies to study and implement new products and services. Since the fifties, it has been studied the strategy managing of the business. This new perspective sees products and services with multi-factors, both internal and external, impacts [59]. Furthermore, SWOT analysis was clarified as a strategy in market research and business strategy development. To clarify what each point means and how we will do the SWOT analysis, it follows a nomenclature suggested by professor Capon from Staffordshire University, where [60], [61]:

- Strength is an internal improvement of the capability, valuable resource or attribute;
- Weakness is an internal inhibitor of the capability, resources, or attributes;
- Opportunity is an external improvement of performance that can be pursued or exploited as a benefit; and
- Threats is an external inhibitor of performance that has the potential to reduce success.

Using this definition for SWOT analysis, we apply this model to the conventional delivering system and UAV/UAS delivery.

3.2.1 SWOT Analysis in conventional delivering systems

In tables 5 and 6 there are a SWOT analysis on the conventional delivering system (e. g. van). We analyze the strengths and weaknesses as internal factors and the opportunities and threats as external factors.

Table 5 - SWOT analysis of a conventional delivering system with internal factors. Source: Own elaboration.

INTERNAL FACTORS	
STRENGTHS (+)	**WEAKNESSES (-)**
• High delivery capacity; • High range; • Easy refueling; • Low experience for the operator; • Easy loading; • Multi-drop capability; • One vehicle per trip; • Can work at any time (with some exceptions with dangerous deliveries); • Adaptability to the payload (refrigerated, big payload, dangerous payload).	• High maintenance cost (during life cycle); • High investment in fleet acquisition; • Oversize vehicle; • Need for big premises for loading, as well as parking.

Table 6 - SWOT analysis of the conventional delivery system with external factors. Source: Own elaboration.

EXTERNAL FACTORS	
OPPORTUNITIES (+)	**THREATS (-)**
• More environmentally friendly fleets with state support; • More communication between the company and the customer; • Routes optimization; • The return of goods.	• High level of traffic; • Tight legislation on urban circulation; • Accidents; • New environmental laws; • Lack of car parking for unloading; • Difficult accesses in old areas of the urban core; • Small average velocity; • Limitation in shift hours; • Future limitations for gasoline and diesel vehicles.

The SWOT analysis in conventional delivery systems can offer some conclusions. Starting on the internal factors, the use of this delivery system offers us a wide range of strengths compared to its weakness, making it the obvious choice to operate in deliveries. It is worth highlighting specific strengths points, such as the capacity of large payloads and a wide range of operations. For its weakness, it is essential to mention that the size of the vehicle and the difficulty to park and unload can bring some threats.

The external factors can conclude that the number of threats is in majority compared to the opportunities, mostly due to this system has reached its maximum potential. With this, we see fewer opportunities and more threats created by the continuous increased new market for deliveries. It is important to highlight the opportunity to change the delivery fleets to a more environmentally friendly option; as threats, the lack of car parking for unloading can be a significant problem when, at the same time, the vehicle has the weakness of being oversized for some old urban cores. Also, the tight legislation that has been introduced to reduce urban traffic can end with this type of delivery system.

3.2.2 SWOT Analysis in UAV/UAS delivery

In tables 7 and 8 there are a SWOT analysis on UAV/UASs, where we analyze the strengths and weaknesses as internal factors and the opportunities and threats as external factors.

Table 7 - SWOT analysis of UAV/UAS's delivery system with internal factors. Source: Own elaboration.

INTERNAL FACTORS	
STRENGTHS (+)	**WEAKNESSES (-)**
• VTOL does not obstruct the public route;	• Low payload capacity;
• Cheap investment;	• Need for specific loading docks;
• Environmentally friendly, it works with electric energy;	• Susceptible to weather conditions;
• Direct delivery routes;	• Low range;
• High average velocity;	• One vehicle per delivery;
• Small vehicle;	• The legislation does not yet allow for use in an urban environment;
• Small premises for loading and parking.	• Daylight flight only.

Table 8 -SWOT analysis of UAV/UASs delivery system with external factors. Source: Own elaboration.

EXTERNAL FACTORS	
OPPORTUNITIES (+)	**THREATS (-)**
• Possible automation for just-in-time business;	• Assaults;
• Streets where road vehicles are prohibited;	• Bird strike;
• Delivery pad optimizable with automation;	• System failure or loss of control;
• Wide adaptability to the business, since last-mile delivery, as well as, between logistic centers;	• Less communication with the customer;
• Capability to return goods;	• Legislation could never allow being used in the urban environment.
• Urgent deliveries;	
• High priority deliveries;	
• Possible multi-drop delivery with small payloads;	
• Possible swarm/formation delivering;	
• Not busy urban airspace.	

The SWOT analysis on UAV/UAS delivering system encountered several important conclusions. On the internal factor, the strengths are well balanced with the weakness, mostly due being a new rising technology that is yet in its early development stages. It is crucial to enhance the possibility of creating direct routes with easy unloading and, at the same time, implement this system with lower investment compared to other conventional systems. Although there are some weaknesses significant to refer to, for example, low payload capacity, low range, and the legislation does not yet allow for use in an urban environment. All this weakness appears due to the initial phase of investigation in this area.

The external factors are in most opportunities. The use of UAV/UAS in the delivery system for urban areas has yet not been implement. Although the opportunities are vast, some important ones are the possible automation for just-in-time business; possible swarm/formation delivering; and a not busy urban airspace utilization. These opportunities are a consequence of the continuously increased market of home deliveries and a more crowded urban area. The threats are, for now, conceptual because it has not yet been possible to test their use on a large scale. To enhance, the system failure or loss of control is one of the biggest concerns in safety and security for aviation authorities, and for that reason, legislation could never allow being used in the urban environment. A solution purposed it would be that UAV/UAS used for operating purposes had to agree with new legislation, creating a maintenance and operation manual for each aircraft, in the same way, nowadays aviation operators are obligated to perform. With this implementation, the level of safety apply to airplanes could also be applied to UAV/UAS, creating a new chapter on aviation legislation for unmanned aerial vehicles.

3.3 VRIO analysis comparison

VRIO is a business analysis strategy for companies to examine their competitivity or a product they pretend to introduce. VRIO is composed of several questions: the value; the rarity; the imitability; and the organization capability. For each concept, we apply the following questions [62], [63]:

- The Question of Value: Can the company neutralize an external threat with the opportunities/capability that they are bringing?
- The Question of Rarity: Is this new source unique? How innovative is it?
- The Question of Imitability: Is it difficult to imitate/duplicate?
- The Question of Organization: Is the firm organized, ready, and able to exploit the new resource?

The results obtained in the SWOT analysis (concluded in the table 5, 6, 7 and 8) can be compared to the performance of the delivering system using a conventional vehicle or a UAV/UAS. From the viewpoint of a company, we can introduce the level of competition that this new delivery system can bring. For this comparison, we use the VRIO analysis that considers the value; the rarity; the imitability; and the organization. This analysis is possible considering all the advantages that we had accomplished in the SWOT analysis for the UAV/UAS. In the table 9, there is the VRIO analysis where the UAV/UAS system of delivery is associated with the other conventional system based on the SWOT analysis made before. Each line is one possible solution, and we will choose the one that better suits our case.

Table 9 - VRIO analysis on a UAV/UAS delivery system. Source: Own elaboration based on [62], [63].

Is it valuable?	Is it rare?	Is it hard to imitate?	Is the company prepared to exploit?	What is the result?
✗				**Competitive disadvantage**
✓	✗			**Competitive equality**
✓	✓	✗		**Short term competitive advantage**
✓	✓	✓	✗	**Unused competitive advantage**
✓	✓	✓	✓	**Long-term competitive advantage**

The VRIO analysis concludes that the UAV/UAS delivery is an unused competitive advantage. The result is in line with what we have mentioned throughout state of the art, that the delivery system with UAV/UAS is a unique opportunity and can overcome its threats. However, its application in large urban areas is not yet legal and is therefore considered a competitive advantage that cannot be used. For a change in the UAV/UASs competitivity, would be necessary new legislation that allows this type of aircraft to operate in urban areas, if that so, this VRIO analysis would conclude a long-term competitive advantage for UAV/UAS's delivery system.

3.4 Conclusion

For a conclusion of chapter 3, we remind the purpose of this investigation. Firstly, understand the meaning and what could bring a SWOT analysis. Then apply to both delivering system, conventional and UAV/UAS, with the final objective to compare and analyze its competitivity.

It can be concluded that for nowadays urban logistics, the use of a conventional delivering system is the obvious choice to operate. It is on its maximum state of the art becoming very useful on its tasks. Although, what the future reserves for this system may not be pleasant. Besides the oversize of the vehicle and future traffic legislations, the urban cores of the cities could become inaccessible. For the use of UAV/UAS it is almost unknown due to a lack of use on a large scale for testing. Being a new continuous increased technology that is yet in its early stages, some weakness appears due to the initial phase of the investigation. Although there are some advantages that a conventional delivery system will never overcome, for example, direct route delivery and access to places where it is prohibited to road vehicles, this is a high level of competition. A significant advantage for UAV/UAS is the ecofriendly system, low material consumption on construction, and it runs on electricity that can easily be created through renewable energy sources.

Though, as the VRIO analysis has shown, the use of these competitive advantages cannot be used due to nowadays legislation. In order to overcome these difficulties, in safe urban airspace, we assume that UAV/UAS used for operating purposes had to agree with the legislation used by nowadays aviation operators, creating a maintenance and operation manual for each aircraft. The level of risk would be in the standards of today's aviation industry, creating a better reception in the final consumer opinion.

Chapter 4

Case of Study

4.1 Introduction

In this chapter, we assume to study the urban logistic systems, implementing a delivery route for daily and urgent medicines from a logistic base into the pharmacies of a city. First, we will detail and describe all parameters and factors, for example, the city to be implemented and the conditions where it will take place. Secondly, we explained the pharmacy operation, detailing the requirements for the delivery. After this, we introduce the operation outline, where we incorporate all the objectives for the delivery system. Lastly, the case study will enter in phase 1 and 2, the establishment of the delivery route.

In the final, it is pretended to uncover all the solutions possible for the delivery systems and encounter a fully optimized delivery system for each phase of implementation.

4.2 City of Aveiro

The scenario chosen for the implementation of our case study is the city of Aveiro. The motivation for being the chosen are many important factors, starting from being the closest big city to where the author lives, would enable direct data collection, and having more personal knowledge about the city. Second, it has many pros for the use of UAV/UAS´s, it is extremely flat, with an average height of 25m and a maximum height of 78m, and there is no building with more than 30 meters of high [64].

4.2.1 Demography

Aveiro is a city located in the center region of Portugal, being the capital of the district of Aveiro, with around 78450 residents divided into ten civil parishes (“freguesias”). Aveiro is part of an urban agglomeration called “Baixo Vouga” that includes 390822 inhabitants, making it one of the most essential populated regions by density in the Center Region of Portugal [12]. The figure 13 describes all the ten parishes of Aveiro and their population.

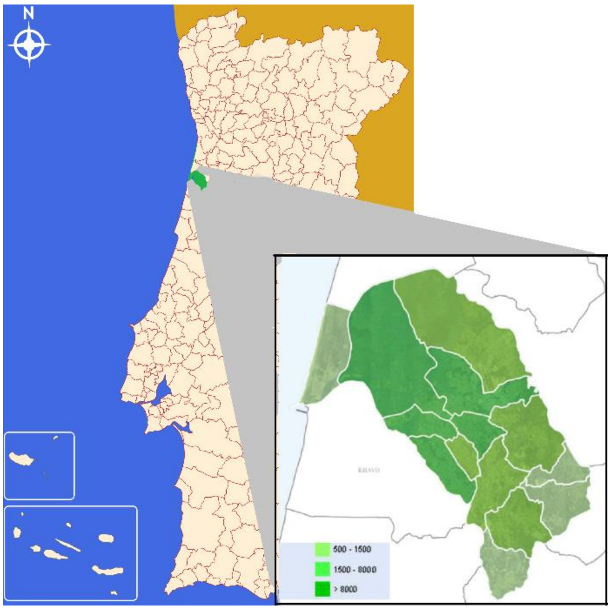
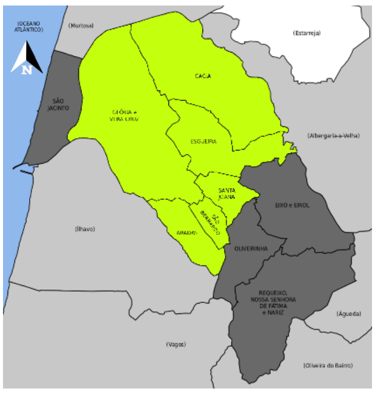


Figure 13 – Aveiro municipality map with population concentration. Source: Own elaboration based on [12].

The urban perimeter is composed of the areas of Glória and Vera Cruz (the original area of the city), extending further to Aradas, Cacia, Esgueira, São Bernardo, and Santa Joana. For our investigation, the civil parish of Cacia will be considered only as of the location of the logistic base for the medicine distribution. The reason for this decision was because the pharmacy location was too far apart from the urban core of the city of Aveiro, that we pretend to study. In table 10, we see the population of each civil parish, wherein green, there are the ones selected for this investigation.



Parishes	Habitants
Aradas	9157
Cacia	7354
Eixo e Eirol	753
Esgueira	13431
Glória e Vera Cruz	18756
Oliveirinha	4817
Requeixo e Nossa Senhora de	1222
São Bernardo	4960
São Jacinto	993
Santa Joana	8094

Table 10 - Population per civil parish of Aveiro. Source: Own elaboration based on [12].

4.2.2 Areas and accessibility

According to the European Commission Aveiro is considered a small city even though it has several different core areas [65]. For better to implement this case study, we divided the city into four significant areas (these areas are represented in figure 14):

- the industrial area (yellow boarder);
- the green protected area (green boarder);
- the peripheral urban area (blue boarder);
- the urban core (red boarder).

The industrial area is where our logistic base will take place; this logistical base of medicines currently existing, and for that reason, we choose to create a delivery route from there to better approach the reality.

The peripheral urban area is composed mostly of small houses, which represents fewer obstacles for the UAV/UAS's delivery system. Although this is a more significant area, which makes the routes wider, becoming a challenge for the endurance of the UAV.

The urban core of the city of Aveiro is where the conventional vehicle will encounter a superior challenge to operate, having a lot more traffic and tight streets, and also some are prohibited for vehicle circulation.

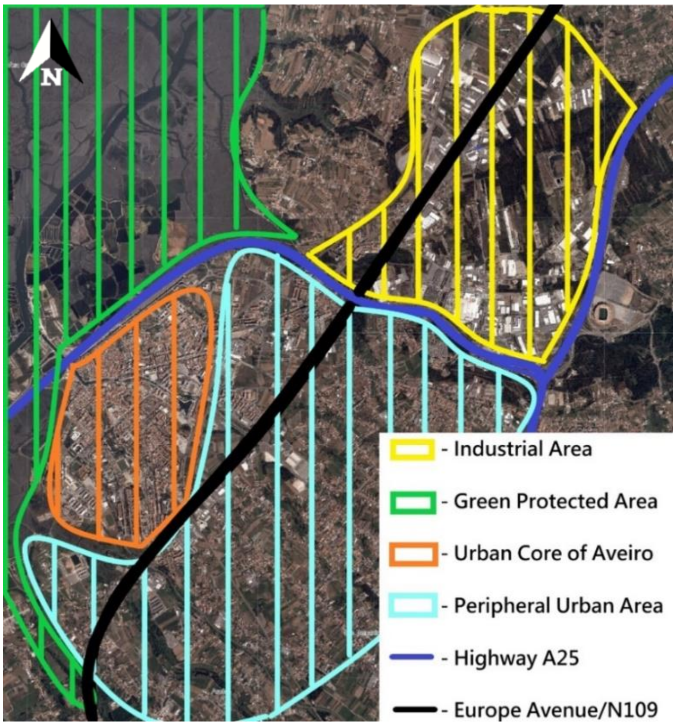


Figure 14 – Areas and access ground infrastructures of Aveiro. Source: Own elaboration based on satellite view from "Direção Geral do Território" (DGT) [7].

The access to the city of Aveiro is quite extensive. The main two are the A25 highway; and Avenida Europa (formerly known as N109). These roads provide an optimal circulation along the periphery of the urban core of the city. In figure 14, we see the A25 highway in blue and Avenida Europa in black.

The Europa avenue is of great importance, as it crosses the urban area of Aveiro, creates a logistical corridor throughout the city, having the urban core in one side and the peripheral urban area on the other.

The A25 allows us to travel a long distance in a short time, from the industrial area of Aveiro to the urban core of the city.

4.2.3 Weather conditions

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

The information required was the value of wind speed in meters per second and the quantity of precipitation in millimeters per hour (mm/h). The scale used for the analysis of precipitation was published on the IPMA website. Regarding the intensity of precipitation, it is important to know:

- weak, for values less than 2 mm/h;
- moderate, for values between 2 mm/h and 10 mm/h;
- strong, for values between 10 mm/h and 50 mm/h;
- violent, for values above 50 mm/h.

The values received represent the data collected from meteorology station number 1210702, located at the University of Aveiro, in the year 2019. The data is assembled in maximum wind recorded per hour and quantity of precipitation per hour. The table 11 represents, as an example, the month of January based on the data from IPMA.

Table 11 – Meteorology data from January first of 2019. Source:[66].

Station: 1210702; year:2019; month:1; day:1					
Hour	Max wind velocity [m/s]	Precipitation [mm]	Hour	Max wind velocity [m/s]	Precipitation [mm]
0	3,8	0	12	2,2	0
1	4,4	0	13	2,3	0
2	3,7	0	14	3,2	0
3	1,6	0	15	4,2	0
4	2,0	0	16	4,3	0
5	2,1	0	17	3,8	0
6	5,8	0	18	2,3	0
7	2,7	0	19	2,5	0
8	2,0	0	20	1,4	0
9	4,7	0	21	2,0	0
10	2,5	0	22	2,1	0
11	2,1	0	23	2,8	0

4.3 Pharmacies operation

The pharmaceutical core business is the sale of medicines, one of the primary goods for our society, making its supply chain one of the most important in the logistic world. To first understand where we need to implement a delivery route, we must define where are the delivery points (the pharmacies) and where is the logistic medicine base. Figure 15, shows the pharmacies and the logistic base location. All the pharmacies are numbered between 1 to 22, the real logistic base as L0, and the possible mobile logistic base L1, L2, L3. All this information was collected from Google Maps, and the figure map displays which are the selected pharmacies [67].

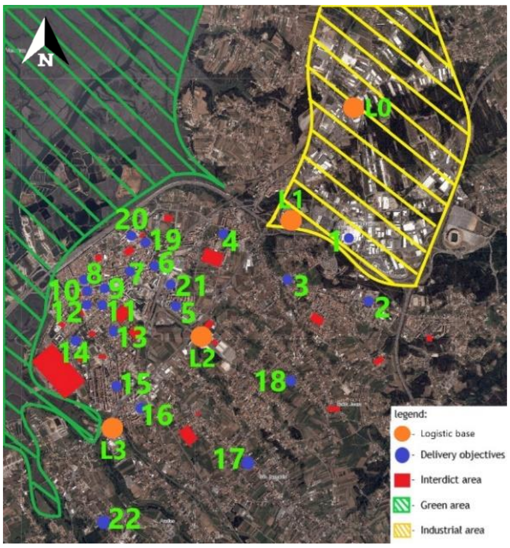


Figure 15 – Aveiro map with the operation scenario. Source: Own elaboration based on satellite view from “Direção Geral do Território” (DGT) [7].

Now that we have all the delivery points, we need to know how much is the demand of each pharmacy. To calculate the demand, we will consider the information provided by Infarmed, the National Medicines, and Health Products Authority. It published a report on medicines statistics in the year of 2018. In this report was exposed that in the center region of Portugal, exactly 40002509 medicines packages were sold through the national health system. Crossing this information with the demography of Aveiro, we arrive at the number of consumptions per person in one year of 17,19 packages. Due to increasing auto medication, we need to set this value higher. For that reason, we agree with 20,13[24] packages consume per year in the region of Aveiro. For emergency medicines, the quantity is 10% of the daily medicines, becoming a value of 2,01 packages per person in one year [68].

We will also consider the information provided by "Associação Nacional de Farmácias" ANF, that on average, a box of medicines weighing 50 g (0.050kg). With this information, we will divide the total weight of medicines for the total number of pharmacies of each parish, considering that all the population of one parish only consumes medicines from a pharmacy of his civil parish.

In the table 12 it is displayed the population of each parish, the percentage of the population that needs daily and emergency medication, and the final weight of medicines to be transported to each civil parish. In the table 13, it is displayed the demand of each pharmacy for daily and emergency delivery with the corresponding number assigned in the figure 15.

The formulation of the problem was:

$$x_d = 20{,}13/365 * \text{Population}, \quad \text{packages for daily medicines delivery;} \quad (4.1)$$

$$y_d = x * 0{,}05, \quad \text{considering 0,050 the medium weight of the medicines.} \quad (4.2)$$

For emergency medicines delivery, we have:

$$x_e = \frac{20{,}13}{365} * 0{,}1 * \text{Population}, \quad \text{packages for emergency medicines delivery;} \quad (4.3)$$

$$y_e = x * 0{,}050, \quad \text{total packages weigh considering 0,050 the medium weight of the medicines.} \quad (4.4)$$

---

[24] This value was obtained from a reasonable increase in auto medication and further ahead adjusted to the total daily medicines delivery of 150 kg (see page 50).

Table 12 – Total demand calculation by civil parish. Source: Own elaboration.

Civil Parish	**Population**	**x_d[25]**	**y_d[25] [kg]**	**x_e[26]**	**y_e[26] [kg]**
Aradas	9.157	505,00	25,25	50,50	2,53
Esgueira	13.431	740,71	37,04	74,07	3,70
Glória e Vera Cruz	18.756	1.034,38	51,72	103,44	5,17
S. Bernardo	4.960	273,54	13,68	27,35	1,37
Santa Joana	8.094	446,38	22,32	44,64	2,23
Total	54.398	3.000,00	150,00	300,00	15,00

For the demand, we divided *y* by all the pharmacies of each parish:

$$\text{demand}=y/\sum(\text{pharmacies per parish}), \quad \text{using } y_d \text{ for daily delivery } \textit{and } y_e \text{ for emergency delivery.} \tag{4.5}$$

Table 13 – Total demand calculation for each pharmacy. Source: Own elaboration.

Civil Parishes	**Pharmacies**	**Demand_d[27] of each pharmacy [kg]**	**Demand_e[28] of each pharmacy [kg]**
Aradas	16, 22	12,63	1,26
Esgueira	1, 2, 3, 4	9,26	0,93
Gloria e Vera Cruz	5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 19, 20, 21	3,69	0,37
São Bernardo	17	13,68	1,37
Santa Joana	18	22,32	2,23

From all the data showed in tables 12 and 13 and the figure 15, it is visible that the area of the urban core of Aveiro has the most significant number of pharmacies, also being the more populated area. Some areas have only one pharmacy, which represents a significant demand for the delivery system.

[25] *d*- Daily delivery.

[26] *e- Emergency delivery*

[27] *d*- Daily delivery.

[28] *e*- Emergency delivery.

The packages volume is not proportional to the weight. The payload is light packages with significant volume due to safety regulations. For that reason, high payloads can be a problem in the UAV delivery system implementation.

4.4 Operation Outline

In this section, we will establish the operation scenario for the delivery system, both the conventional (e.g., van), as also the UAV/UAS delivery system. The figure 16 displays the final operation map, with the logistic base, the several options for the mobile logistic base, and all the delivery points (pharmacies).

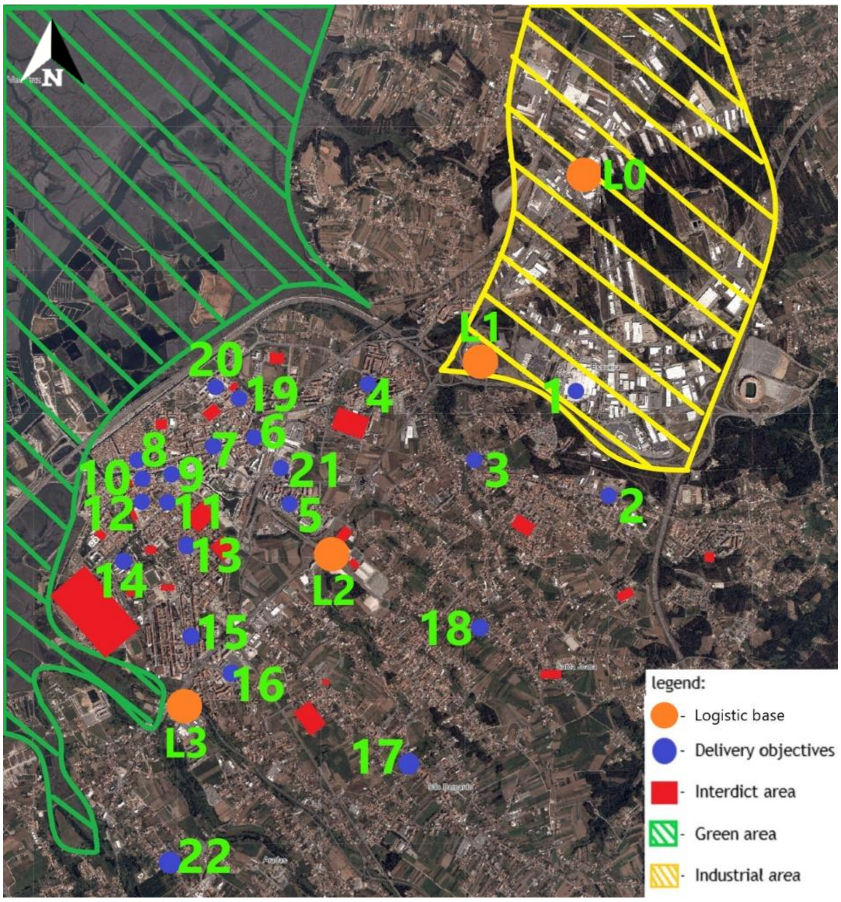


Figure 16 – Aveiro map with the operation scenario. Source: Own elaboration based on satellite view from “Direção Geral do Território” (DGT) [7].

There are several points and areas in the operation scenario (shown in red on figure 16) that cannot be overflown due to legislation. This could easily be overcome with an autonomous system used in the UAS that would always change the path if any of these areas appeared in the way.

The operation for medicine delivery will consist of several objectives, separated into 2 phases. Tables 14 and 15 displays all the objectives for each phase and introduces an outline for all our investigation.

Table 14 – Operation outline for phase 1. Source: Own elaboration.

Phase 1			
Both delivery methods will depart from the logistic base located in "L0" (see figure 16). This scenario considers the location of the logistic base currently existing in the industrial area of Aveiro.			
Daily delivery		**Emergency delivery**	
Conventional delivery	UAV/UAS delivery	Conventional delivery	UAV/UAS delivery
1. Departure from the logistic base; 2. Delivery to each pharmacy their demand; 3. Return to the logistic base; 4. Repeat if necessary, until all demand is delivered.			
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.	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.

The mobile logistic base will be positioned on L0, L1, L2, or L3. According to the literature, the position for a facility must be outside of an urban area, with good accessibility and ground clearance for UAV landing and take-off. These sites are located alongside the Europe Avenue/N109, the main road that goes through the city (see figure 14, from subsection 4.1.2). This base will consist of a van or a container that incorporates medicines stock and from there will depart the UAV to deliver all the demand. This base would be considered the UAV base port for battery change or maintenance.

In order to initiate the operation, there is a need to select the preferential vehicles for the conventional distribution and the UAV/UAS delivery. From several field research, we conclude that the delivery system used in the pharmaceutical logistic branch is the medium type van (see figure 17 further ahead). To best choose the van that will operate, the table 16 shows several vans. All comply with the pharmacy requirements for distribution that we saw in tables 12 and 13.

Table 15 – Operation outline for phase 2. Source: Own elaboration.

Phase 2			
The conventional vehicle (e.g., van) will depart from the logistic base "L0" (see figure 16), and the UAV delivery system will require a departure from a mobile logistic base (L0, L1, L2, or L3).			
Daily delivery		**Emergency delivery**	
Conventional delivery	UAV/UAS delivery	Conventional delivery	UAV/UAS delivery
1. Departure from the logistic base; 2. Delivery to each pharmacy their demand; 3. Return to the logistic base; 4. Repeat if necessary, until all demand is delivered.	1. Select the best location for the mobile facility base (L0, L1, L2 or L3); 2. Departure from the mobile logistic base; 3. Delivery to each pharmacy their demand; 4. Return to the mobile logistic base; 5. Repeat if necessary, until all demand is delivered.	1. Departure from the logistic base; 2. Delivery to each pharmacy their demand; 3. Return to the logistic base; 4. Repeat if necessary, until all demand is delivered.	1. Select the best location for the mobile facility base (L0, L1, L2 or L3); 2. Departure from the mobile logistic base; 3. Delivery to each pharmacy their demand; 4. Return to the mobile logistic base; 5. Repeat if necessary, until all demand is delivered.
It will be completed using a van in an optimized path with the TSP algorithm.	The location of the mobile base will be chosen using the uncapacited FLP. It will be completed with UAV/UAS delivery in an optimized path with the CW algorithm and TSP algorithm.	It will be completed using a van in an optimized path with the TSP algorithm.	The location of the mobile base will be chosen using the uncapacited FLP. It will be completed with UAV/UAS delivery in an optimized path with the CW algorithm and TSP algorithm.

Table 16 - Selected vans for the delivery of goods. Source: Own elaboration.

	Conventional delivery vehicles (vans)		
	Consumption (l/100km)	**Payload (kg)**	**Price (€)**
Mercedes Sprinter [69]	8,60	3.000	31.503
Fiat Ducato [70]	8,50	2.000	25.160
Renault Master [71]	9,00	2.800	31.601
Peugeot Boxer [72]	9,65	3.000	32.431
Citroen Jumper [73]	6,70	3.000	32.793
VolksWagen Crafter [74]	8,30	3.000	31.871
Ford Transit [75]	8,60	3.500	31.249

For that reason, we choose the Fiat Ducato, as having a more reasonable payload compared to our requirements, and that reflects on the final price of 25.160 €, the lowest of all vans. Consumption is one of the best that can translate into less operating costs. According to google maps and municipal legislations, this vehicle can operate on any road of the city of Aveiro, not having any maximum weigh or vast limitations [67], [76].

For recurring costs, we are going to considerer:

- Fuel costs - 1,31€/l [77];
- Operation costs – 1.500€/year, including:
    - Insurance;
    - General maintenance.

The vehicle selection for the UAV/UAS distribution will follow the following requirements:

- The payload capacity of 15 kg;
- Max flight capacity with max wind of 50 km/h.

The table 17 depicts some of the most popular UAV heavy lifters.

Table 17 - Selected UAV/UAS heavy lifters. Source: Own elaboration.

UAV/UAS	**Endurance (min)**	**Payload (kg)**	**Price (€)**	**Max wind (km/h)**
Vulcan D8 [78]	18	15	30.000,00	50,0
DJI Agras T16 [79]	10	15	18.561,05	28,8
Alta 8 Pro [80]	10	10	15.105,62	------
OnyxStar HYDRA-12 [81]	30	12	--------	50,0
FB2 [82]	25	30	40.000,00	54,0

The information displayed in table 17, was obtained through several email conversations with the UAV companies. Unfortunately, some values were not disclosed by the companies.

Some of the UAVs on table 17 do not comply with the requirements, making the final choice between the Vulcan D8, the DJI Agras T16, and the FB2. The Vulcan D8 is considered by the Vulcan company a delivery UAV, being possible to accommodate deliveries with no alteration. The DJI Agras T16 is an agricultural UAV, and this means that its system is adapted to pulverizing fields, making the transformation into a delivery drone more difficult. The FB2 is the UAV with the highest payload capacity and endurance, making it the preferential choice. Even if its price may be the highest, we foresee a low operating cost.

The UAV/UAS operation will be under the legislation of the national aviation authority, "Autoridade Nacional Aviação Civil" (ANAC), that follows the same guidelines of EASA. The UAV must operate under 120 meters of height and manage the take-off and landing to be safe and secure with a wide radius of clearance. Another option to ensure the safety would be with landing-ports APL stations mentioned in Chapter 2. The flight will be taken at 80 meters of height in reference to the ground, where there are no obstructions.

This operation requires to indicate all risks and operation limits in order to never jeopardize lives or material damages. There are several risks on the ground and in the air. On the ground, the UAV must always have the capability to land in a safe and with a wide radius of clearance. Besides that, the UAV must have an emergency procedure in case of signal loss or thrust failure to land or crash in a safe area with low population density, according to the guidelines stated by EASA shown in Chapter 2. In the air, the UAV will need to foresee all the obstacles, buildings; trees; wildlife; or other aircraft. The flight operation will have some restrictions:

- The wind limit of 50 km/h;
- Operate only with low precipitation;
- Payload limitation of 15kg;
- Prohibit to operate under a thunderstorm; and
- Flight speed of 40 km /h.

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 with approved conditions for flying. All the other days did not meet acceptable conditions.

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, as mentioned, the Fiat Ducato (see figure 17) for the conventional delivery system and the FB2 (see figure 18) for the UAV/UAS delivery system.

Figure 17 - Fiat Ducato. Source: [70].

Figure 18 - UAV FB2. Source: [83].

The operation outline can now be implemented in the next phases, where the delivery route will be created.

4.5 Phase 1

In phase 1, we will implement the distribution network using a van starting from location L0, passing through all pharmacies, and returning to L0, being the path optimized with the TSP algorithm. For the UAV/UAS delivery network, we will use the Clarke and Wright savings algorithm, due to payload, and endurance limitation, then, optimizing each route with the TSP algorithm.

4.5.1 Phase 1 with conventional vehicles delivery

With the data collected for vehicle routing generated automatically in Google Maps, we build the table 37 presented in appendix 2, where all distances between each pharmacy and the logistic facility are gathered. The total demand is 150kg for daily delivery and 15kg for 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.

From table 37 (see appendix 2), we have begun to build the first route of the companies' van using the TSP algorithm. The process used the Solver tool of the Office Excel with the parameters expressed in appendix 3. We conduct a minimum value possible iteration, producing the lowest value of total distance computed with the TSP algorithm. According to the TSP algorithm, all locations were tested as starting points of the circuit, and the optimized solution is shown further ahead.

We introduce all the delivery point from L0 to 22 with the premise that it must start at L0 and end at L0. As a first entry for the program to calculate the optimal route, we apply the standard route shown in the first column of tables 18 and 19. In sequence, all the locations were tested as starting points, in order to comply with the final route found with the TSP algorithm.

The final values obtained with the TSP algorithm were done with 1000 iterations. This process was repeated several times to ensure that the results were the same. The results for the conventional route vehicle are shown in the second column of table 18 for daily delivery and for emergency delivery in the second column if table 19. These results will establish a new route that will be almost the minimal cost possible. The time displayed in the last column in table 18 and 19 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 18 - Data obtained from Office Excel using the TSP algorithm for Phase 1 and 2, daily van delivery. Source: Own elaboration.

Original Route	Route TSP	Distance [km]	Payload [kg]	Time [min]
Lo	Lo	3,10		7,50
1	4	1,70	9,26	7,50
2	21	2,40	3,69	8,50
3	5	1,40	3,69	6,50
4	6	1,30	3,69	6,50
5	19	0,28	3,69	3,50
6	20	1,20	3,69	6,50
7	7	0,65	3,69	4,50
8	8	0,65	3,69	5,50
9	10	0,35	3,69	4,50
10	9	0,50	3,69	5,50
11	11	0,80	3,69	5,50
12	13	0,80	3,69	5,50
13	12	1,80	3,69	7,50
14	14	1,30	3,69	5,50
15	15	0,85	3,69	5,50
16	16	2,60	12,63	7,50
17	22	3,50	12,63	8,50
18	17	3,00	13,68	7,50
19	18	2,50	22,32	6,50
20	2	1,10	9,26	4,50
21	3	1,70	9,26	6,50
22	1	2,40	9,26	4,00
Lo	Lo			
Total		35,88	150,00	141,00

Table 19 - Data obtained from Office Excel using the TSP algorithm for Phase 1 and 2, emergency van delivery. Source: own elaboration.

Original Route	Route TSP	Distance [km]	Payload [kg]	Time [min]
Lo	Lo	3,10		7,50
1	4	1,70	0,93	7,50
2	21	2,40	0,37	8,50
3	5	1,40	0,37	6,50
4	6	1,30	0,37	6,50
5	19	0,28	0,37	3,50
6	20	1,20	0,37	6,50
7	7	0,65	0,37	4,50
8	8	0,65	0,37	5,50
9	10	0,35	0,37	4,50
10	9	0,50	0,37	5,50
11	11	0,80	0,37	5,50
12	13	0,80	0,37	5,50
13	12	1,80	0,37	7,50
14	14	1,30	0,37	5,50
15	15	0,85	0,37	5,50
16	16	2,60	1,26	7,50
17	22	3,50	1,26	8,50
18	17	3,00	1,37	7,50
19	18	2,50	2,23	6,50
20	2	1,10	0,93	4,50
21	3	1,70	0,93	6,50
22	1	2,40	0,93	4,00
Lo	Lo			
Total		35,88	15,00	141,00

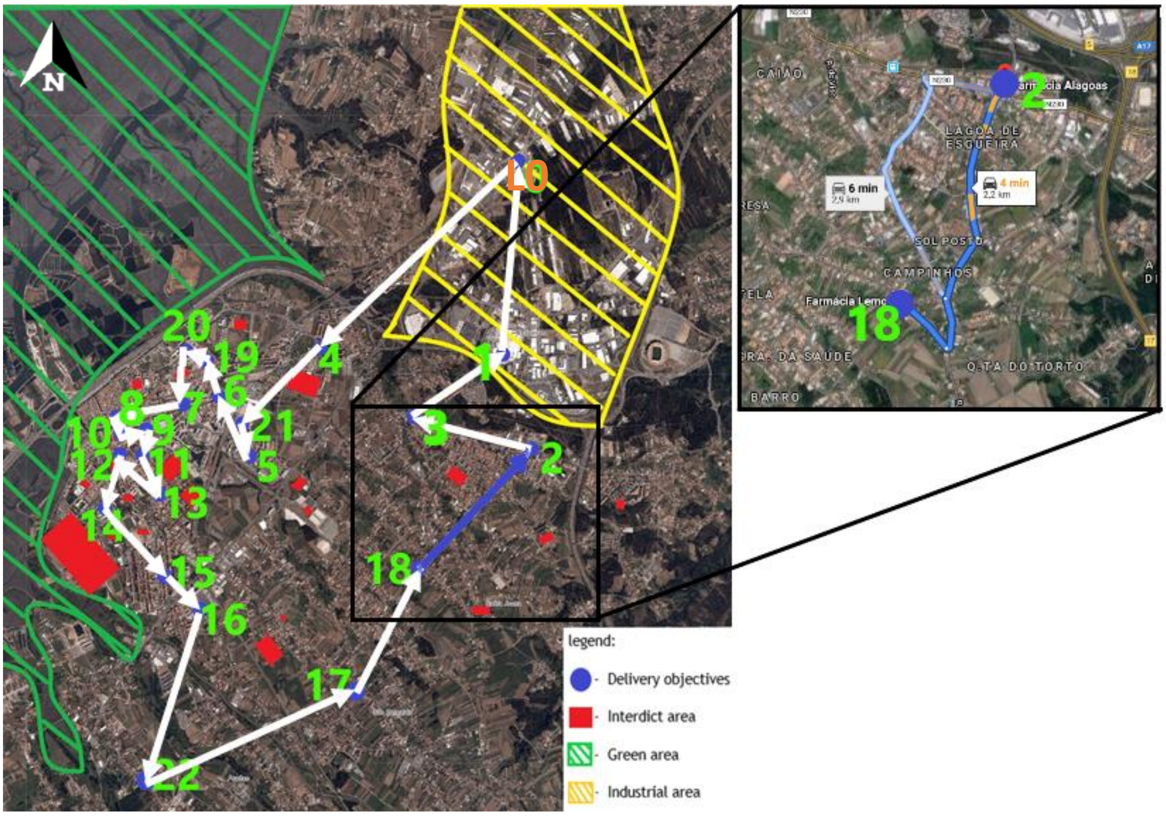


Figure 19 - Delivery route map obtained from the TSP algorithm for Phase 1 and 2, daily, and emergency van delivery. Source: Own elaboration based on satellite view from "Direção geral do território" (DGT) [7].

Tables 18 and table 19 exhibits the daily medicines delivery and the emergency delivery, respectively, with a total distance traveled by the van of 35,88 km and a travel time of 2 hours and 21 minutes (141 minutes). The total payload transported was 150 kg for the daily delivery and 15,00 for the emergency delivery.

Figure 19 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 19, 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.

4.5.2 Phase 1 with UAV/UAS delivery

For the UAV/UAS system, we will collect all the distances between pharmacies using Google Maps direct distance tool. The information is gathered in table 38 of appendix 2. 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) described in chapter 2, section 2.3.3. For better clarification, in appendix 5 is displayed all the steps used with Office Excel to find the near optimal route. We start to apply the CW algorithm presented in appendix 1, a), 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 considered all the possible direct routes to each pharmacy (see figure 38 from appendix 3), 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 using the equation A1.2 from the CW algorithm displayed in appendix 1, a).

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). The reorganized groups for daily delivery and emergency delivery are presented in table 20 and table 21, respectively.

Table 20 - Routes for daily delivery with UAV/UAS in phase 1. Source: Own elaboration .

Routes	Solution
Route A	L0, 13, 14, 15
Route B	L0, 8, 10, 12
Route C	L0, 7, 9, 11
Route D	L0, 18, 19, 20
Route E	L0, 5, 6, 21
Route F	L0, 1
Route G	L0, 2
Route H	L0, 3
Route I	L0, 4
Route J	L0, 16
Route L	L0, 17
Route M	L0, 18
Route N	L0, 22

Table 21 - Routes for emergency delivery with UAV/UAS in phase 1. Source: Own elaboration .

Routes	Solution
Route A	L0, 15, 16
Route B	L0, 12, 13, 14
Route C	L0, 9, 10, 11
Route D	L0, 3, 17, 18
Route E	L0, 6, 7, 8, 19
Route F	L0, 4, 5, 20, 21
Route G	L0, 1, 2
Route H	L0, 22

These routes achieved with the CW algorithm are not fully optimized. For that reason, we apply the TSP algorithm (see appendix 1, b), and appendix 3) to each group with the objective to find an optimal route for our UAV operation. 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 22 and table 23, 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.

Table 22 – Routes for phase 1 UAV daily delivery. Source: Own elaboration.

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 23 - Routes for phase 1 UAV emergency delivery. Source: Own elaboration.

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

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 appendix 5, figures 25 and 26 with the routes displayed over the map of Aveiro, both for daily delivery and emergency delivery with the UAV/UAS system.

4.6 Phase 2

In phase 2, we will implement the distribution network using a van, starting in location L0, passing through all pharmacies, and returning to L0. This operation will be the same already implemented in phase 1. For the UAV/UAS delivery network, we will start from selected the optimal location for the mobile logistic base, between L0, L1, L2, and L3 with the uncapacitated FLP. To the new logistic base, we apply the Clarke and Wright savings algorithm, due to payload, and endurance limits, then, optimizing each route with the TSP algorithm.

4.6.1 Phase 2 with conventional vehicles 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, we build table 37, presented in appendix 2. The process used the Solver tool of the Office Excel with the parameters expressed in appendix 1, b). The lowest possible value of total distance computed with the TSP algorithm is presented in phase 1, on tables 18 and 19 from subsection 4.4.1.

4.6.2 Phase 2 with facility location problem

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.

The uncapacitated FLP will consider all the four possible locations and produce the best location where our mobile logistic base will take place. We start from collecting all the distances between each pharmacy and each possible facility (L0, L1, L2, and L3) (see figure 16 of the subchapter 4.3). Using Google Maps direct distance tool, we assembled the table 24. The last line will present the cost to allocate the facility in the L0, L1, L2, or L3. The value comes in kilometers as a referential measure to the dislocation of a mobile logistic base.

Table 24 – Distances between each facility and the pharmacies with the implementing costs. Source: Own elaboration.

Locations	L0 [km]	L1 [km]	L2 [km]	L3 [km]
1	1233,70	419,75	1642,50	3014,90
2	1919,90	1175,30	1511,10	2825,10
3	1912,60	773,80	941,70	2357,90
4	1846,90	689,85	1051,20	2336,00
5	2781,30	1584,10	394,93	1387,00
6	2657,20	1511,10	861,40	1679,00
7	2898,10	1759,30	1014,70	1584,10
8	3285,00	2182,70	1343,20	1489,20
9	3175,50	2109,70	1160,70	1416,20
10	3343,40	2233,80	1306,70	1387,00
11	3219,30	2065,90	1029,30	1255,60
12	3379,90	2241,10	1211,80	1226,40
13	3431,00	2255,70	956,30	919,80
14	3737,60	2555,00	1314,00	883,30
15	3723,00	2511,20	1000,10	462,82
16	3796,00	2584,20	1014,70	402,96
17	3832,50	2722,90	1445,40	1627,90
18	2949,20	1934,50	1131,50	2080,50
19	2598,80	1547,60	1211,80	1941,80
20	2671,80	1642,50	1277,50	1956,40
21	2635,30	1452,70	606,63	1576,80
22	4978,60	3766,80	2175,40	1022,00
Implementation costs [km]	0,00	2482,00	3431,00	4453,00

The algorithm of uncapacitated FLP has the objective to minimize the equation 4.6. 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.

$$\min \quad \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}\, d_i y_{ij} + \sum_{j=1}^{n} f_j\, x_j \qquad i=1,\dots,m \qquad (4.6)$$[29]

[29] The restrictions for this equation are presented in appendix 1, c).

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 open, taking the value of 1 for x_j.

Introducing formula 4.6 to each column of table 24, we arrive at an annual cost presented in table 25.

Table 25 – Final annual cost in km for each facility location. Source: Own elaboration.

Annually cost [km]				
Location	**L0**	**L1**	**L2[30]**	**L3**
Annual cost	66.006,60	44.201,50	29.033,56	39.285,68

The solution from the implementation of the uncapacitated FLP algorithm concludes that the optimal location for the mobile logistic base will be L2 (see figure 20), with an annual total of 29.033,56 kilometers done.

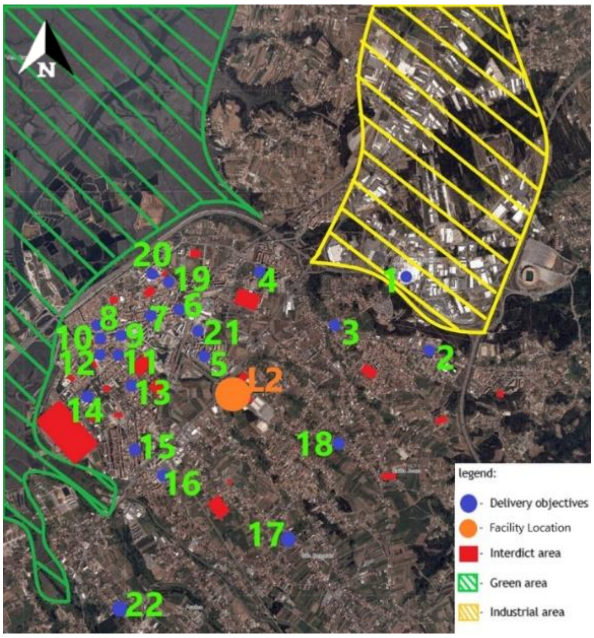


Figure 20 – Operation scenario for phase 2 with UAV delivery. Source: Own elaboration based on satellite view from "Direção Geral do Território" (DGT) [7].

[30] 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.

4.6.3 Phase 2 with 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 established in subchapter 4.5.2. The outcome of the new operation scenario is presented in figure 20.

For this new operation scenario, we will start with the construction of a delivery route using the CW algorithm described in chapter 2, section 2.3.3. For better clarification, in appendix 4 is displayed all the steps used with Office Excel to find the near optimal route. We start to apply the CW algorithm presented in appendix 1, a), 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 using the equation A1.2 from the CW algorithm.

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). The reorganized groups for daily delivery and emergency delivery are presented in table 26 and table 27, respectively.

Table 26 -Daily delivery routes with UAV for phase 2. Source: Own elaboration.

Routes	**Solution**
Route A	L2, 8, 9, 10, 12
Route B	L2, 6, 7, 19, 20
Route C	L2, 11, 12, 14, 15
Route D	L2, 5, 21
Route E	L2, 1
Route F	L2, 2
Route G	L2, 3
Route H	L2, 4
Route I	L2, 16
Route J	L2, 17
Route L	L2, 18
Route M	L2, 18
Route N	L2, 22

Table 27 - Emergency delivery routes with UAV for phase 2. Source: Own elaboration.

Routes	Solution
Route A	L2, 8, 9, 10, 11, 12, 14
Route B	L2, 15, 16, 17
Route C	L2, 5, 6, 7, 13, 19, 20, 21
Route D	L2, 1, 2, 3, 4, 18

These routes achieved with the CW algorithm are not fully optimized. For that reason, we apply the TSP algorithm (see appendix 1, a) for CW, and appendix 1, b) for TSP algorithms) to each group intending to find a near optimal route for our UAV. 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 28 and table 29, there are presented 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.

Table 28 – Phase 2 daily delivery optimized with TSP optimization for UAV/UAS. Source: Own elaboration.

Routes	Solution	Payload [kg]	Distance [km]	Time [min]
Route A	L2-12-10-8-9-L2	14,78	3,86	15,80
Route B	L2-6-19-20-7-L2	14,78	3,70	15,55
Route C	L2-11-13-14-15-L2	14,78	4,57	16,85
Route D	L2-5-21-L2	7,39	1,721	7,581
Route E	L2-1-L2	9,26	4,50	9,25
Route F	L2-2-L2	9,26	4,14	8,71
Route G	L2-3-L2	9,26	2,58	6,37
Route H	L2-4-L2	9,26	2,88	6,82
Route I	L2-16-L2	12,63	2,78	6,67
Route J	L2-17-L2	13,68	3,96	8,44
Route L	L2-18-L2	15,00	3,10	7,15
Route M	L2-18-L2	7,32	3,10	7,15
Route N	L2-22-L2	12,63	5,96	11,44
Total		150,00	46,85	127,78

Table 29 – Phase 2 emergency delivery optimized with TSP for UAV/UAS. Source: Own elaboration.

Routes	Solution	Payload [kg]	Distance [km]	Time [min]
Route A	L2-11-9-8-10-12-14-L2	2,22	4,62	24,43
Route B	L2-15-16-22-17-L2	4,26	7,70	24,04
Route C	L2-13-7-20-19-6-21-5-L2	2,59	4,61	24,41
Route D	L2-4-3-1-2-18-L2	5,94	7,50	23,75
Total		15,00	24,43	96,65

For daily delivery, we encounter a total of 150kg transported, 46,85 kilometers traveled for 127,78 minutes (2 hours and 7 minutes). For the emergency delivery, we observe a total demand of 15 kilograms, 24,43 kilometers traveled for 96,65 minutes (1 hour and 36 minutes). The final operation scenario is presented in appendix 5, on figure 27 and 28 with the routes displayed over the map of Aveiro, both for daily delivery and emergency delivery with the UAV/UAS system.

4.7 Conclusion

On a final note for chapter 4, the case study implementation was successfully achieved. The analysis of the city of Aveiro allowed us to understand better how we could achieve our initial objectives. This study allowed us to explore the topography of the territory, an essential task for the UAV operation. In order to meet the demand of all pharmacies, the demography of Aveiro was studied in parallel with the consumption of medicines in the region. Aveiro's meteorological knowledge was essential to optimize our operation and never take unnecessary risks.

In the implementation of the operation outline, we were able to obtain the main guidelines, from the selection of vehicles for the operation to the analysis of the risks and limits that each vehicle may have.

In the implementation of phases 1 and 2 of the delivery systems, 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.

Chapter 5

Analysis of the case study

5.1 Introduction

Chapter 5 follows on from chapter 4, where several delivery systems were implemented, requiring a more in-depth analysis of all the results obtained. For this reason, chapter 5 will be a critical analysis of the results.

We start by comparing the phases independently, where we also compare for daily and urgent deliveries. From here, we will compare values such as delivery times, distances traveled, and costs of implementation.

As a final objective, we verify which would be the best system to be implemented and to obtain some conclusions about how this process would be made.

5.2 Phase 1 results analysis

Phase 1 consists of the implementation of a delivery system starting from location "L0", where is establish the logistic base for medicines in the city of Aveiro. From the results achieved in chapter 4, we can now compare both daily and emergency delivery of medicines into the pharmacies.

5.2.1 Phase 1 comparison with daily delivery

We start by looking for the results of tables 18, 20, and 22 of subchapter 4.4. 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 subchapter 4.3 of the operation outline. The other 91 days will be operated with the van.

The first data to be compared is the daily delivery. In table 30, we proceed to assemble all the total values for all payload transported, the total distance, and the time travel of the full year.

Table 30 –Phase 1 total for the daily distribution performance of each delivery system in one year. Source: Own elaboration.

Daily delivery of medicines in one year		
	With van	**With UAV and van**
Total payload [kg]	54.750,00	54.750,00
Total distance [km]	13.096,20	33.482,90
Total delivery time [min]	51.465,00	73.912,72

The values of table 30 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 doesn´t 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.

5.2.2 Phase 1 comparison with emergency delivery

Considering now the emergency delivery, the results from table 19, 21, and 23 are analyzed. The table 31 gathers the total values of payload distance and time travel.

Table 31 – Phase 1 total for emergency distribution performance of each delivery system in one year. Source: Own elaboration.

Emergency delivery of medicines in one year		
	With van	**With UAV and van**
Total payload [kg]	5.475,00	5.475,00
Total distance [km]	13.096,20	24.618,45
Total delivery time [min]	51.465,00	59.931,05

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 11522,25 km traveled than the van delivery, but only differentiate in 8466,05 minutes in time traveled (141 hours). In a full year of work, this difference is almost as non. 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 23, from subchapter 4.4.2) 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.

5.3 Phase 2 comparative analysis

Phase 2 consists of the implementation of a delivery system starting from location "L0, L1, L2, or L3", where is established the mobile logistic base for medicines in the city of Aveiro. From the results achieved in chapter 4, we can now compare both daily and emergency delivery of medicines into the pharmacies.

5.3.1 Facilities new location

In the case study was selected from several possible facilities for a mobile logistic base, where would depart the UAV for distribution. The uncapacitated FLP algorithm allowed the choice for the new location to be the near optimal facility location. There were four possible locations (L0, L1, L2, L3). From the results was concluded that L2 would be the best location. Analyzing point L2, we find that it is located next to Avenida Europa/N109, and in a car park area. It is located between the peripheral area of the city and the urban core, is preferential for distribution from a UAV. The site is entirely unobstructed, wide, and easy to access. This way, the mobile platform will never have to enter the urban area, avoiding major traffic jams, and wasted time looking for parking.

5.3.2 Phase 2 comparison with daily delivery

Going through the results shown on tables 18, 26, 28, 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 (see subchapter 4.1.3).

The first data to be compared is the daily delivery, wherein table 32, we gather all the total values for all payload transported, the total distance, and the time travel of an all year.

Table 32 – Phase2 total for daily distribution performance of each delivery system in one year. Source: Own elaboration.

Daily delivery of medicines in one year		
	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

In this scenario, the system with UAV/UAS and van has the lowest accumulated time travel in comparison to the van system. The values from the distance traveled, the van does lower values, what 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. These values are possible due to the location of the logistic base that by standing in the L2 position optimizes the distance between the pharmacies and enables the UAV to deliver on more pharmacies before reaching the limits of payload and endurance. Although, with the same problem stated in phase 1, 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.

5.3.3 Phase 2 comparison with emergency delivery

Going through the results shown on tables 19, 27, and 29, 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 (see subchapter 4.1.3).

The data to be compared is the emergency delivery, wherein table 33, we gather all the total values for all payload transported, the total distance, and the time travel of an all year.

Table 33 – Phase 2 total for emergency distribution performance of each delivery system in one year. Source: Own elaboration.

Emergency delivery of medicines in one year		
	With van	**With UAV and van**
Total payload [kg]	5.475,00	5.475,00
Total distance [km]	13.096,20	9.958,90
Total delivery time [min]	51.465,00	39.311,73

In this scenario, the best system is undoubtedly the UAV/UAS and van distribution. The values from the operation implementation, we see 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 shows that it would be the best choice to implement this delivery.

5.4 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 50000 kilometers in a way to compare both systems, the conventional and the UAV/UAS. This comparison is based on the data collected in the subchapter 4.3 of the operation outline, where is presented the implementation cost for both systems and an estimative for maintenance costs. We assemble in table 34 all the information needed to compare total cost associated and the price per kilometer that each system will charge.

Table 34 – Implementation costs for each vehicle. Source: Own elaboration.

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 €

The van system has low implementation costs, though the recurring costs are significant compared to the acquisition of the vehicle. This value is considered the lowest in the market. As we saw in subchapter 4.3 of the operation outline, this vehicle was the less expensive and with one of the best fuel consumptions.

The final difference between one vehicle and the other is not so great. Even though the UAV/UAS 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 is endurance and payload capabilities. Another point to enhance is the fact that this technology is at the beginning of is evolution path, becoming an expensive acquisition. We can foresee that in the future of the UAV/UAS market, the competition between builders will increase, and the prices will decline into more attractive prices. The maintenance of a UAV/UAS 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 50000 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 and gather with the implementation costs. 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 35, assuming the cost per kilometer and the travel distance done in one year.

For the UAV and van system, the solution comes from:

$$Total\ cost_{VAN} = (vankmcost) * d1 * d2, \qquad d1 = distance\ pre\ day, \tag{5.1}$$

$$Total\ cost_{UAV/VAN} = (UAVkmcost) * d1 * d2 + (vankmcost) * d1 * d2, \qquad d2 = working\ days. \tag{5.2}$$

Table 35 – Total implementation costs for a full year. Source: Own elaboration.

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	26.721,02	10.215,04	19.629,46

Phase 2	**Daily**		**Urgent**	
	Van	**UAV and van**	**Van**	**UAV and van**
Distance [km]	13.096,20	16.102,53	13.096,2	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	12.816,72	10.215,04	7.901,82

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/UAS will be the best option, that could save at the end of the year around 2.313 €. 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.

5.5 Conclusion

The analysis of the case study starts with the results from phase 1. This scenario was implemented successfully. For both systems, the depart was from the L0 facility. The results from this scenario, both daily and emergency delivery, were conclusive. The UAV performance was not up to the van system. The study concludes that for now, with the operation scenario implemented, the best delivery system to be implemented is the conventional van delivery.

The phase 2 study had the same scenario for the conventional delivery system, departing from L0. For the UAV/UAS was introduce a new facility location, one that could be mobile, and optimize the delivery of medicines. The study began with the choice of a new facility location, where the results were quite conclusive. The best location between L0, L1, L2, and L3 is location L2, where the new mobile logistic base would take place for the UAV/UAS delivery. This study enables several opportunities/options.

On the one hand, the van delivery scenario was the same. On the other hand, the UAV had its facility location optimized. The results from daily delivery showed an enormous improvement in performance, making this system the fastest, although its distance was highest. This result is possible due to the direct routes and no unforeseen stops. For the emergency delivery, the UAV/UAS performance was higher than the van system, both on the distance and time delivery, making this system the preferential to be implemented.

The results from cost implementation were also conclusive. For the several systems studied, van delivery still is the best option and more cost-effective. Even though in the emergency delivery of phase 2, the results have shown that the best option for implementation is the UAV delivery, it has the best performance and the low implementation cost. Besides, this system can be implemented quickly, the payload is extremely low, and the volume capacity can be respected. For daily delivery, the UAV would have several problems with volume capacity, due to oversized medicines packages.

Chapter 6

Conclusion

6.1 Introduction

This chapter presents the result of the study methodology and to conclude if our initial objectives were achieved. This chapter will first show all the results discuss through the thesis and foresee its limitation. Furthermore, we introduce the future research that could be done. The concluding remarks end this chapter.

6.2 Dissertation synthesis

The initial process for this thesis 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 thesis. 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 thesis 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/UAS more competitive; and find the best solution for the urban logistic system.

The importance of this thesis 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 and the types of aircraft that it was possible to find. 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.

For the objective of optimizing the delivery system that we pretended to implement, we introduce the algorithms to be used in the case study. The importance of their application is maximum. These algorithms allow us to obtain considerable reductions in recurring operating costs. So, we will have systems optimized and ready to be implemented.

The SWOT analysis was an essential study on this thesis (chapter 3). This analysis enables us to answer several of our initial objectives. The study concludes that for nowadays urban logistics, the use of a conventional delivering system is the obvious choice to operate. Although, what the future reserves for this system could not be pleasant. Besides the oversize of the vehicle and future traffic legislations, the urban cores of the cities could become inaccessible. For the UAV/UAS as a technology that is yet in its early stages, on the one hand, has many limitations. On the other hand, this technology has many opportunities that will overcome the conventional vehicle. There are some problems that a conventional delivery system will never overcome. For example, a direct route delivering and access to places where it is prohibited to road vehicles would never be possible. This is the primary advantage of UAV/UAS. Besides is an ecofriendly system, low material consumption on construction, and it runs on electricity that can easily be created through renewable energy sources. For this reason, the UAV/UAS was considered in the VRIO analysis, a competitive technology that cannot be used due to legislation factors.

The study case (chapter 4) 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 (chapter 5). 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 preferential 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.

The objectives of this thesis were achieved, as there was found a consensus in the use of UAV/UAS for the management of urban air logistics.

6.3 Limitations

There are several limitations presented in this thesis investigation. The data collected for the demand of each pharmacy is an average value predicted by the population of the Aveiro region and the value of medicines sold through the national health system in pharmacies in the Aveiro area. Therefore, we assume that the population of each area buys only at the pharmacies in their area of residence, which may not portray the reality. Unfortunately, it would be impossible to collect complete information from all pharmacies in Aveiro, due to the short investigation period and mainly pandemic COVID-19 restrictions.

Another 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.

6.4 Future work

For future investigation, several studies can take this thesis 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.

Furthermore, it would be interesting to investigate this type of delivery system under the new legislation that may already be available. This could include different preparation of operation scenarios, with more rigid laws and procedures.

A possible investigation to be realized would be to adopt just-in-time business with UAV/UAS technology, or with this model, introduce the swarm UAV system, creating new networks of delivery systems.

6.5 Conclusion

This thesis offers an approach to what could be the future of urban logistics. For transport engineers, aeronautical engineers, urban planners, and aviation authorities, this can be an important change in the concept of how we plan our transport chain. This starting point must be investigated in order to overcome all difficulties and risks that this rising technology can bring. This thesis will contribute to the transport industry and the aeronautical field as a conceptual idea for operation scenarios in urban logistics.

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Appendix 1 – Algorithms formulations

a) Clarke and Wright Savings Algorithm

"(...) With a number of trucks x_i, each with a capacity of C_i (i=1...N), where a load of q_j is required to be delivered to points P_j (j=1...M), from a depot P_0. With the distance given between all delivery point it is asked to minimize the total distance covered by the trucks.

For a better computation C_i are ordered such that $C_{i-1}<C_i$ (i=2...N) and it is assumed that

$$C_1 << \sum_{j=1}^{j=m} q_j \tag{A1.1}$$

to ensure that all loads are allocated x_1 need to be sufficiently large. When $C_n \geq \sum_{j=1}^{j=n} q_j$ the problem becomes the traveling salesman problem (...)" [52][31]

The algorithm used was divided in 4 steps:

- Step 1: Make the combination two by two of all points (from "i" to "j");

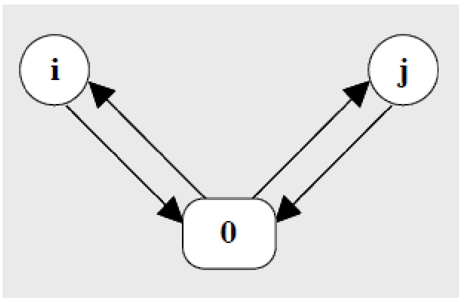

Figure 21 - Combination of two by two routes starting always at point 0. Source: Own elaboration.

- Step 2: Calculate the savings of all pairs of points;

$$S_{i,j}=C_{i,0}+C_{0,j}-C_{j,i} \qquad i, j=1,\dots,n \text{ and } i\neq j \tag{A1.2}$$

This will create n-1 routes, appearing as route (1, *i*, 1), where i=2,... ,n.

[31] [52], pp 568.

- Step 3: Sort the savings of each pair $S_{i,j}$ in descending order;

Table 36 - Example of two by two pairs in descending order. Source: Own elaboration.

Routes Si,j	Savings
3, 4	20
2, 3	18
4, 5	15
5, 6	12
…	…

- Step 4: Consider two vehicle routes containing arcs $(i, 1)$ and $(1, j)$, respectively. If $S_{i,j} > 0$, merge these routes by introducing the arc (i, j) and by deleting arcs $(i, 1)$ and $(1, j)$.

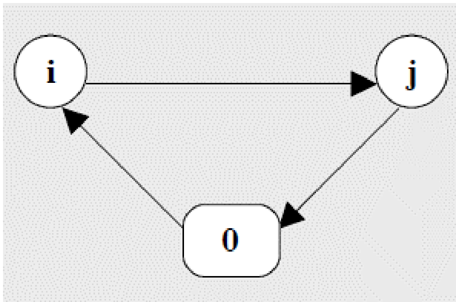

Figure 22 - Optimized route with Clarke and Wright Savings Algorithm. Source: Own elaboration.

Merge the next arc that appears in next from step 3. Repeat this step 4 until no further improvement is possible, or the final capacity of the vehicle is reached [52], [55], [84].

b) Traveling Salesman Problem (TSP)

"(...) (1) - A salesman is required to visit each of n cities, indexed by 1 to n. He leaves from a "base city" indexed by 0, visits each of the n other cities exactly once, and returns to city 0. During his travels, he must return to 0 exactly *t* times, including his final return (here *t* may be allowed to vary), and he must visit no more than *p* cities in one tour (by a tour we mean a succession of visits to cities without stopping at city 0.) It is required to find such an itinerary which minimizes the total distance traveled by the salesman.

Note that if *t* is fixed, then for the problem to have a solution we must have $tp \geq n$. For $t = 1, p \geq n$, we have the standard traveling salesman problem. Let $d_{i,j}$ $(i \neq j = 0,1, \dots, n)$ be the distance covered in traveling from city i to city j. The following integer programming problem will be shown to be equivalent to the initial problem.

(2) - Minimize the linear form

$$\sum_{0 \leq i \neq} \sum_{j \leq n} d_{i,j}.x_{i,j} \qquad \text{(A1.3)}$$

over the set determined by the relations

$$\sum_{\substack{i=0 \\ i \neq j}}^{n} x_{i,j}=1 \qquad (j=1, \dots, n) \qquad \text{(A1.4)}$$

$$\sum_{\substack{i=0 \\ i \neq j}}^{n} x_{i,j}=1 \qquad (j=1, \dots, n) \qquad \text{(A1.5)}$$

$$u_1-u_j+px_{i,j} \leq p-1 \qquad (1 \leq i \neq j \leq n) \qquad \text{(A1.6)}$$

where the $x_{i,j}$ are non-negative integers and the u_i $(i = 1, \dots, n)$ are arbitrary real numbers. (We shall see that it is permissible to restrict the u_i to be non-negative integers as well). If *t* is fixed it is necessary to add the additional relation:

$$\sum_{i=1}^{n} x_{i,o}=t \qquad \text{(A1.7)}$$

Note that the constraints require that $x_{i,j} = 0 \text{ or } 1$, so that a natural correspondence between these two problems exists if the $x_{i,j}$ are interpreted as follows: The salesman proceeds from city *i* to city *j* if and only if $x_{i,j} = 1$. Under this correspondence the form to be minimized in (2) is the total distance to be traveled by the salesman in (1), so the burden of proof is to show that the two feasible sets correspond; i.e., a feasible solution to (2) has $x_{i,j}$ which do define a legitimate itinerary in (1), and, conversely a legitimate itinerary in (1) de- fines $x_{i,j}$, which, together with appropriate u_i, satisfy the constraints of (2). Consider a feasible solution to (2). The number of returns to city 0 is given by

$$\sum_{i=1}^{n} x_{i,0} \qquad \text{(A1.8)}$$

The constraints of the form

$$\sum_{i=1}^{n} x_{i,0}=1 \qquad \text{all } x_{i,j} \text{ non-negative integers,} \qquad \text{(A1.9)}$$

represent the conditions that each city (other than zero) is visited exactly once (...)" [57] [32].

[32] [57], pp 326-327.

c) Uncapacitated Facility Location Problem

"(...) A company would like to set up facilities in order to serve geographically dispersed customers at minimum cost. The m customers have known annual demands d_i, for $i = 1, \dots, m$. The company can open a facility of capacity u_j and fixed annual operating cost f_j in location j, for $j = 1, \dots, n$. Knowing the variable cost c_{ij} of transporting one unit of goods from location j to customer i, where should the company locate its facilities in order to minimize its annual cost.

To formulate this problem, we introduce variables x_j that take the value 1 if a facility is opened in location j, and 0 if not. Let y_{ij} be the fraction of the demand d_i transported annually from j to i.

$$\min \quad \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}\, d_i y_{ij} + \sum_{j=1}^{n} f_j\, x_j \qquad i=1,\dots,m \qquad \text{(A1.10)}$$

$$\sum_{j=1}^{n} y_{ij} = 1 \qquad i=1,\dots,m \qquad \text{(A1.11)}$$

$$\sum_{j=1}^{n} d_i y_{ij} \le u_j x_j \qquad j=1,\dots,n \qquad \text{(A1.12)}$$

$$y \ge 0 \qquad \text{(A1.13)}$$

$$x = \{0,1\}^n. \qquad \text{(A1.14)}$$

The objective function is the total yearly cost (transportation plus operating costs). The first set of constraints guarantees that the demand is met, the second type of constraints are capacity constraints at the facilities. Note that the capacity constraints are fixed charge constraints, since they force $x_j = 1$ whenever $y_{ij} > 0$ for some i.

A classical special case is the uncapacitated facility location problem, in which $u_j = +\infty$, $j = 1, \dots, n$. In this case, it is always optimal to satisfy all the demand of client i from the closest open facility, therefore y_{ij} can be assumed to be binary. Hence the problem can be formulated as

$$\min \quad \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}\, d_i y_{ij} + \sum_{j=1}^{n} f_j\, x_j \qquad i = 1, \dots, m \qquad \text{(A1.15)}$$

$$\sum_{j=1}^{n} y_{ij} = 1 \qquad i = 1, \dots, m \qquad \text{(A1.16)}$$

$$\sum_{j=1}^{n} y_{ij} \leq m x_j \qquad j = 1, \ldots, n \qquad \text{(A1.17)}$$

$$y \in \{0,1\}^{m \times n}, \quad x \in \{0,1\}^{n} \text{ (...)" [85]}^{33} \qquad \text{(A1.18)}$$

The facility *j* with the minimal value will be the selected.

33 [85], pp 67-68.

Appendix 2 – Tables of distances between delivery points

Distance between delivery points road routes (km)																							
Pharmacies	L0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
L0	0,00	2,40	2,90	3,60	3,10	4,60	5,00	4,70	5,30	5,50	7,00	5,30	5,30	5,50	7,10	5,10	6,00	6,90	5,50	4,40	4,60	4,40	7,50
1	2,40	0,00	2,10	1,70	2,50	4,80	4,40	4,00	4,70	4,80	6,30	4,60	4,70	4,90	6,40	5,00	5,40	6,30	4,90	3,70	3,60	3,70	6,70
2	2,90	2,10	0,00	1,10	2,40	3,80	4,20	3,90	4,50	4,70	4,50	4,50	4,50	4,70	6,30	4,80	5,20	3,60	2,50	5,30	4,60	3,60	6,50
3	3,60	1,70	1,10	0,00	1,40	2,80	3,20	2,80	3,40	3,60	3,50	3,40	3,50	3,70	5,20	3,80	4,20	5,10	3,40	3,60	4,80	4,60	7,50
4	3,10	2,50	2,40	1,40	0,00	2,70	2,00	1,60	2,20	2,50	2,30	2,30	2,40	3,60	5,10	3,60	4,00	4,90	3,50	1,80	1,70	1,70	5,50
5	4,60	4,80	3,80	2,80	2,70	0,00	1,40	2,60	2,10	2,00	2,10	1,70	1,80	1,50	3,70	2,00	2,70	3,30	3,00	2,10	2,30	2,40	3,90
6	5,00	4,40	4,20	3,20	2,00	1,40	0,00	0,65	1,30	1,70	1,30	1,30	1,50	2,10	3,20	2,70	3,40	4,00	3,70	1,30	1,50	2,10	5,00
7	4,70	4,00	3,90	2,80	1,60	2,60	0,65	0,00	0,65	1,00	0,65	1,20	1,20	1,80	3,30	2,40	3,20	4,30	4,10	1,40	1,20	1,80	5,60
8	5,30	4,70	4,50	3,40	2,20	2,10	1,30	0,65	0,00	1,00	0,65	1,10	1,20	1,80	3,30	2,40	3,20	4,30	5,10	4,20	1,80	2,40	4,40
9	5,50	4,80	4,70	3,60	2,50	2,00	1,70	1,00	1,00	0,00	0,35	0,50	0,55	1,10	3,00	1,70	2,50	3,70	4,40	4,00	2,10	2,70	4,30
10	7,00	6,30	4,50	3,50	2,30	2,10	1,30	0,65	0,65	0,35	0,00	0,50	0,55	1,20	2,80	1,70	2,60	3,70	4,40	3,70	1,80	2,40	4,40
11	5,30	4,60	4,50	3,40	2,30	1,70	1,30	1,20	1,10	0,50	0,50	0,00	1,20	0,80	1,80	1,30	2,20	4,20	3,90	2,00	1,90	2,50	4,00
12	5,30	4,70	4,50	3,50	2,40	1,80	1,50	1,20	1,20	0,55	0,55	1,20	0,00	0,80	1,80	1,30	2,20	4,10	5,20	4,60	1,90	2,50	4,20
13	5,50	4,90	4,70	3,70	3,60	1,50	2,10	1,80	1,80	1,10	1,20	0,80	0,80	0,00	2,10	1,40	2,30	3,40	4,30	2,70	2,50	3,30	3,00
14	7,10	6,40	6,30	5,20	5,10	3,70	3,20	3,30	3,30	3,00	2,80	1,80	1,80	2,10	0,00	1,30	2,60	4,60	5,60	4,10	5,80	4,80	3,40
15	5,10	5,00	4,80	3,80	3,60	2,00	2,70	2,40	2,40	1,70	1,70	1,30	1,30	1,40	1,30	0,00	0,85	2,80	3,80	4,60	4,40	3,40	2,40
16	6,00	5,40	5,20	4,20	4,00	2,70	3,40	3,20	3,20	2,50	2,60	2,20	2,20	2,30	2,60	0,85	0,00	2,70	3,70	4,50	4,80	3,80	2,60
17	6,90	6,30	3,60	5,10	4,90	3,30	4,00	4,30	4,30	3,70	3,70	4,20	4,10	3,40	4,60	2,80	2,70	0,00	3,00	6,40	5,70	4,60	3,50
18	5,50	4,90	2,50	3,40	3,50	3,00	3,70	4,10	5,10	4,40	4,40	3,90	5,20	4,30	5,60	3,80	3,70	3,00	0,00	5,70	4,30	3,30	5,60
19	4,40	3,70	5,30	3,60	1,80	2,10	1,30	1,40	4,20	4,00	3,70	2,00	4,60	2,70	4,10	4,60	4,50	6,40	5,70	0,00	0,28	2,60	6,40
20	4,60	3,60	4,60	4,80	1,70	2,30	1,50	1,20	1,80	2,10	1,80	1,90	1,90	2,50	5,80	4,40	4,80	5,70	4,30	0,28	0,00	2,60	6,50
21	4,40	3,70	3,60	4,60	1,70	2,40	2,10	1,80	2,40	2,70	2,40	2,50	2,50	3,30	4,80	3,40	3,80	4,60	3,30	2,60	2,60	0,00	5,30
22	7,50	6,70	6,50	7,50	5,50	3,90	5,00	5,60	4,40	4,30	4,40	4,00	4,20	3,00	3,40	2,40	2,60	3,50	5,60	6,40	6,50	5,30	0,00

Table 37 -Distance between delivery points and facilities for road routes. Source: Own elaboration.

Distance between delivery points with direct routes (km)

Distances	L0	L2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
L0	0	4,7	1,69	2,63	2,62	2,53	3,81	3,64	3,97	4,50	4,35	4,58	4,41	4,63	4,70	5,12	5,10	5,20	5,25	4,04	3,56	3,66	3,61	6,82
L2	4,70	0,00	2,25	2,07	1,29	1,44	0,54	1,18	1,39	1,84	1,59	1,79	1,41	1,66	1,31	1,80	1,37	1,39	1,98	1,55	1,66	1,75	0,83	2,98
1	1,69	2,25	0,00	1,11	0,972	1,32	2,39	2,44	2,79	3,38	3,18	3,42	3,16	3,41	3,33	3,78	3,58	3,64	3,55	2,36	2,58	2,71	2,3	5,18
2	2,63	2,07	1,11	0,00	1,01	1,93	2,07	2,77	3,12	3,68	3,43	3,68	3,34	3,59	3,36	3,85	3,43	3,34	2,71	1,48	3,07	3,23	2,49	4,64
3	2,62	1,29	0,97	1,01	0,00	0,95	1,29	1,76	2,10	2,68	2,45	2,70	2,36	2,68	2,47	2,94	2,65	2,66	2,68	1,59	2,05	2,17	1,49	4,18
4	2,53	1,44	1,32	1,93	0,95	0,00	1,44	1,22	1,17	2,05	1,86	2,11	1,87	2,12	2,00	2,56	2,56	2,71	3,28	2,45	1,23	1,37	1,07	4,39
5	3,81	0,54	2,39	2,07	1,29	1,44	0,00	1,18	1,39	1,84	1,59	1,79	1,41	1,66	1,31	1,80	1,37	1,39	1,98	1,55	1,66	1,75	0,35	2,98
6	3,64	1,18	2,44	2,77	1,76	1,22	1,18	0,00	0,34	0,93	0,72	0,97	0,75	0,98	1,11	1,46	1,65	1,92	3,13	2,72	0,48	0,59	0,34	3,64
7	3,97	1,39	2,79	3,12	2,10	1,17	1,39	0,34	0,00	0,59	0,39	0,63	0,49	0,68	0,94	1,19	1,55	1,86	3,25	2,96	0,51	0,52	0,63	3,54
8	4,50	1,84	3,38	3,68	2,68	2,05	1,84	0,93	0,59	0,00	0,26	0,14	0,46	0,35	0,87	0,87	1,50	1,88	3,54	3,40	0,94	0,86	1,18	3,44
9	4,35	1,59	3,18	3,43	2,45	1,86	1,59	0,72	0,39	0,26	0,00	0,25	0,25	0,30	0,72	0,84	1,36	1,72	3,31	3,15	0,84	0,80	0,94	3,33
10	4,58	1,79	3,42	3,68	2,70	2,11	1,79	0,97	0,63	0,14	0,25	0,00	0,39	0,22	0,76	0,72	1,38	1,76	3,44	3,35	1,04	0,97	1,19	3,29
11	4,41	1,41	3,16	3,34	2,36	1,87	1,41	0,75	0,49	0,46	0,25	0,39	0,00	0,27	0,48	0,71	1,13	1,48	3,09	2,96	0,98	0,96	0,87	3,12
12	4,63	1,66	3,41	3,59	2,68	2,12	1,66	0,98	0,68	0,35	0,30	0,22	0,27	0,00	0,54	0,55	1,15	1,54	3,25	3,18	1,14	1,09	1,13	3,09
13	4,70	1,31	3,33	3,36	2,47	2,00	1,31	1,11	0,94	0,87	0,72	0,76	0,48	0,54	0,00	0,48	0,64	1,00	2,71	2,78	1,43	1,45	1,09	2,62
14	5,12	1,80	3,78	3,85	2,94	2,56	1,80	1,46	1,19	0,87	0,84	0,72	0,71	0,55	0,48	0,00	0,82	1,21	3,07	3,23	1,67	1,63	1,50	2,60
15	5,10	1,37	3,58	3,43	2,65	2,56	1,37	1,65	1,55	1,50	1,36	1,38	1,13	1,15	0,64	0,82	0,00	0,39	2,24	2,56	2,04	2,07	1,53	1,97
16	5,20	1,39	3,64	3,34	2,66	2,71	1,39	1,92	1,86	1,88	1,72	1,76	1,48	1,54	1,00	1,21	0,39	0,00	1,90	2,34	2,33	2,38	1,73	1,72
17	5,25	1,98	3,55	2,71	2,68	3,28	1,98	3,13	3,25	3,54	3,31	3,44	3,09	3,25	2,71	3,07	2,24	1,90	0,00	1,25	3,61	3,70	2,78	2,24
18	4,04	1,55	2,36	1,48	1,59	2,45	1,55	2,72	2,96	3,40	3,15	3,35	2,96	3,18	2,78	3,23	2,56	2,34	1,25	0,00	3,15	3,27	2,35	3,33
19	3,56	1,66	2,58	3,07	2,05	1,23	1,66	0,48	0,51	0,94	0,84	1,04	0,98	1,14	1,43	1,67	2,04	2,33	3,61	3,15	0,00	0,13	0,82	4,02
20	3,66	1,75	2,71	3,23	2,17	1,37	1,75	0,59	0,52	0,86	0,80	0,97	0,96	1,09	1,45	1,63	2,07	2,38	3,70	3,27	0,13	0,00	0,95	4,06
21	3,61	0,83	2,30	2,49	1,49	1,07	0,35	0,34	0,63	1,18	0,94	1,19	0,87	1,13	1,09	1,50	1,53	1,73	2,78	2,35	0,82	0,95	0,00	3,44
22	6,82	2,98	5,18	4,64	4,18	4,39	2,98	3,64	3,54	3,44	3,33	3,29	3,12	3,09	2,62	2,60	1,97	1,72	2,24	3,33	4,02	4,06	3,44	0,00

Table 38 – Distance between delivery points and facilities for direct routes. Source: Own elaboration.

Appendix 3 – TSP algorithm Excel process

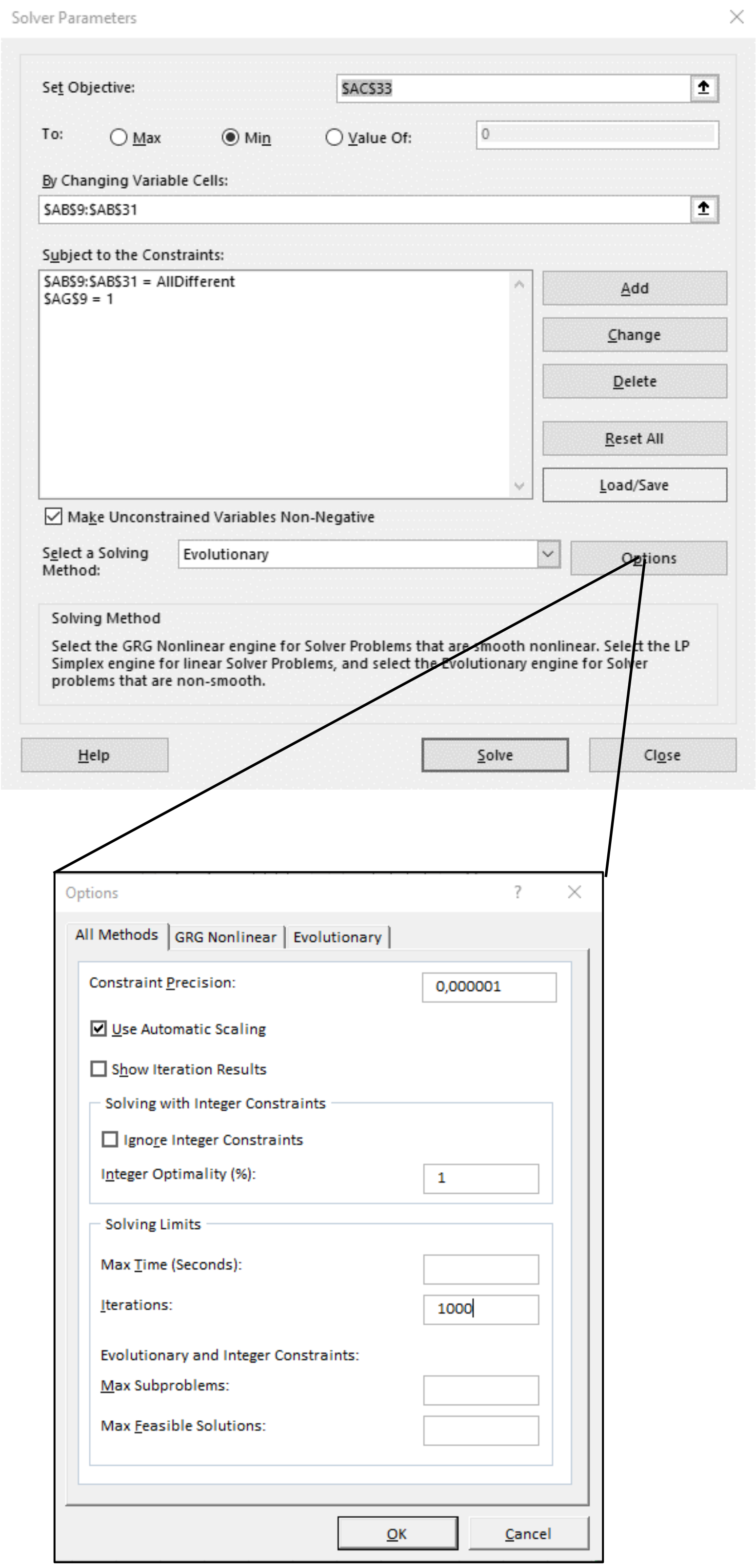

Figure 23 – TSP algorithm process in Office Excel. Source: Own elaboration.

Appendix 4 – CW algorithm Excel process

The following scheme represents an example of the CW algorithm process using the Office Excel program.

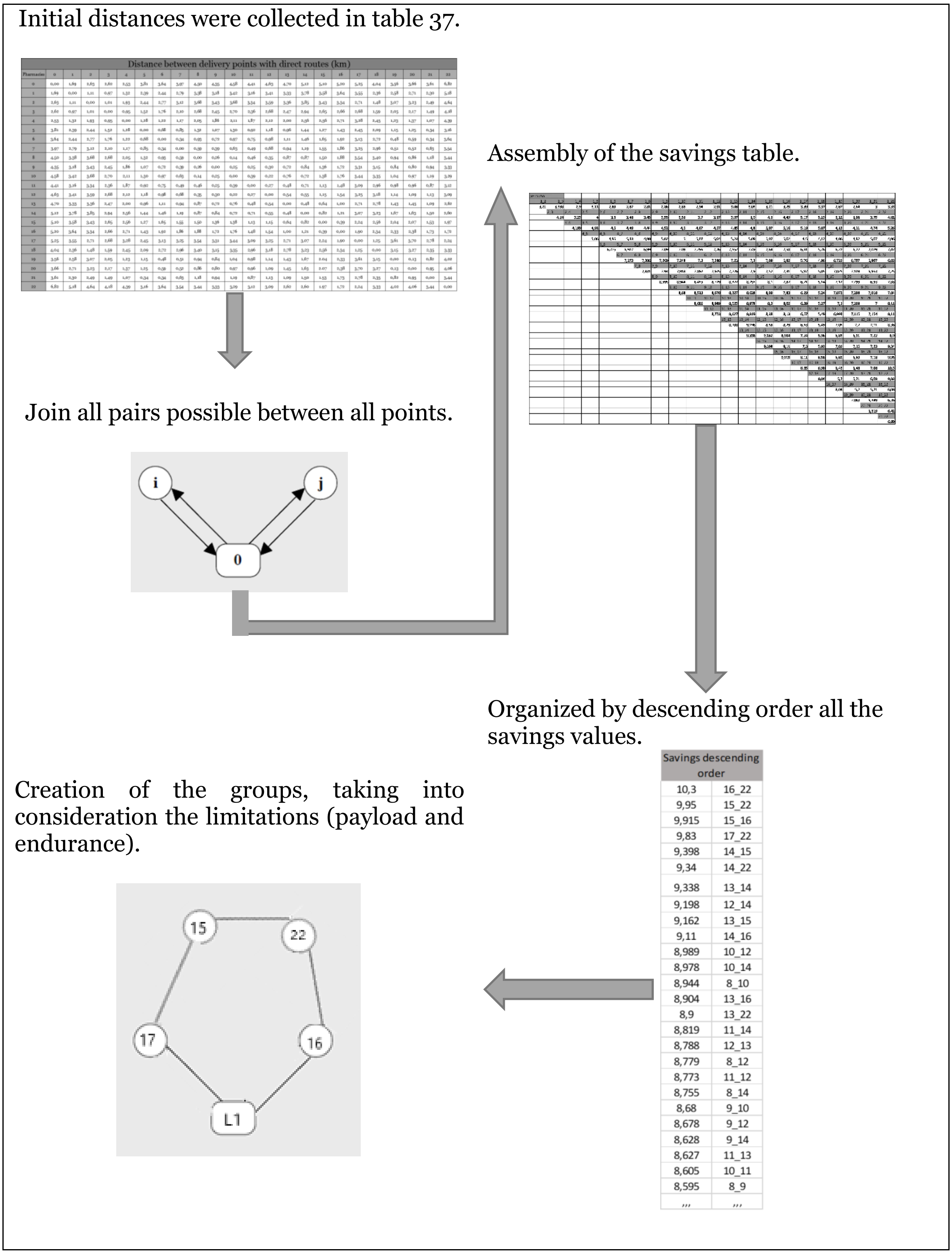

Figure 24 – Scheme of the CW algorithm process used in the Office Excel program. Source: Own elaboration.

Appendix 5 – Delivery routes maps

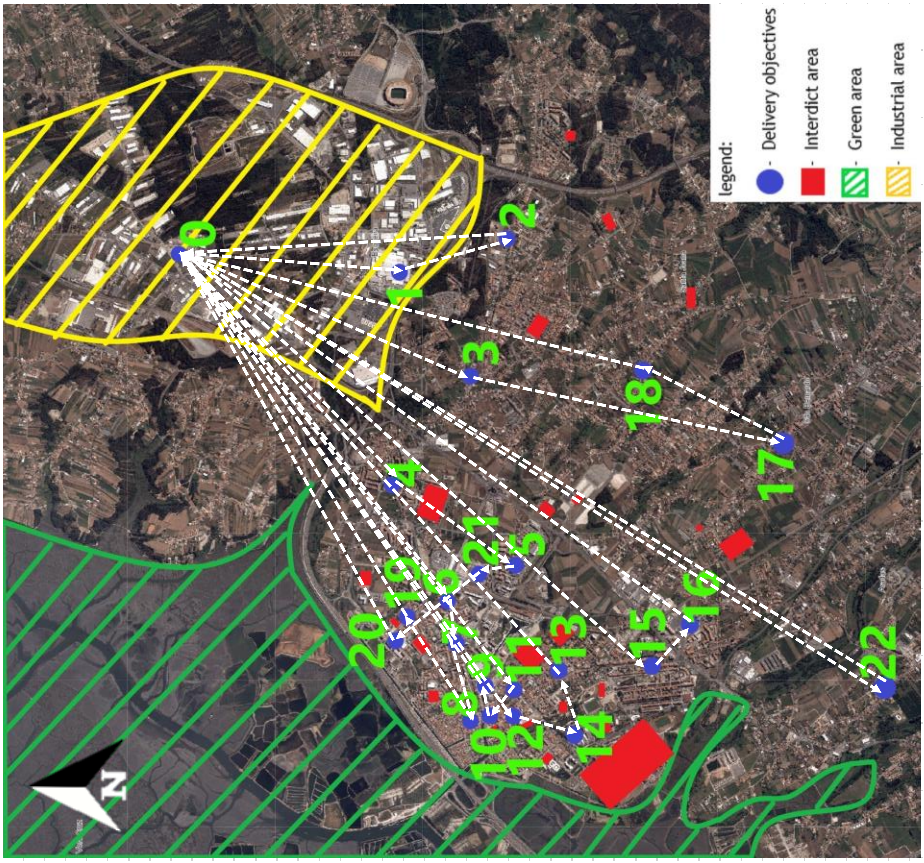

Figure 26 – Phase 1 emergency delivery system with UAV. Source: Own elaboration based on satellite view from "Direção geral do território" (DGT) [7].

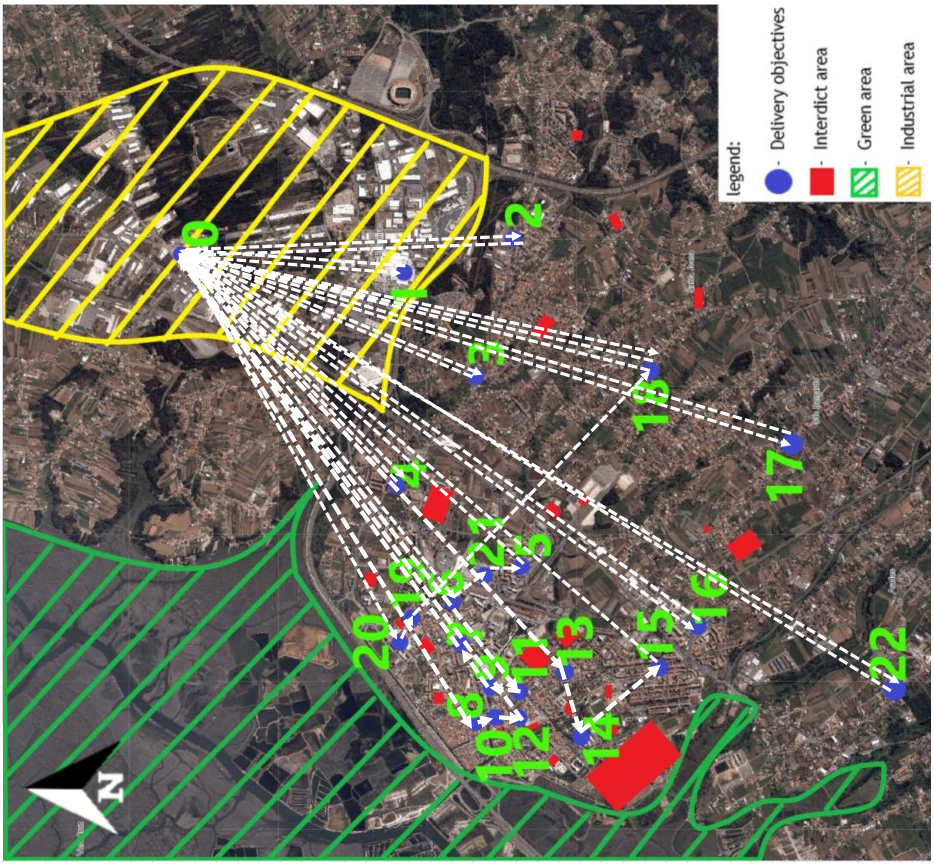

Figure 25 – Phase 1 daily delivery system using a UAV. Source: Own elaboration based on satellite view from "Direção geral do território" (DGT) [7].

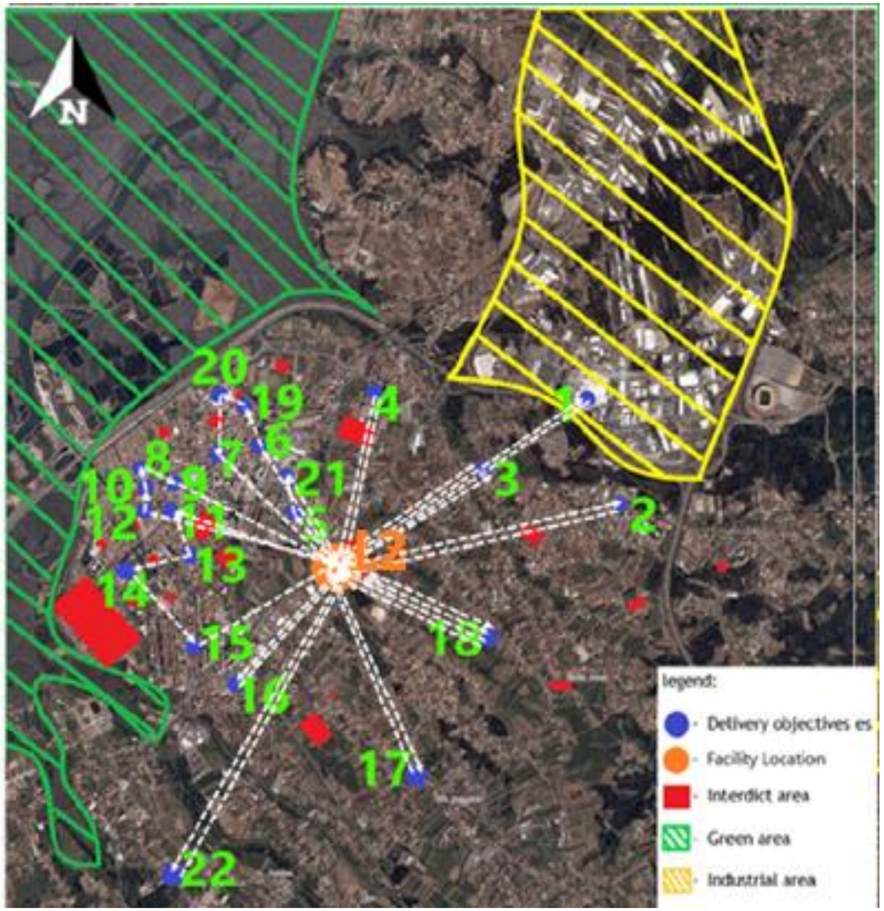

Figure 27 – Phase 2 daily delivery system with a UAV. Source: Own elaboration based on satellite view from “Direção Geral do Território” (DGT) [7].

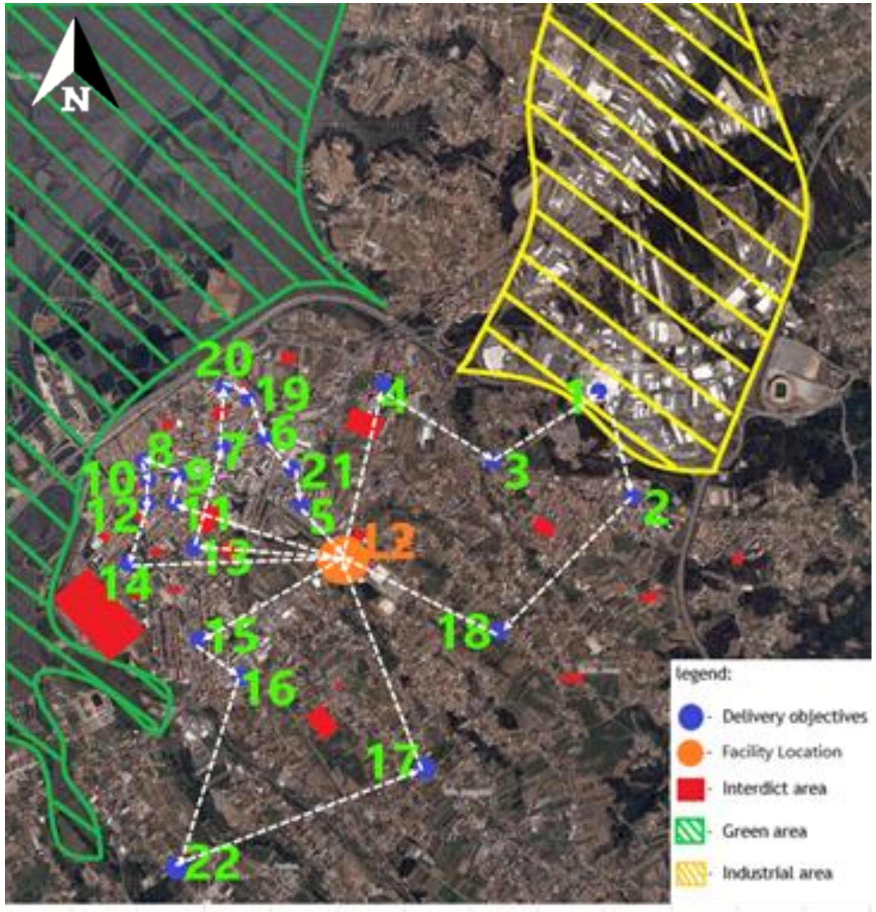

Figure 28 – Phase 2 daily delivery system with a UAV. Source: Own elaboration based on satellite view from “Direção Geral do Território” (DGT) [7].

Appendix 6 – Articles for publication

a) Article for the Journal of Airline and Airport Management

MANAGEMENT OF URBAN AIR LOGISTICS WITH UNMANNED AERIAL VEHICLES.

THE CASE OF MEDICINE SUPPLY

IN AVEIRO, PORTUGAL

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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/approach: We set as 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 in the urban environment 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 can not 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;

b) Article for the "Revista Portuguesa de Estudos Regionais" (RPER)

Veículo Aéreo Não Tripulado na gestão de Logística Aérea Urbana.
Um caso de estudo português

Unmanned Aerial Vehicle for Urban Air Logistics Management.
A Portuguese Case Study

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Abtract/Resumo

This article focuses on urban logistics. There is a significant growth of populations in urban areas that have created some limitations to the good flow of logistics. Several technologies are being implemented to improve flow and reduce costs. The unmanned aerial vehicle (UAV) has been pointed out as the next step for logistics. For that reason, the aim of this article is to undertake a conceptual scenario for UAV delivery and understand if it is viable and competitive with a nowadays conventional delivery vehicle. This article studies a route system for van and UAV delivery concerning the full optimization of the path. The results for UAV delivery are satisfying has an emerging technology, having the capability to compete with the van delivery for low payload and within an urban environment.

Keywords: unmanned aerial vehicles (UAV), unmanned aerial systems (UAS), urban logistics, route optimization, facilities location;

JEL codes: L93, R41.

Este artigo enfoca a logística urbana. Há um crescimento significativo da população em áreas urbanas que tem criado algumas limitações ao bom fluxo logístico. Diversas tecnologias estão sendo implementadas para melhorar o fluxo e reduzir custos. O veículo aéreo não tripulado (UAV) tem sido apontado como o próximo passo para a logística. Por esse motivo, o objetivo deste artigo é realizar um cenário conceitual para a entrega de UAV e entender se é viável e competitivo com um veículo de entrega convencional nos dias de hoje. Este artigo estuda um sistema de rotas para entrega de van e UAV visando a otimização total do caminho. Os resultados para a entrega de UAV são satisfatórios com uma tecnologia emergente, tendo a capacidade de competir com a entrega de van para baixa carga útil e dentro de um ambiente urbano.

Palavras-chave: veículos aéreos não tripulados (UAV), sistemas aéreos não tripulados (UAS), logística urbana, otimização de rotas, localização de instalações;

Código JEL: L93, R4