Analysis of supply chain operational performances using vehicle routing with UAV delivery in city logistics

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ANALYSIS OF SUPPLY CHAIN OPERATIONAL PERFORMANCES USING VEHICLE ROUTING WITH UAV DELIVERY IN CITY LOGISTICS

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1. Problem statement

Mobility is an important problem today and on-road transport has reached its limits. For instance, a study conducted by motoring federation Touring Mobilis showed 1,588.5 hours of traffic queues in 2018[1].

This is especially true, when we consider urgency transport of medical materials such as organs that need to be transplanted or blood that needs to be transfused. Having timely access to blood of the right type and in sufficient quality is a matter of life and death inhealth systems of any county of the world. On the other hand, blood products are very challenging to manage. There are many types, they have short shelf life and it is difficult to accurately forecast demand for each blood type before patients need transfusion[2]. Given the complexity of the problem, traditional heath supply chain is balancing a compromise between increasing access and reducing waste[3]. In order to maximize the access, it is needed to store as much product as possible in large quality in each medical facility so the patients always have the medicine they need but a consequence of this is that the supply chain system suffers from a lot of expired inventory that can lead to huge financial losses.

The use of unmanned aerial vehicles (UAVs or drones) in the city logistics provides interesting opportunities to solve the problem. UAVs have a very high flexibility, are relatively cheap, can carry up to 10 kg of material, can fly over distances of 75 km, only need a limited space for landing and take-off and flying routes can be pre-programmed, therefore, reducing operational costs. Fast supply by UAVs from central facilities therefore provides a way to increase access and reduce losses.

However, practical implementation of UAVs is strongly restricted by the current legislation. The repressive legislation is rooted in a negative image UAVs have with policy makers and the general public. This negative perception is fueled by several socio-economic and ethical concerns and limited quantitative data on the operational performances of UAVs in specific cases.

[1] Flanders Today. (2018, December 29). 2018 sees record traffic jams. Retrieved from http://www.flanderstoday.eu/2018-sees-record-traffic-jams
[2] World Health Organization. (2017). The 2016 global Status Report on blood safety and availability.
[3] Australian Red Cross Blood Service. (2009). Monitoring wastage. Retrieved from https://transfusion.com.au/inventory_management/wastage

To make the use of UAVs for our most urgent mobility problems possible, renewed public and political debate on UAVs and relaxation of the legislation is needed. In order to build this debate on rational grounds:

1. a comprehensive overview of state-of-the-art of drone specificatiosn and technical requirements for their operation is needed (i.e. a Unmanned Ashould be provided, also to allow 2. and 3. below),
2. socio-economic and ethical concerns should be identified and evaluated, and possibly detailed in the light of the current UAV operational characteristics,
3. the supply chain operational performances using vehicle routing with UAVs should be quantified and compared to traditional transport by road trucks.

2. Research objective

The goal of this work is to study the ethical and socio-economic factors and supply chain operational performances shaping the public opinion on UAVs in order to increase the knowledge basis of the general public and policy makers. This can lead to a renewed discussion, relax legislation and facilitate the use of UAVs to solve our most urgent mobility problems.

Specifically, the privacy, safety, ecological and socio-economical aspects of UAV will be analyzed as well as relative benefits in supply chain operational performance of using UAVs as compared to traditional trucks.

Hereto, following sub-objectives will be addressed:

1. **Repressive legislation**. The constraints that are imposed by the current legislation on the use of UAVs will be mapped. This will create a clear picture on which changes in legislation will be needed -after renewed debate- in order to make UAVs delivery possible.
2. **The fundamental knowledge basis.** The goal is to provide the fundamental knowledge basis of UAVs. Specifically, the state of the art in drone specifications will be studied as well as the operational procedures and requirements. Case studies on successful implementation of drones will be provided. The increase of the fundamental knowledge will facilitate future discussion on the use of UAVs as well as provide the basis to detail socio-economic and ethical concerns and analyze operational performances of UAVs (sub-objectives 3,4).
3. **Socio-economic and ethical concerns**. The goal is to study socio-economic and ethical factors that underlie the negative public opinion on UAVs. Privacy, safety, and ecological concerns as well as potential effect on employment will be investigated. It will then be investigated to which extent these concerns are justified and to which extent the technological advancements can relieve these concerns. Detailing of the socio-economic and ethical concerns is expected to positively influence the public opinion on UAVs.
4. **Supply chain operational performances**. It will be studied to which extent the use of UAVs can outperform traditional transport by trucks. Specifically, a case study will be built around transport emergence supply to 21 hospitals in the Brussels-Capital Region. The relative performance of UAVs compared to trucks is studied for different potential delivery routes which are dependent on the UAVs

characteristics carrying capacities and flight range. Quantification of UAVs operational performance will contribute to a rationalized discussion of using UAVs.

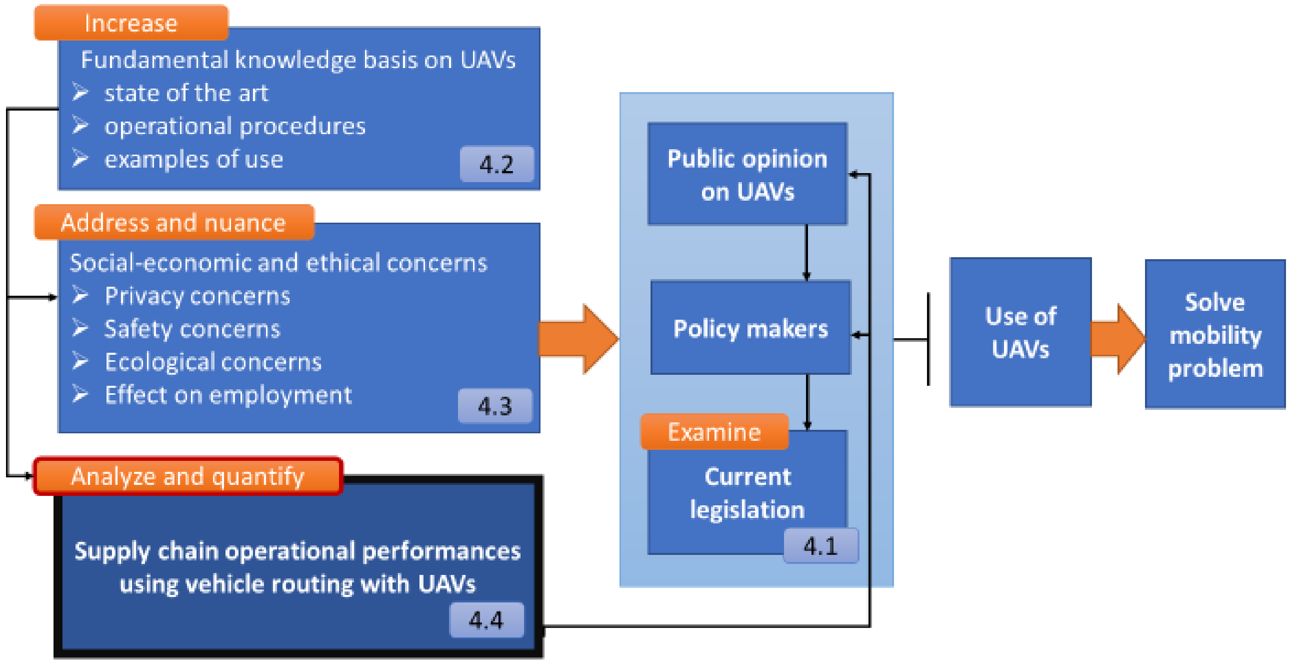

Figure 1: Addressing objectives and sub-objectives

3. Methodology

The first step is secondary data gathering using academic literature, commercial materials, statistical and legal information, actual news and interviews with newsmakers in the field of UAVs use. Some specific aspects of the work were addressed in the master thesis “Opportunités opérationneles des drones dans le secteur de la construction” of 2017/2018 academic year by Karima Nauar. All of this is analyzed according to the following structure:

1. **The legislation**. Since UAV operators must fulfill several criteria, firstly the current European aerial regulation is reviewed, pointing the parts related to UAVs. Next, information from the website of European Union Aviation Safety Agency concerned UAVs is gathered to demonstrate the way the new UAVs legislation in Europe is going to look like and highlighting the crucial dates from the timetable.

Information from Belgian FPS Mobility and Transport was also gathered and summarized into a picture of the legal situation on the national scale. Next, another legal document possibly concerning the use of UAVs is named.

Afterwards the information is summarized, the main constrains are identified and discussed giving examples of actions that were carried out during last years and compared with international experience of already established projects in terms of interaction and cooperation with national authorities.

2. **The fundamental knowledge basis.** Based on academic literature review the definition of a UAV is made and existing UAV types that are useful for application in logistics are named.

Since this work aims to find an alternative to truck delivery, UAVs using vans as a launching pad weren’t taking into consideration[4].

After the suitable types are identified, the UAVs market is analyzed as to whether there are companies active on the market that propose available models up-to-use in city logistics. The models are named, and specifications gathered from official web sites, releases, interviews with technical specialists are summarized in a table, such as the range a UAV can operate in, flying speed and payload for further comparison.

[4] Mercedes-Benz [Web site]. (2019, April 16). Retrieved from https://www.mercedes-benz.com/en/mercedes-benz/vehicles/transporter/vans-drones-in-zurich/

After different types of UAVs and models available on the today's market are presented, scientific articles and patents are reviewed in order to describe operational procedures and requirements proposing various ways of delivery using UAVs at different stages. In order to highlight distinction between the reviewed operational procedures, they are reviewed separately but their particular features and the operating methods are presented as a modification of the prior one in order to avoid reiteration.

Next, two cases- studies are proposed as an example of implementing some of the previously reviewed theoretical methods and features. The first example shows a network of medical supply chains in Rwanda. The second example shows a delivery system with UAVs in Reykjavik, Iceland. This part describes their operational procedures starting from take-off and finishing by the way a UAV returns to the base. For this purpose, information from various sourcesis inspected. Among them official websites, press releases, interview with CEO, technological reviews and newspaper articles.

3. **Socio-economic and ethical concerns**. Academic literature, news, statistical information was analyzed and summarized into a list of ethical factors concerning the use of UAV in city logistics.

Next, a course of business ethics is reviewed in order to find philosophical frameworks that can be suitable for all the stakeholders involved when dealing with the previously named concerns.

Next, use of UAVs is considered to be an innovation, therefore, a change. The course of change management is reviewed, and the best practices of polyphonic managerial style in this regard are described. Finally, a change management model is chosen and proposed as an effective tool of working with earlier named concerns (see 4.3)

4. **Supply chain operational performances**. Two delivery systems, i.e. UAVs and traditional trucks, are analyzed and compared. Vehicle routine problem models are used aiming to find an optimal set of routes for a fleet of vehicles to traverse in order to deliver to a given set of customers[5] .Terefore, simulation will be made in order to visualize and compare several delivery methods.

[5] G. Clarke and J. Wright (1964) Scheduling of vehicles from a central depot to a number of delivery points, Operations Research, 12 #4, 568-581

A case study is built around medical supply delivery from a central distribution center to customer medical entities. For the experiment 22 medical entities are chosen that fulfill the following criteria:

1. They must be in the territory of the Brussels-Capital Region that is chosen as a virtual "test site";
2. They have infrastructure suitable for UAVs operational procedures (see 4.2.2)

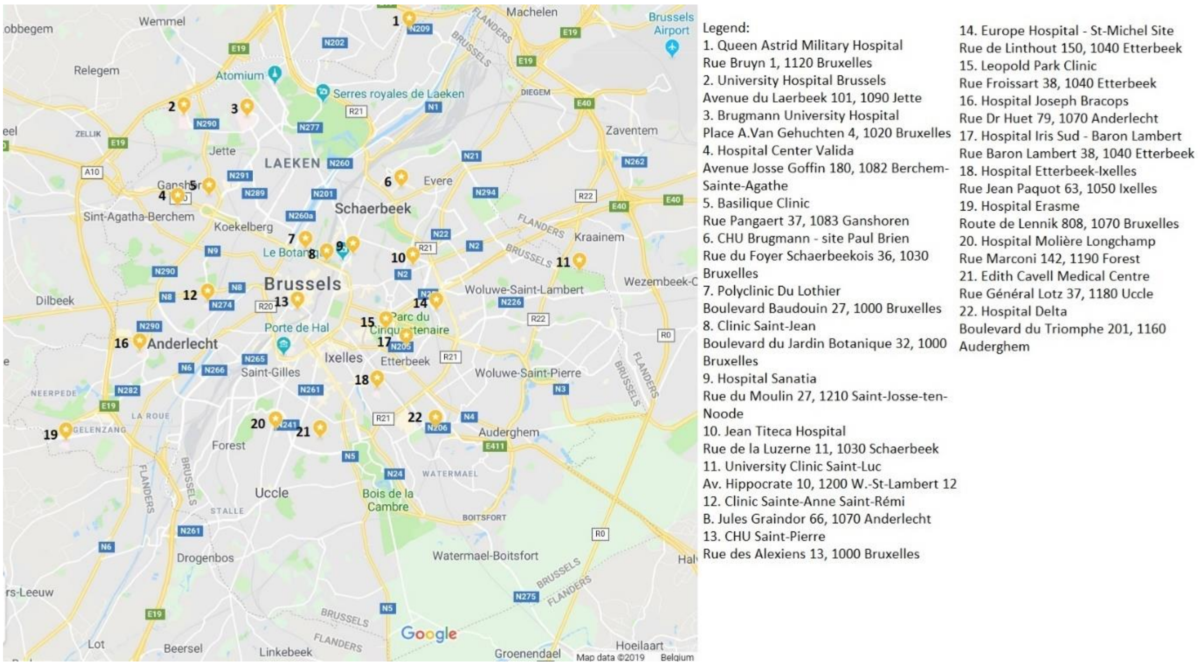

Figure 2: Map of the Brussels-Capital Region with chosen medical entities

In order to build an optimal route between claimed customers OptimoRoute is used. The software helps to build the shortest routes from a distribution center to numerous customers considering the geographical and infrastructural features. It allows dividing the customers into several groups and assigning them to different drivers. It also allows to transfer the outcome in Excel and google maps for further analyzing[6].

Addresses of 22 chosen hospitals are uploaded in OptimoRoute and CHU Saint-Pierre - Site César De Paepe is considered to be the only distribution center, therefore, all the deliveries to the other 21 hospitals start and end at this point.

In models the supply chain operational performances of trucks are compared with UAVs. Simulations are made in a pair, trucks versus UAVs, and the outcome is described after each simulation. In analyzing the problem, the emphasis is made on the time subject. After

[6] OptimoRoute Inc [web site]. Retrieved from https://optimoroute.com/

interim findings are obtained, the feasibility of the method is examined. Next, another method that can improve the feasibility is proposed.

Firstly, one truck and one UAV are used for a delivery simulation.

Next, three trucks and three UAVs are used but each case is analyzed separately.

The outcomes of OptimoRoute with weblinks to interactive maps are in appendix II-V.

Taking into account the results of the conducted experiments and prior academic literature review with examples of practical implementation of UAVs, this part next illustrates another possible way to improve the previous methods and use one of them in order to demonstrate the way a distribution center can be equipped if several constraints are applied. Here no comparison with trucks is conducted.

Next, a mathematical model describing the problem is written. The price and number of UAVs are taken as decision variables, objective function (minimize the total cost of purchasing UAVs) is written and, after that, constraints that must satisfy the solution are described in accordance with earlier made assumptions[7].

Next, the assumption on the efficiency (that supposedly depends on the flying range) is neglected which allows to propose the second mathematical model without a strict limitation on the variation of UAV models.

[7] Anderson, D.R., Sweeney, D.J. and T.A. Williams, 2000. An introduction to Management Science, Quantitative Approaches to Decision Making, ninth edition, South-Western College Publishing.

4. Results and discussion

This section sets out the key experimental results, interprets and explains them.

4.1 Legal situations

Since the legislation is considered to be the main constraint for operating UAVs, it is highly important to review European and Belgian legislation in this regard in order to identify already established legal acts and requirements as well as to highlight those legal texts that are currently in the process of discussion but are going to be adopted in the near future. It is crucial to understand not only the criteria UAV operators must satisfy but also to draw special attention to the timeline the legislation can be influenced by involved stakeholders.

This part also aims to describe the situation at the national level, therefore, it is relevant to name actors and events that are currently influencing the course of actions in the UAV field in Belgium.

At last, in order to compare the process of law-developing Belgium with another international experience, the example of collaborative work by the private sector and the state authorities in Rwanda is given.

4.1.1 Legislation in Europe

There are legal documents regulated operating aerial vehicles. Parts that can be concerned the use of UAVs are depicted and analyzed in this part.

According to the Manual of Air Traffic Services: CAP 493[8], there are seven international classes A-G, that depend on the flight rules of Air Traffic Control. Considering the air-traffic density and the size of the country class C and G are used in Belgium[9]:

> -Class C. Instrument Flight Rules (IFR) and Visual Flight Rules (VFR) flights are permitted, all flights are provided with air traffic control service and IFR flights are separated from other IFR flights and from VFR flights. VFR flights are separated from IFR flights and receive traffic information in respect of other VFR flights.

[8] The Civil Aviation Authority. (2017, December 28). CAP 493: Manual of Air Traffic Services (6.1 Corrigendum) Retrieved from https://publicapps.caa.co.uk/modalapplication.aspx?catid=1&pagetype=65&appid=11&mode=detail&id=6657
[9] Everaerts, J., & Lewyckyj, N. (2011). Obtaining a permit-to-fly for a HALE-UAV in Belgium. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *38*(1/C22).

-Class G. Instrument Flight Rules (IFR) and Visual Flight Rules (VFR) flights are permitted and receive flight information service if requested. Flight Information service is a service provided for the purpose of giving advice and information useful for the safe and efficient conduct of flights. (ICAO Annex 11: Air Traffic Services)[10]

JAR-OPS 1.960[11] details qualification requirements for pilots to carry out IFR flights. Minimum requirements for VFR flight are detailed in EU-OPS 1[12] and JAR-OPS 3[13].

On the other hand, in February 2019 the European Commission's proposal for an implementation act that should further regulate all the operation with UAVs met positive reaction and support from the EU Aviation Safety Agency Committee[14].

The regulation admits that technologies of manufacturing and operating UAVs are evolved enough to capacitate a broad variety of possible ways UAVs can be used and, therefore, UAV use must be subject to regulation in order to prevent the risk in this regard. The act states that the EU Member states will be flexible to implement their own rules regarding to the local characteristics as population density[15].

The operations that cannot fulfill the requirements of the open category (the low-risk operations), e.g. operation in visual line of sight, are automatically covered by the regulation of a specific category. Is it reasonable to suggest that this category will be applied for the UAVs used for delivery in city logistics, therefore, in order to start working, operators of the UAVs

[10] International Civil Aviation Organization. (2001). Annex 11 to the Convention on International Civil Aviation : Air Traffic Services (Thirteenth Edition).
[11] Authorities, J. A. (1996). JAR-OPS. *Flight operations*.
[12] European Commission. (2008). Commission Regulation (EC) No 859/2008 of 20 August 2008 amending Council Regulation (EEC) No 3922/91 as regards common technical requirements and administrative procedures applicable to commercial transportation by aeroplane. *Official J. Eur. Union*.
[13] Authorities, J. A. (2007). NPA-OPS 50. *Operation of Helicopters Certified for Flight in Limited Icing Conditions*.
[14] European Union Aviation Safety Agency. (2019, March 01). One step closer to harmonised rules for safe drones operation in Europe. Retrieved from https://www.easa.europa.eu/newsroom-and-events/news/one-step-closer-harmonised-rules-safe-drones-operation-europe
[15] EU. (2018). Regulation 2018/1139 of the European Parliament and of the Council of 4 July 2018 on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency, and amending Regulations (EC) No 2111/2005, (EC) No 1008/2008, (EU) No 996/2010, (EU) No 376/2014 and Directives 2014/30/EU and 2014/53/EU of the European Parliament and of the Council, and repealing Regulations (EC) No 552/2004 and (EC) No 216/2008 of the European Parliament and of the Council and Council Regulation (EEC) No 3922/91. Official Journal of the European Union, L 212/1.

will be obliged to conduct a risk assessment. Another proposed option is that an operator must follow a standard scenario or have a certificate with privileges[16].

Meanwhile, there is another category of UAVs that must be certified. This special category concerns large drones in controlled airspaces. It also states that a pilot is required to have a license as well as the operator itself must be approved by the competent authority[17].

Already in October 2019 the Guidance Material and Acceptable Means of Compliance, the description of measures to act in accordance with the regulation will be issued by the EU Aviation Safety Agency Committee. Here the risk assessment methodology that is required for the UAVs in the specific category will be described. The discussion in this regard will be possible during the coming year according to the timeline of commission implementing regulation on the rules and procedures for the operation of unmanned aircraft[18].

Since EU Parliament or the EU Council did not have any objections to the implementing acts, they entered into force in June 2019. It means that there is one year for the UAVs operators and EU member states to discuss and actualize the national regulation. The regulation will be applicable by piecemeal beginning from 2020. By June 2022 the developed rules will be mandatory[19].

4.1.2 Legislation in Belgium

According to Belgium's national aviation and travel authorities, the Federal Public Service Mobility & Transport and the Belgian Civil Aviation Authority, flying a drone is legal in Belgium but the requirements UAV operators must meet to use drones depend on the weight of the drone and where they want it to fly. The royal decree of 2016, Arrêté royal relatif à l'utilisation des aéronefs télépilotés dans l'espace aérien belge in French, distinguishes three classes: class 1, class 2 and private use:

[16] European Union Aviation Safety Agency. (2018, February 06). Opinion 01/2018: Unmanned aircraft system (UAS) operations in the 'open' and 'specific' categories. Retrieved from https://www.easa.europa.eu/document-library/opinions/opinion-012018

[17] European Union Aviation Safety Agency. (2019, July 01). Drones - regulatory framework background. Retrieved from https://www.easa.europa.eu/easa-and-you/civil-drones-rpas/drones-regulatory-framework-background

[18] European Union Aviation Safety Agency. (2019, July 01). Civil drones (Unmanned aircraft). Retrieved from https://www.easa.europa.eu/easa-and-you/civil-drones-rpas#0

[19] European Union Aviation Safety Agency. (2019, Jun 11). EU wide rules on drones published. Retrieved from https://www.easa.europa.eu/newsroom-and-events/news/eu-wide-rules-drones-published

Class 1a Operations is applied for drones operating at the height up to 90 meters outside controlled airspace with a fly closer than 50 meters from people, goods on the ground or even overfly them or flying around an obstacle closer than 30m.

Class 1b Operations is applied for drones operating at the height up to 90 meters outside controlled airspace with a fly farther than 50 meters from people and goods on the ground.

The weight of a UAV for both classes must not exceed 150 kg.

Class 2 Operations is applied for drones operating at the height up to 45 meters outside controlled airspace and outside urban arias. The weight of a UAV must not exceed 5 kg.

For all the classes UAV can be used only in daylight conditions. The pilot must always keep an eye contact with the UAV. A pilot must have a license[20].

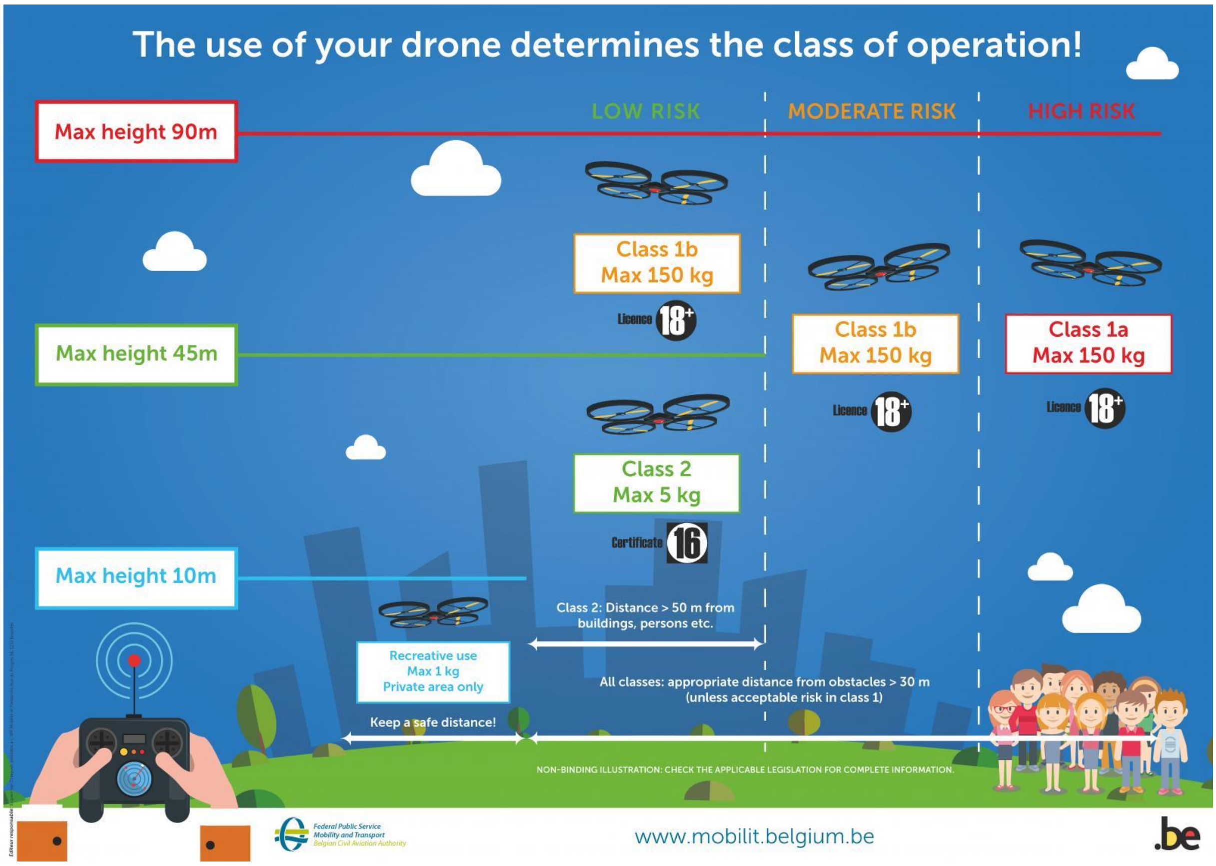

Figure 3: Illustration of the UAV policy by FPS Mobility and Transport

On the other hand, beginning from 2018, the operations made by UAVs equipped by cameras can be regulated by the Belgian law on protection of natural persons regarding the

[20] FPS Mobility and Transport. (2019, July 01). Drones. Retrieved from https://mobilit.belgium.be/fr/transport_aerien/drones

processing of personal data, in French “Loi relative à la protection des personnes physiques à l’égard des traitements de données à caractère personnel” . The law concerns companies collecting and analyzing the data but the fact the law implicitly mentions the necessity of the individual consent can potentially block using UAVs.

4.1.3 Listing and discussion the legal constraints

The main constraint for UAV application in Belgium is the fact that using UAV for transporting mails or freights is explicitly forbidden according to the official web site of the Federal Public Services and Public Planning Services[21]

Such requirements as the fact that the operating UAVs must be in sight of a pilot can be considered as an absolute veto over using UAVs that are capable to cross long distances and goes in accordance with the prohibition of transporting mails or freights.

On the other hand, several UAV hubs have been founded in Belgium during last years. For instance, Euka, the non-profit drone cluster, was launched in 2017 in East Flanders[22]. In 2019 another UAV center, DronePort, was launched at the place of a former military airbase in Limburg[23].

The hubs advocate for the safe and flexible integration of UAV in a real environment and optimization of the legislation for this purpose. They also provide companies interested in using UAV for different purposes with their expertise and an opportunity to examine, prove and show their innovation, as is stated on the web sites of Euka and Drone Port.

Despite the fact that the current Belgian legislation remains a collection of limitations towards the use of UAVs, there are many politicians who showed their enthusiasm and willingness to develop the domain and benefit from the advantages. One of them, the Minister of Mobility François Bellot was advocating for support of the UAV sector already in the year 2016[24].

Later in 2019 Limburg’s Drone Port has been chosen to be a center to coordinatethe way the EU legislation will look like in the coming future. The newly granted status allows

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[21] FPS Mobility and Transport. (2019, July 01). Faites voler votre drone en toute sécurité (classe 1 et 2). Retrieved from https://mobilit.belgium.be/fr/transport_aerien/drones/faites_voler_votre_drone_en_toute_securite_classe_1_et_2
[22] EUKA Flemish Drone Federation [Website]. (2019, June 05). Retrieved from https://euka.org/
[23] DronePort [Website]. (2019, June 01). Retrieved from https://droneport.eu/
[24] SPF Chancellerie du Premier Ministre. François Bellot. (2019, June 01). Retrieved from https://bellot.belgium.be/fr/le-ministre-fran%C3%A7ois-bellot-pr%C3%A9sente-deux-chantiers-en-mati%C3%A8re-de-drones

Drone Port to ignore the legal limits as flying no more then up to 650 meters from the ground and operation during the day only[25].

In the same 2019 in Wallonian Liernu the inauguration took place of a testing zone reserved for all types of drones that are not allowed for operating by the current Belgian legislation[26]

With regard to the international experience, it is interesting that one of the most important first steps for Zipline in Rwanda was to work with the Rwandan civil aviation authorities in order to implement the world's first modern regulatory practice on UAVs. As such they integrated the system in the airspace in a way that it is safe for people flying in airplanes, is safe for people on a ground and that allows Zipline to make lifesaving delivery to patients in hospitals, as explained by the CEO and co-founder of Zipline Keller Rinaudo to the BBC's Dan Simmons in an interview[27].

Zipline UAVs had to face regulatory as well as engendering challenges but after years of collaboration on implementation of new UAV regulation, nowadays Zipline works in close connection with Rwanda's authorities and, e.g. communicates directly with Rwanda's air traffic control in Kigali airport[28].

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[25] Furniere, A. (2019, January 13). New drone hub in Limburg off to a flying start [article]. Flanders Today. Retrieved from http://www.flanderstoday.eu/new-drone-hub-limburg-flying-start

[26] EspaceDrone [Website]. (2019, June 01). Retrieved from https://www.espacedrone.be/fr/ebr65

[27] Simmons, D. [Dan]. (2016, October 21). 10 Minutes with Keller Rinaudo [Video file]. Retrieved from https://youtu.be/__3vloFmtK0

[28] McManus, B. [Real Engineering]. (2019, January 25). How Rwanda Built A Drone Delivery Service [Video file]. Retrieved from https://youtu.be/jEbRVNxL44c

4.2 Fundamental knowledge basis about UAVs

In this part information concerning UAVs aims to build a fundamental knowledge basis.

The definition of and stating types of UAVs suitable for use in city logistics helps to build a framework for further search for available models up-to-use for the purposes on the today's market. Knowing their specifications allows to examine whether the models can theoretically meet the requirements imposed by the Belgian (see 4.1.2) and developing EU legislation (see 4.1.1).

It also shows whether there are special features or advanced technology used for manufacturing the UAVs that could help to allay the ethical and socio-economic concerns (see 4.3).

And finally, this knowledge allows to test the feasibility of each experiment conducted in the analysis of the supply chain operational performances of delivery with UAVs (see 4.4).

The next part aims to gather together different methods and features the modern technology provides, in order to describe the ways UAVs can be employed to accurately deliver items, verify that the delivery location is correct and decide where to safely leave packages. This is necessary to identify the entities that can be assigned as a distribution center and customer during the process of modulation (see 4.4).

This the reviewed is focused onfixed-wing, multirotor and hybrid UAVs, only operational procedures concerning these models are taken into consideration.

This part also provides two cases that illustrate operational procedures of successfully implemented cases.

The first describes the use of UAVs in Rwanda where since 2016 Zipline is operating its UAVs for emergency medical supplying[29] because it demonstrates the example of how some of those theoretical methods and features are implemented into an already working network.

Taking into account that Rwanda is considered to be a developing country with rural infrastructure, it is highly important to find another example of using UAVs in the city. That's

[29] Rosen, J. (2017, June 8). Zipline's ambitious medical drone delivery in Africa. *MIT Technology Review.*

why this part ends by an example of Flytrex that has already launched delivery with UAVs and currently expanding its supply capacities in Reykjavik[30].

4.2.1 Unmanned Aerial Vehicles

Basically, an unmanned aircraft is an aircraft or balloon that does not carry a human operator and is capable of flight under remote control or autonomous programming[31] and an unmanned aerial vehicle, also a UAV, is an aircraft without a human operator on board and is commonly referred to as a 'drone'. The latest models of UAVs can operate autonomously when a UAV follows the pre-programmed route according the GPS coordinates or another prior information as well as to be mainly operated from a distance[32].

There are several types of aerial drones that can be used in city logistics. The most common types for these purposes are fixed-wing and multi-rotor UAVs.

The fixed-wing UAVs typically resemble a model of airplanes. The wings are attached to the body of the aircraft and remain motionless. It relies on thrust to accelerate. For maneuvering it uses its flaps, wings and the tail[33]. They are much more efficient with greater endurance and range, but they require a platform to take off and land[34].

The most common UAV configuration is a multirotor that typically resembles helicopters and, therefore, has multiple rotors. There are many different types of multirotor UAVs including quadcopters, hexacopters and octocopters[35]. UAVs with more motors are more maneuverable, less affected by wind and can carry more weight. Multirotor drones are flying slower than fixed-wing drones and have shorter flight times compared to direct flights. Their main feature is that they can take off and land vertically[36].

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[30] Ross, P. E. (2018). Iceland's consumers try drone delivery: The startup Aha takes on Amazon with basic drones bearing burgers-[News]. *IEEE Spectrum*, *55*(10), 12-13.
[31] Gortney, W. E. (2012). Dictionary of Military and Associated Terms.
[32] Wolfrum, R. (Ed.). (2013). *The Max Planck Encyclopedia of Public International Law: Index and Tables* (Vol. 11). Oxford University Press.
[33] Beard, R. W., Kingston, D., Quigley, M., Snyder, D., Christiansen, R., Johnson, W., ... & Goodrich, M. (2005). Autonomous vehicle technologies for small fixed-wing UAVs. Journal of Aerospace Computing, Information, and Communication, 2(1), 92-108.
[34] Crowther, W. J. (2000, October). Perched landing and takeoff for fixed wing UAVs. In NATO symposium on unmanned vehicles for aerial, ground, and naval military operations (pp. 9-13).
[35] Jiang, Q., Mellinger, D., Kappeyne, C., & Kumar, V. (2011, January). Analysis and synthesis of multi-rotor aerial vehicles. In *ASME 2011 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference* (pp. 711-720). American Society of Mechanical Engineers.
[36] Agrawal, K., & Shrivastav, P. (2015). Multi-rotors: A revolution in unmanned aerial vehicle. *International Journal of Science and Research*, *4*(11), 1800-1804.

Hybrid UAVs is a new concept. They are equipped with wings and rotors and can land and take off vertically and use fixed wings for the horizontal flying. It means they can combine the advantages of both two previous types of UAVs.[37]

Apart from them, PwC and Agoria in their 2018's report concerning the development of commercial drone applications in Belgium also proposed the class of lighter-than-air drones that don't need airspeed to generate lift. It means there is almost no time limit for the duration of a flight, but the weather has a way stronger influence for the operating capabilities[38].

There are many UAV manufacturers in the world but only fewof them produce drones suitable for logistics. In this part, examples of modern fixed-wings, multirotor and hybrid UAV types are presented:

Amazon Prime Air is a UAV delivery system in development by Amazon. The company released information about the version of its UAV, therefore, the following specifications of the model are used for the further work[39]:

Prime Air is a helicopter UAV that can fly on approximately 32 km with speed of 80 km/hr. It can carry a payload of 2 kg.

Figure 4: Model of Amazon Prime Air

[37] Carlson, S. (2014). A hybrid tricopter/flying-wing vtol uav. In *52nd Aerospace Sciences Meeting* (p. 0016).
[38] Culus, J., Schellekens, Y., Smeets, Y. (2018). A drone's eye view. Overview of the Belgian UAV ecosystem & the development of commercial drone applications in Belgium. PwC Belgium and Agoria vzw/asbl
[39] Renouard, C., & Bommier, S. (2018). *L'entreprise comme commun: Au-delà de la RSE*. ECLM.

DHL Parcelcopter

The modern parcelcopter having label 4.0 is a UAV of the hybrid type. It can fly on approximately 12 km with speed of 130 km/hr. It can carry a payload of 1.2 kg. The model 4.0 has an autopilot as well as automated takeoff and landing functions.

The DHL Parcelcopter was initially designed for shipping in hard-to-reach areas. It has an autopilot and can takeoff land automatically[40].

Figure 5: Model of DHL Parcelcopter

Flytrex is an Israeli UAV manufacturer. They offer a cloud-connected multirotor UAV designed to work with a platform. Flytrex also develops drone hardware tailored for point-to-point or point-to-area delivery. It is very important to highlight that Flytrex produces UAVs that do not carry cameras or any imagining system[41]. They use UPS for navigation following routes encoded in advance to make sure there is no tree or any other obstacles[42] . In 2018 Flytrex started operating in Reykjavik, the capital of Iceland, with no accidents during 500 successfully deliveries for five months[43].

It can fly on approximately 11 km with speed of 29 km/hr. It can carry a payload of 3 kg.

[40] Deutsche Post, D. H. L. (2018). Rapid response from the air: medicines successfully delivered using a parcel drone in East Africa.
[41] Safadinho, D., Ramos, J., Ribeiro, R., Caetano, R., & Pereira, A. (2017, April). UAV multiplayer platform for real-time online gaming. In *World Conference on Information Systems and Technologies* (pp. 577-585). Springer, Cham.
[42] Flytrex [Website] (2019, May 15). Retrieved from https://www.flytrex.com/
[43] Ross, P. E. (2018). Iceland's consumers try drone delivery: The startup Aha takes on Amazon with basic drones bearing burgers-[News]. *IEEE Spectrum*, *55*(10), 12-13.

Figure 6: Model of Flytrex

Flirtey is the UAV manufacturer from the USA, in 2018 accepted by FAA and Department of Transportation to accelerate intensify UAVs' integration. The UAV uses an airport as a launching pad and drops the shipping item by rope[44].

Flirtey is targeting companies involved in medical, food, retail and ecommerce delivery in time-sensitive last mile logistics. The UAVs

Flirtey produces can fly on approximately 5 km with speed of 20 km/hr. It can carry a payload of 10 kg[45].

[44] Scott, J., & Scott, C. (2017, January). Drone delivery models for healthcare. In *Proceedings of the 50th Hawaii international conference on system sciences*.
[45] Flirtey [Website]. Retrieved from https://www.flirtey.com/

Figure 7: Model of Flirtey

Project Wing is a UAV delivery company started by Alphabet, Google's parent company. In 2017 they launched a delivery program in Australia that carried burritos and other food to remote regions.

Prototypes used during Australian tests in 2017 could travel a maximum of 120 km per hour, could take off and land vertically and had a wingspan of less than 1.5 meters.

During tests the maximum distance the aircraft have flown was about 14 km round-trip, although they typically travelled about 10km to make deliveries.

In testing the drones have carried parcels of food and medicine weighing up to 1.5 kg[46]

[46] X DEVELOPMENT LLC [Website]. Retrieved from https://x.company/projects/wing/

Figure 8: Model of Project Wing

Zipline is one of the biggest startups using drones to provide medical equipment and services to remote areas. They started operating UAVs in Rwanda in 2016 to deliver blood and other much needed supplies to rural villages[47]. In 2018, they worked with the Ghana government to establish plans to build a drone base in Ghana as well. The ability to manufacture their drones on site enables Zipline to ramp up their delivery service to more hospitals and to provide equipment to the distribution centers.

Special feature of the UAVs is that in order to remove the delay of connection with GPS satellite, Zipline moved the GPS circuitry from the plane to the battery. It means that it is always on and always connected. With the same purposes, it uses a catapult for its take-off and requires a landing pad. Currently Zipline works on some improvements as increasing the payload of its UAVs and making the takeoff and landing fully autonomous[48].

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[47] Rosen, J. (2017, June 8). Zipline's ambitious medical drone delivery in Africa. *MIT Technology Review.*
[48] Geuther, S., Capristan, F., Kirk, J., & Erhard, R. (2018). A VTOL Small Unmanned Aircraft System to Expand Payload Capabilities.

Zipline's UAV can fly on approximately 75 km with speed of 100 km/hr. It can carry a payload of 1 kg[49].

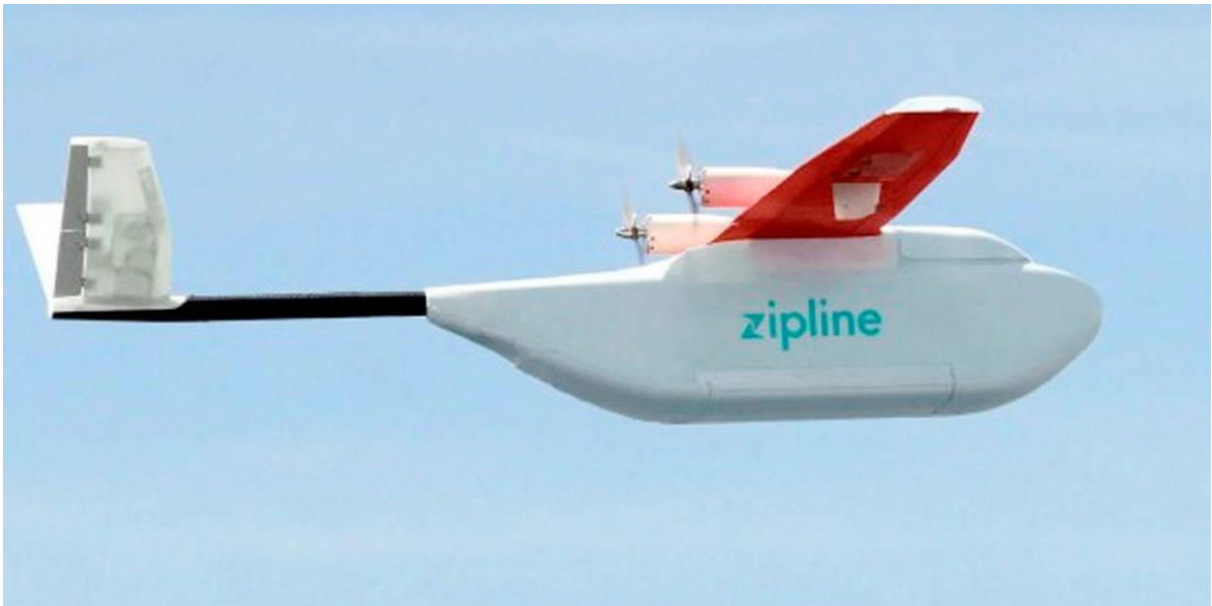

Figure 9: Model of Zipline

The following table presents the comparison of the flight range, speed and payload of reviewed UAVs.

	The longest flight (km)	Speed (km/hr)	Payload (kg)
Flytrex	11	29	3
Amazon PrimeAir	32	80	2
Flirtey	5	20	10
Project Wing	14	120	1.5
Zipline	75	100	1
DHL Parcelcopter	65	130	4

Table 1: Comparison of the flight range, speed and payload among reviewed UAVs

[49] Zipline [Website]. Retrieved from https://flyzipline.com/product/

4.2.2 Operational procedures and requirements

In this part different methods and features of operating drones in logistics are described.

4.2.2.1 Fiducial mark as a landing pad

To make a request the customer must provide the shipping address, next he obtains a unique barcode of a feasible size. It must be printed and placed outdoor in a location suitable for UAV shipping.

According to the patent application, after the request, the required sypply is packaged and loaded onto a UAV that is programmed to fly to reach the shipping address using GPS coordinates. The described method proposes using mapping services such as Google maps based on the shipping address that is proved to be an easily accessible tool and feasible for use[50].

The UAV leaves the distribution center and reaches the GPS coordinates uses a built-in camera to detect where the printable fiducial marker is placed. The UAV lands in the exact location. The UAV can also place the delivery item onto the fiducial marker or fly back to the distribution center[51].

The method is suitable for UAVs that are equipped by cameras since a fiducial marker must be detected. There are also UAVs that can navigate without visual tools as Flytrex that uses a cloud connection with 3G mobile network module installed in the UAV[52]. In this regard, all the steps concerned fiducial markers can be neglected.

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[50] Li, H., & Zhijian, L. (2010, December). The study and implementation of mobile GPS navigation system based on Google Maps. In *2010 International Conference on Computer and Information Application* (pp. 87-90). IEEE.

[51] Greiner, H., Walker, J., Norman, C. O., Bohorquez, F., & Zaparovanny, A. (2017). *U.S. Patent Application No. 14/581,027*.

[52] Safadinho, D., Ramos, J., Ribeiro, R., Caetano, R., & Pereira, A. (2017, April). UAV multiplayer platform for real-time online gaming. In *World Conference on Information Systems and Technologies* (pp. 577-585). Springer, Cham.

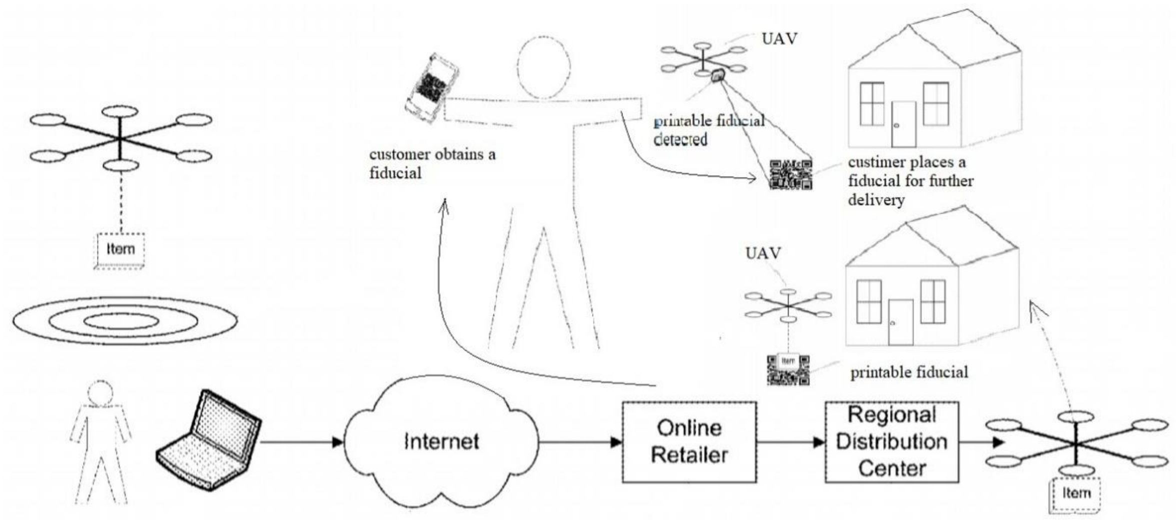

Figure 10: Operational procedures with a fiducial mark as a landing pad

4.2.2.2 Permanent fiducial marks as landing pads

The method is a modification of the previously reviewed one with the difference that if the shipping address is permanent and shipping requests made on a frequent basis, it can be installed at the desired location[53]. The method can also be suitable when a delivery network between distribution centers and customers is already built and remains stable or when customers acting as small distribution centers making frequent exchange of supply with each other.

[53] Greiner, H., Walker, J., Norman, C. O., Bohorquez, F., & Zaparovanny, A. (2017). *U.S. Patent Application No. 14/581,027*.

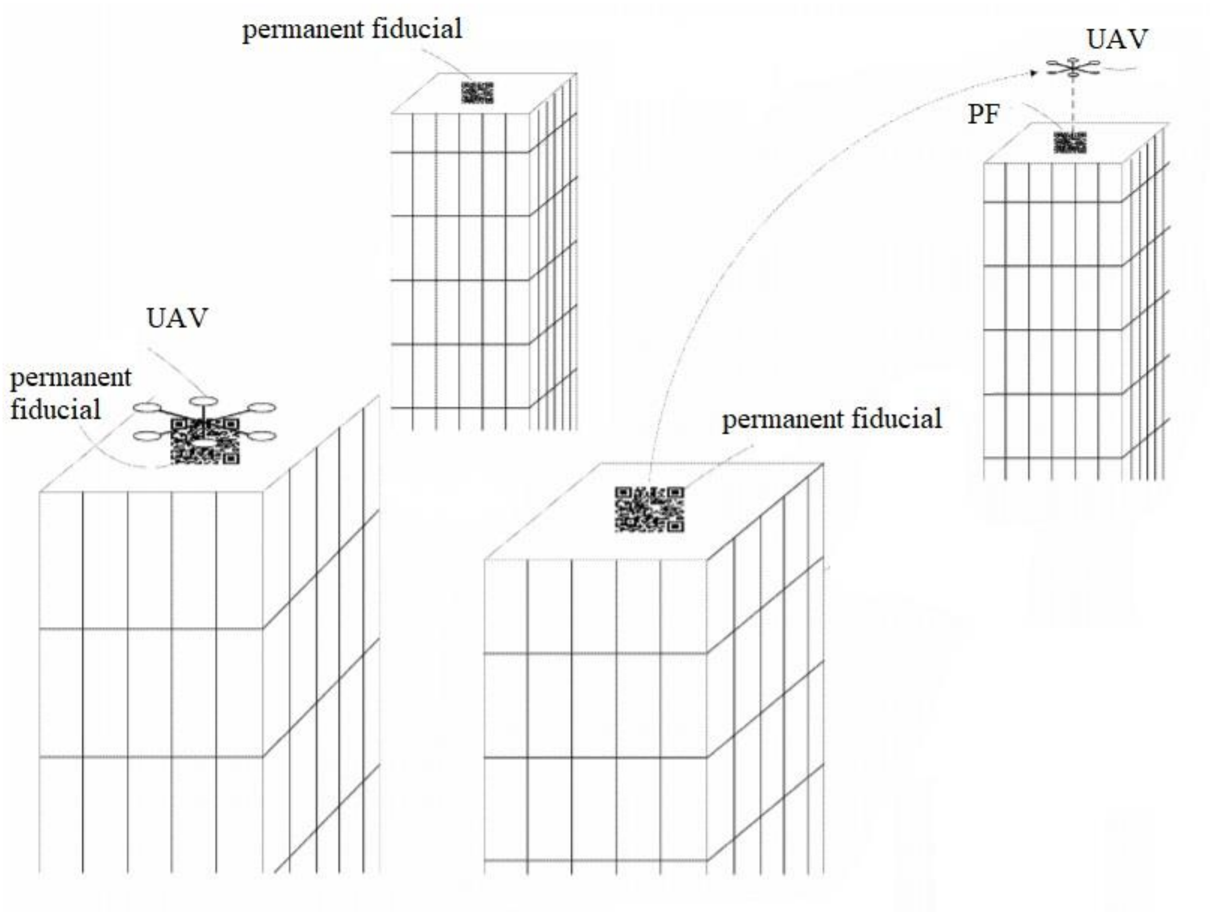

Figure 11: Operational procedures with permanent fiducial marks

4.2.2.3 Landing pads with an infrared stereo vision system

The method was earlier examined using a GPS navigation system and an infrared stereo vision system built on two infrared cameras that can detect an object of size of 1.8 m on 0.5 m at the range 12 km and recognized at 6k m, which is enough for the landing process. The main difference with the previous approach is that instead of using a printable fiducial marker the method uses a ground station that is less flexible in regards of the shipping address due to a necessity of preparing the landing pad that has a length of 60 m and width of 8 m.[54]

The method is appropriate for multirotor (e.g. the experiment was conducted with a quadcopter) as well as fix wing and hybrid UAVs that can fly autonomously with the aid of GPS waypoint navigation system.

[54] Kong, W., Zhang, D., Wang, X., Xian, Z., & Zhang, J. (2013, November). Autonomous landing of an UAV with a ground-based actuated infrared stereo vision system. In *2013 IEEE/RSJ International Conference on Intelligent Robots and Systems* (pp. 2963-2970). IEEE.

The method uses an autopilot system and a navigation module that includes a triaxial gyro, triaxial accelerometer, triaxial magnetic field meter, GPS module, barometric altimeter, airspeed gauge and thermometer. It provides real-time 3D information including attitude angle, angular rate, position, speed, acceleration, true air speed, calibrated air speed. The autopilot system

The stereo vision system is built on two infrared cameras that can detect an object (1.8m×0.5m) at the range 12km and recognized at 6km, which is sufficient for the landing process.

The communication between the UAV and ground station is based on a device with up to 22 km outdoor RF line-of-sight range.

Because UAV is detected by infrared sensor in case of fix wing vehicles a propeller should not be at the end of the body, so the method is suitable for puller-type medium size airplanes.

For fixed-wing landing, the process can be divided into five segmentations: the vision system is catching the UAV, the autonomous landing process starts and checks the relative position and velocity of the aircraft. After the final approach process, the UAV lands on ground or hooks the arresting cable

The landing field must consist of a take-off runway, a flying zone, a drop zone and a landing area.

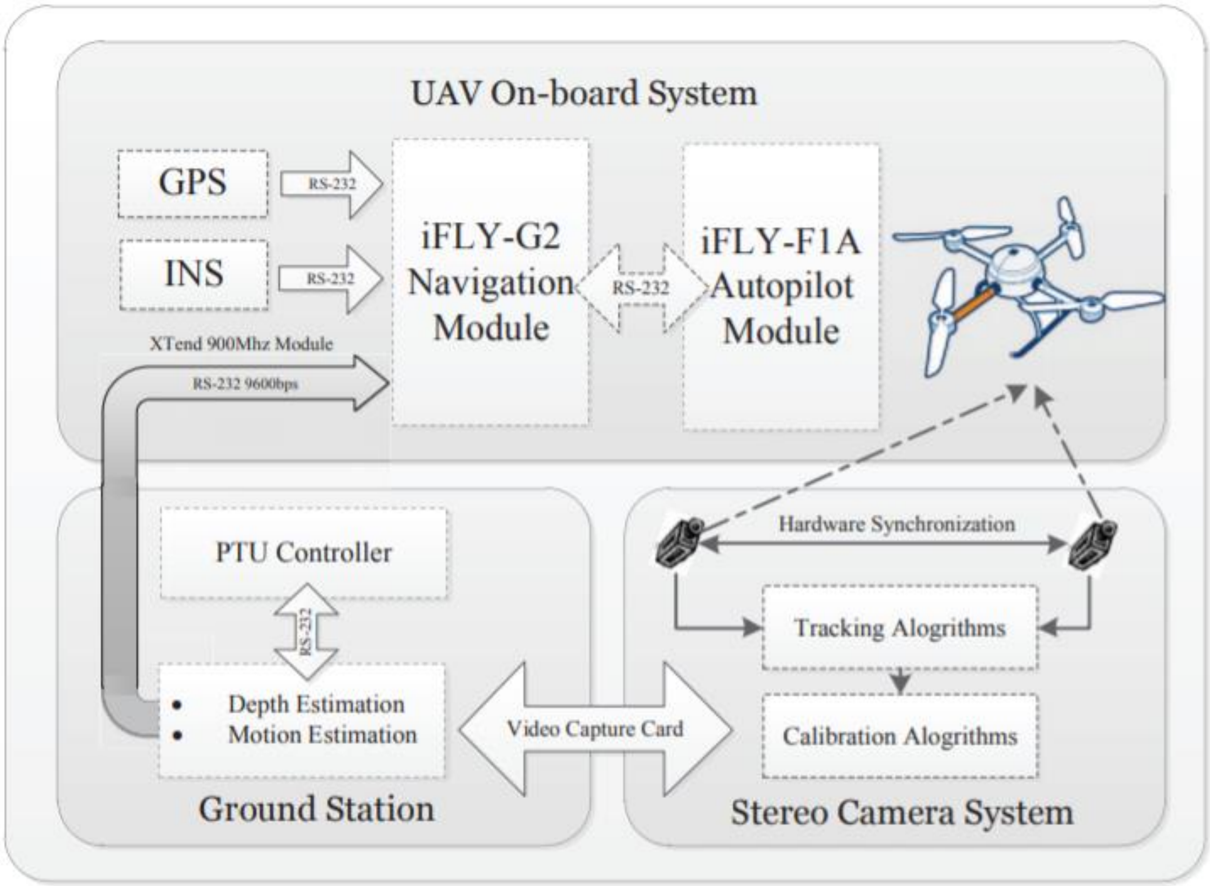

Figure 12: Operational procedures with landing pads equipped by infrared stereo vision system

4.2.2.4 Drop zone and open-loop drop techniques

The method differs from the others because it does not require any landing pad. In this case a UAV continues flying to another customer or a distribution center. It is appropriate for multirotor, fix-wings and hybrid UAVs and doesn't have specific technical restrictions as having a camera, etc.

In this regard, the open-loop drop, or wire-drop technique can be used to lower the shipping object on the ground with an installed drop zone or without one while a UAV continues flying.

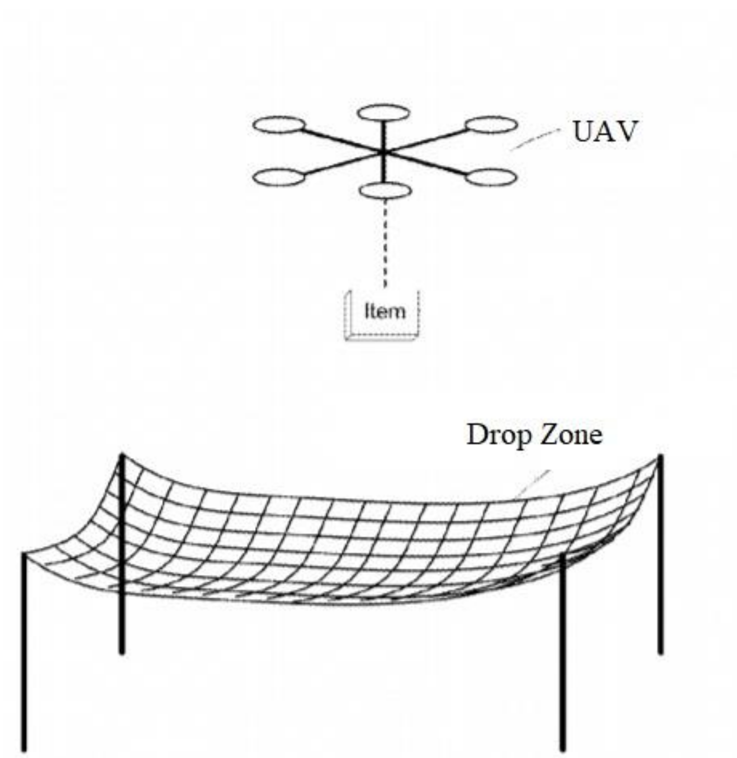

Figure 13: Operational procedures with a drop zone

The method can use a tether for slowing the lowering by the winch. The shipping object can be released during delivery, depending on the way the delivery platform is used, or a tether may be cut while opening or closing a loop. The shipping object can be relieved after contact with the ground as well as above ground[55]

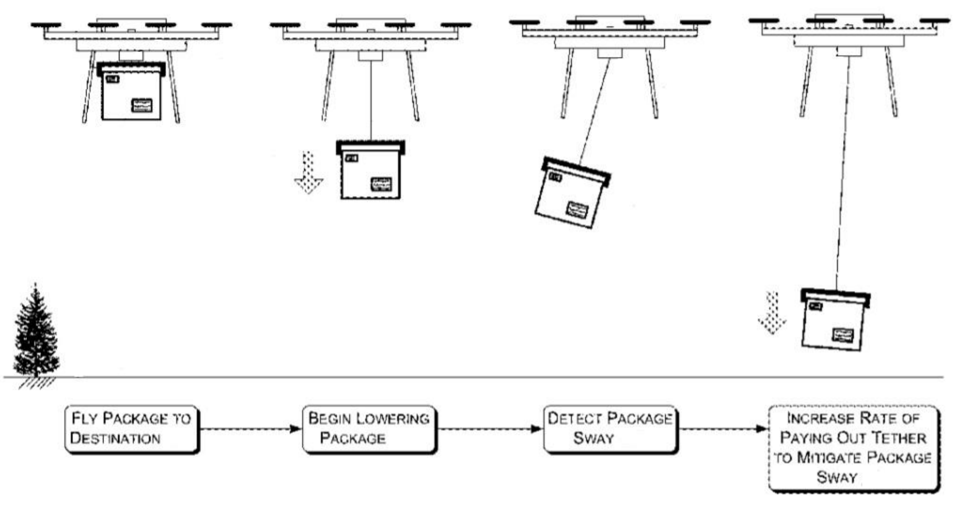

Figure 14: Operational procedures with opening or closing a loop

[55] Buchmueller, D., Legrand III, L. L., Neal, L. T., Schoenberg, Y. C. A., & Wilcox, S. M. (2018). *U.S. Patent No. 9,969,494*. Washington, DC: U.S. Patent and Trademark Office.

4.2.5 Examples of UAV implementation

Before reviewing the examples, it is crucial for understanding to compare their context because, despite the fact these both cases use UAVs in their operation, they very much differ from each other.

Rwanda is a country with an underdeveloped transportation system, e.g. of the 14000 km of roads in Rwanda only 2600 km are paved, and the rest consists of uneven dirt roads that are impossible to use country's raining season[56]. It is important to see the average route a UAVshould follow in order to deliver medical supply from the main distribution center to hospitals of the main cities located closer to the border of the country, which according to google maps varies from 65.11 km for to 106 km (as it shows the figure 15). This can explain the reasons why Zipline preferred implementing one feature to another.

Reykjavik, in its turn, is a capital of Island with a very highly developed infrastructure[57]. Nevertheless, it is a compact city and the largest distance from the city center to the potential delivery point is 7.5 km (as it shows the figure 15). The demonstration of two successfully developed networks, that are crucially different from each other, can help to find the "golden mile" for a scenario applying this in the Brussels Capital Region or highlight the ideas that are appropriate for partial implementation (see 4.4.4).

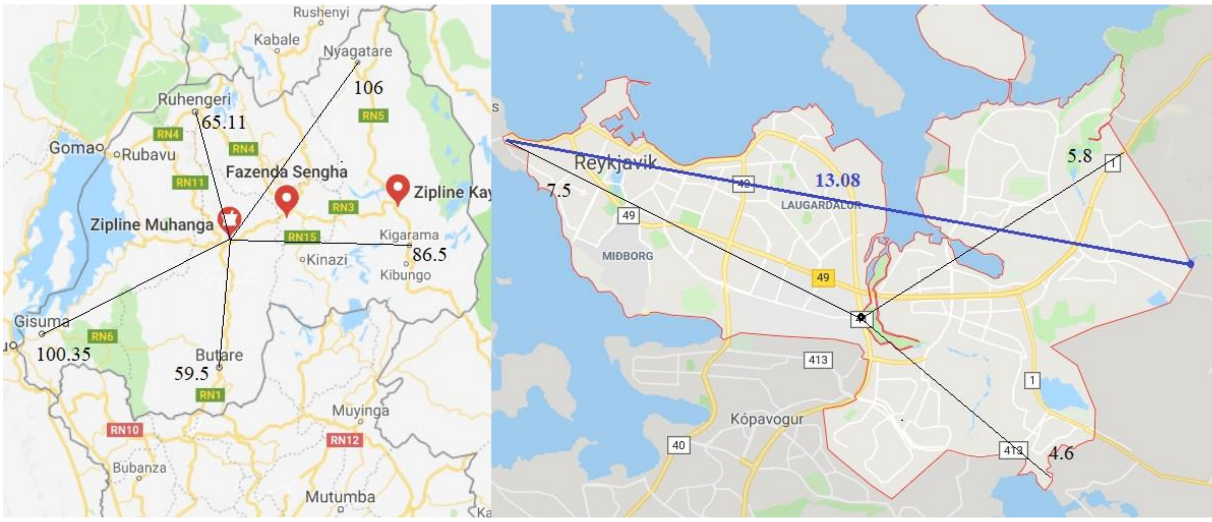

Figure 15: Operating area comparison (Rwanda and Reykjavik)

[56] Niyonsenga, D. (2012). *Assessing public transport supply for Kigali, Rwanda*. University of Twente Faculty of Geo-Information and Earth Observation (ITC).
[57] Schwab, K. (2018). The global competitiveness report 2017–2018. World Economic Forum.

Concerning Zipline's experience, the company was launched in 2014 and started using UAVs in 2016[58]. By 2019 around 65% of Rwanda's blood supply was delivered by Zipline, operating in 21 hospitals with 6 distribution centers.[59] The fact that the company has already successfully established the network makes the case particularly interesting for this research.

The method Zipline uses for its fix-wings UAVs combines parts of all earlier reviewed methods applying them in accordance with the specifications of the UAV used, viz., the delivery request can be send to the distribution center the easiest for a clinic way, via Zipline's website as well as via SMS or WhatsApp[60]. The closest distribution center accepts the request and Zipline claims that there are in average five minutes from order to launch. So, after the conformation is sent, GPS coordinates are used to build a route to the delivery point while stuff is loading the UAV[61].

There are four parts that need to be assembled before the flight. First the requested supply is placed inside the drop patch of the fuselage that is then placed on the launcher. The wings are then attached followed by the battery. The pre-flying checks are made using a mobile appointed to the launching system. Each control point has a QR code that technicians have to scan to let the computer vision algorithm make a pass or fail judgment for each control surface. A launching pad is simply a catapult that allows to gain high speed just from the moment of

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58 Rosen, J. (2017, June 8). Zipline's ambitious medical drone delivery in Africa. *MIT Technology Review.*

59 de Leon, R. (2019, April 24). Zipline takes flight in Ghana, making it the world's largest drone-delivery network. *Consumer News and Business Channel, Retrieved from newspaper homepage https://www.cnbc.com/2019/04/24/with-ghana-expansion-ziplines-medical-drones-now-reach-22m-people.html*

60 Zipline. (2018, June 31). Zipline - Impact in Rwanda - New Generation Edition [Video file]. Retrieved fromhttps://youtu.be/dfNpQzivkJA

61 Rosen, J. (2017). Zipline's ambitious medical drone delivery in Africa. *MIT Technology Review.*

launching.

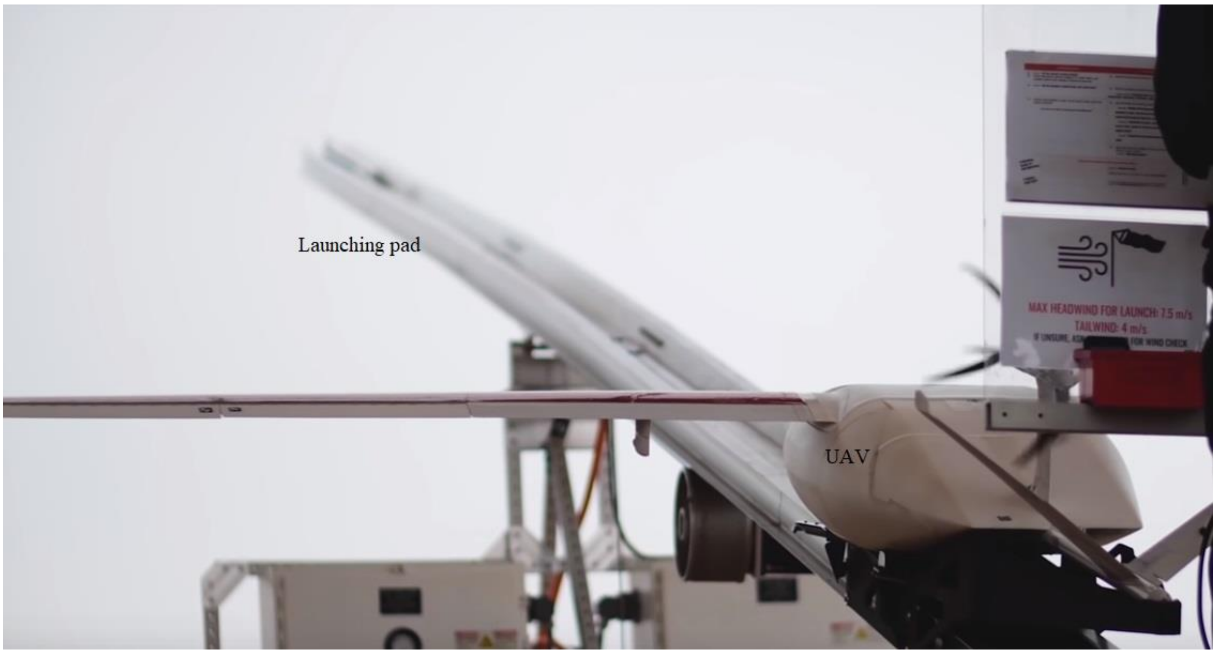

Figure 16: Zipline’s catapult (take-off)

A UAV doesn’t land at the destination point but drops the supply packed in a box with a parachute. It means that clinics don’t need any infrastructure to be supplied.

In order to land a UAV, it is automatically directed to a prepared landing pad equipped by two actuated arms with a wire connected to side of the capture system. The arms raise and catch a hook on the UAV’s tailed bob with their wire[62].

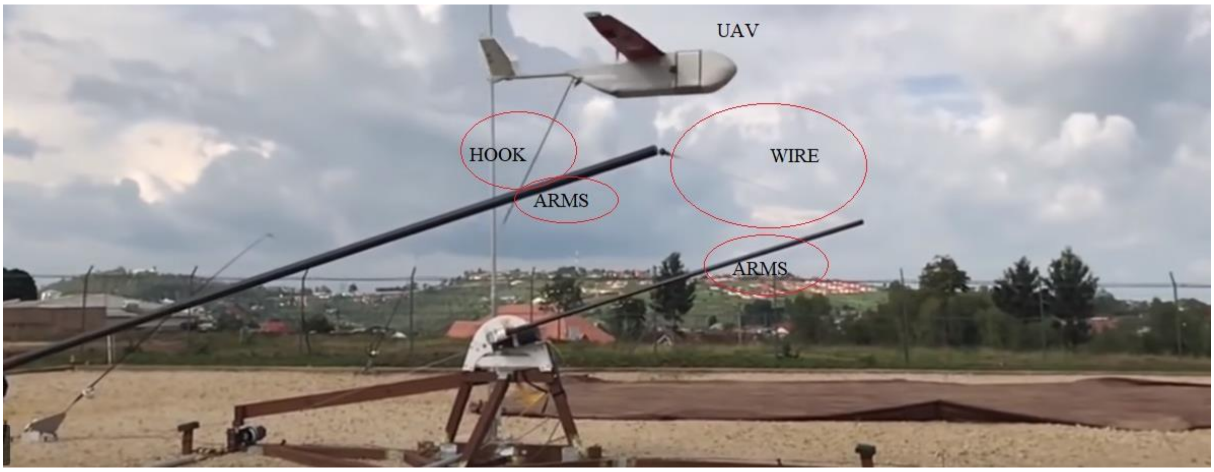

Figure 17: Zipline’s UAV landing

[62] McManus, B. [Real Engeneering]. (2019, January 25). How Rwanda Built A Drone Delivery Service [Video file]. Retrieved from https://youtu.be/jEbRVNxL44c

Flytrex, on its turn, is an Israeli UAVs manufacturer that in a partnership with Aha.is, Iceland's largest on-demand supplier of restaurant food, operates UAVs in the city of Reykjavik. The city is divided by a large bay so the mission of Flytrex was to use a route inaccessible for trucks, in order to deliver packages from one side of the bay to another[63]. It reduces delivery time from 20 min for 7 km to a flight of around 7 min[64].

Flytrex's UAVs combine several already reviewed features in operating with some little differences, therefore, the operational process represents the following: customers make their requests on an online ordering app that includes the address of a drop-off point that can be either on the customers property or a pre-designed public location. Since GPS coordinates are known and the package is loaded in the delivery box, the UAV takes off and follows the pre-programmed route. The Flytrex's UAVs do not carry any cameras and navigate using GPS and sensors only. Customers can follow the UAV on Flytrex's app and as soon as the UAV reaches the drop-off point, they must approve package release. Next, the UAV lowers-down the package on a wire and as soon as it touches the ground the wire detaches from the drone. The UAV returns to its base. Since Flytrex operates multirotor UAVs, there is no need in special launching or landing pads[65].

4.3 Socio-economic and ethical concerns

Adopting new technology doesn't always come naturally due to some real and subjective concerns diverse groups of involved individuals as well as entities might have. Ethical constraints arise out of potential risks incurred by the use of a UAV that must be considered. This is highly important because if the society do not accept, e.g. being afraid of innovations, even the most modern and impressive technology may remain unused.

One of the main obstacles is the legislation that cannot be easily changed without bottom-up demand if the Copenhagen criteria of democracy and governance is satisfied[66]. Even though in this work totalitarian methods of government are not considered, theoretically,

[63] Burton, E., Meier, C., Olarte, R., Skeini, H., & Zahan, F. (2017, November). Airshare: a food sharing concept. In *Proceedings of the 29th Australian Conference on Computer-Human Interaction*(pp. 634-639). ACM.
[64] Solomon, S. (2018, August 7). Israel's Flytrex set to supply half of Reykjavik with food by drone. The Time of Israel. Retrieved from https://www.timesofisrael.com/israels-flytrex-set-to-supply-half-of-reykjavik-with-food-by-drone/
[65] Flytrex [Website] Retrieved from https://www.flytrex.com/
[66] Kochenov, D. (2004). Behind the Copenhagen façade. The meaning and structure of the Copenhagen political criterion of democracy and the rule of law. *European Integration Online Papers*, *8*(10), 1-24.

business lobby can achieve some beneficial changes, the government however depends on the society and represents the population of the country through elections.

That's why in this part aside from the main pro and contra, several methods from business ethics and change management are proposed. They can serve as useful tools for better communication with a higher number of stakeholders in order to facilitate the adoption of the UAV's use in the most correct and effective way.

4.3.1 Privacy

Even if privacy nowadays is considered to be a fundamental human right[67], it is still challenging enough to define the term covering all the aspects of the meaning.

Nevertheless, the most commonly used definition states that it is "the presumption that individuals should have an area of autonomous development, interaction and liberty, namely a "private sphere" with or without interaction with others, free from state intervention and from excessive unsolicited intervention by other uninvited individuals"[68].

As was covered (as discussed in 4.2), most of the UAVs use cameras to capture a fiducial marker or stereo-camera system to connect with a ground base. It raises the issue of privacy and the ethical collection and use of data.

On the other hand, the Belgian society is concerned about the right of privacy, as shown by the fact that the new data protecting law entered into force in 2018 (as discussed in 4.1.2).

Professor David J. Gunkel in his investigation into the assignment of moral responsibilities and rights to intelligent and autonomous machines of our own making emphasizes that if a UAV is operated by an individual, therefore, the actions made by the UAV are intended by the individual[69]. In other words, it is not the UAV what people are afraid of but possible malicious intentions of an individual that is operating the UAV.

This strong argument needs to be discussed and can be responded to by the fact that UAVs use the cameras exclusively for safety reasons while landing. It should also be emphasized that "right to be forgotten" can be fulfilled by being able to erase the collected data after finishing the flight[70].

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[67] Assembly, U. G. (1948). Universal declaration of human rights. *UN General Assembly*, *302*(2).
[68] La Rue, F. (2011). The Promotion and Protection of the Right to Freedom of Opinion and Expression. *Accesed on*, *25*, 2013.
[69] David Gunkel, The Machine Question, The MIT Press, Cambridge Mass., 2012, pp. 65-74
[70] Villaronga, E. F., Kieseberg, P., & Li, T. (2018). Humans forget, machines remember: Artificial intelligence and the right to be forgotten. *Computer Law & Security Review*, *34*(2), 304-313.

Another possible solution is proposed by Flytrex: the UAVs carry no cameras at all and instead use only GPS and sensors for navigation[71] (as discussed in 4.2).

4.3.2 Safety

Using UAVs in the urban area with a high density always raises questions of safety. What if the UAV just fell down from the sky? Everything unknown is mostly perceived being risky by most people[72].

This is the reason why most of the UAV manufacturers claim the safety and reliability features as the most important, as confirmed by the fact that for last years several patents concerning the safety issues were attributed to Zipline[73][74][75][76].

As stated by Zipline's head of product & engineering in his interview, the company is adopting a new parachute landing system in case of an emergency, e.g. if the authorities ask to clear the sky or unexpected extreme weather [77]. On the other hand, taking into account a possibly large UAV's network, Zipline dedicates working on the UAV's autonomous control system[78].

Safety with regard to drone use is usually considered as being able to prevent an accident and harming people. But the issue is much broader taking into consideration the harm UAVs can possibly cause to wildlife. Since there are not many researches concerning the impact UAVs have on the urban wildlife available, there is evidence that some animals show a limited

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[71]Flytrex [Website] Retrieved from https://www.flytrex.com/

[72] OTWAY, H. & WINTERFELDT, D. Beyond Acceptable Risk: On the Social Acceptability of Technologies, Policy Sciences, 0032-2687, Vol. 14, p.247, 1982

[73] Chambers, A., Wyrobek, K., Rinaudo, K., Oksenhorn, R., & Hetzler, W. (2016). *U.S. Patent No. 9,488,979*. Washington, DC: U.S. Patent and Trademark Office.

[74] Chambers, A., Wyrobek, K., Rinaudo, K., Oksenhorn, R., & Hetzler, W. (2018). *U.S. Patent No. 9,910,432*. Washington, DC: U.S. Patent and Trademark Office.

[75] Chambers, A., Wade, B., Drula, C., Halley, D., Napolskikh, I., Wyrobek, K., ... & Hetzler, W. (2016). *U.S. Patent No. 9,489,852*. Washington, DC: U.S. Patent and Trademark Office.

[76] Abeles, P., & Wyrobek, K. (2018). *U.S. Patent Application No. 10/029,788*.

[77] Wyrobek, K. [Zipline]. (2019, February 28). Zipline's World Class Drone Safety Features [Video file]. Retrieved from https://youtu.be/QTnBm3rXmss

[78] Chambers, A., Oksenhorn, R., Schwartz, J., & Wyrobek, K. (2018). *U.S. Patent No. 9,997,080*. Washington, DC: U.S. Patent and Trademark Office.

psychological response to UAVs[79], therefore, there are several recommendations given for using UAVs to minimize disturbance in wildlife in a biological field[80].

Another aspect of the question that must be taken into consideration is that UAVs themselves might be harmed by people. It happened in the USA state Kentucky, where a man was arrested for shooting down a UAV believing that one is spying for his daughter as the local police reported[81].

However, there are legal options allowing to manage these sorts of unique risks. For instance, one of the products that Allianz Global Corporate & Specialty offers is a commercial drone insurance covering accidents during the operating, damage caused by lightning, landslide, earthquake, rock-fall, high water, flooding, hail, avalanches, snow pressure and storm, fire and explosion, theft, robbery, unauthorized use by persons outside the company and finally damage and destruction by an individual no affiliated with operator [82]

4.3.3 Ecology

On the subject of the wildlife safety, it is necessary to mention the ecological aspect of the topic. People started realizing that climate change might have a dramatic impact on our lives. Despite all efforts which can contribute to a reduction of climate change, specific measures should be foreseen in order to minimize the possible harm to the environment[83].

"Claim the climate" became a popular slogan and mobilized many people, e.g. in December 2018 approximately 70000 persons joined manifestations on Brussels streets asking for an ambitious and socially just climate policy[84].

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[79] Ditmer, M. A., Vincent, J. B., Werden, L. K., Tanner, J. C., Laske, T. G., Iaizzo, P. A., ... & Fieberg, J. R. (2015). Bears show a physiological but limited behavioral response to unmanned aerial vehicles. *Current Biology*, *25*(17), 2278-2283.

[80] Hodgson, J. C., & Koh, L. P. (2016). Best practice for minimising unmanned aerial vehicle disturbance to wildlife in biological field research. *Current Biology*, *26*(10), R404-R405.

[81] Arrest information: William Merideth. Retrieved from https://kentucky.arrests.org/Arrests/William_Merideth_23624235/https://kentucky.arrests.org/Arrests/William_Merideth_23624235/

[82] AGCS - Allianz Global Corporate & Specialty. (2019, July 23). Drone insurance: Solutions for commercial and private drone users. Retrieved from https://www.agcs.allianz.com/solutions/aviation-insurance/drone-insurance.html

[83] Jamieson, D. (2010). Climate change, responsibility, and justice. *Science and engineering ethics*, *16*(3), 431-445.

[84] M.R. (AVEC BELGA). (2018, December 02). "Claim the Climate": environ 70.000 personnes dans les rues, "un formidable succès de mobilisation citoyenne" estime Charles Michel. La Libre.be. Retrieved from https://www.lalibre.be/belgique/claim-the-climate-environ-70-000-personnes-dans-les-rues-un-formidable-succes-de-mobilisation-citoyenne-estime-charles-michel-photosvideos-5c03bd03cd70fdc91bc0cc21

On the other hand, Belgium as one of the member states of European Union by 2030 must develop National Energy Climate Plans with a goal of decreasing greenhouse gas emissions minimum by 40%[85].

According to European Environment Agency in 2016, the transport sector is responsible for 27 % of all greenhouse gas emissions[86].

Replacement of trucks using diesel fuel by UAVs in transportation could lower the greenhouse gas emissions since the last ones work on electricity[87]

4.3.4 Efficiency and Human Enhancement

Since it is not a secret anymore that life, including some basic details, already in the closest future can resemble something different and most people can see it during their own life[88], human enhancement has emerged as an important question at very different levels.

On the one hand, the economic potential of UAVs is very high. According to the report of PwC the total addressable market would be worth 408.9 million euros annually, with the Transport & Logistics industry having a value of 43.6 million euros[89]. The sum can be possibly achieved by replacing the existing infrastructure by drones including the cost of maintenance, related activities and the labor cost. While it might seem to be economically attractive for business owners, such innovations are usually associated with forced loosing low-skills jobs and further unemployment[90].

But on the other hand, adoption of such new technology as UAVs can create new human jobs required[91]. There can be a large range of positions for private and commercial operators, manufacturers, distributors, repairers. Since the emerged jobs require new unique skills, flight schools and training facilities will be in-demand. Nowadays there are active training centers as

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[85] The Directorate-General for Energy. National Energy and Climate Plans. (2019, June 15). Retrieved from https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/governance-energy-union/national-energy-climate-plans

[86] The European Environment Agency. (2018, November 22). Greenhouse gas emissions from transport. Retrieved from https://www.eea.europa.eu/data-and-maps/daviz/transport-emissions-of-ghgs-5#tab-chart_1

[87] Stolaroff, J. K., Samaras, C., O'Neill, E. R., Lubers, A., Mitchell, A. S., & Ceperley, D. (2018). Energy use and life cycle greenhouse gas emissions of drones for commercial package delivery. *Nature communications*, *9*(1), 409.

[88] Savulescu, J., & Bostrom, N. (Eds.). (2009). *Human enhancement*. OUP Oxford.

[89] Culus, J., Schellekens, Y., Smeets, Y. (2018). A drone's eye view. Overview of the Belgian UAV ecosystem & the development of commercial drone applications in Belgium. PwC Belgium and Agoria vzw/asbl

[90] Loi, M. (2015). Technological unemployment and human disenhancement. *Ethics and Information Technology*, *17*(3), 201-210.

[91] Wilson, H. J., Daugherty, P., & Bianzino, N. (2017). The jobs that artificial intelligence will create. *MIT Sloan Management Review*, *58*(4), 14.

Belgian Drone School SPRL in Nivelles offering training for operating the 1st and 2nd category of UAVs[92]

4.3.5 Saving lives

Finally, UAVs can be considered as an opportunity to save lives by shipping vital medical supplies or urgent delivery in critical situations rather than just a fancy way to deliver your pizza[93].

Adoption of such technologies can help with improving an existing supply chain or building a new more effective network using the part of still available airspace in accordance with geographical, architectural, ecological, etc. features of the place to be implemented.

Examples include Zipline that built a countrywide emergence care network in Rwanda which helps to deliver vital medical supplies by UAVs[94].

4.3.6 Integrating socio-economic and ethical concerns in the debate

In order to communicate and integrate these findings in a correct and efficient way, it seems to be necessary to review potential available frameworks. Ethical frameworks can show the way all the stakeholders should act in assigned circumstances and managerial frameworks, in their turn, can be used as an algorithm for a manager to govern the changes.

5.4.6.1 Philosophical framework for the individuals to act

The ethical approach that might help to find a compromise in this case is Aristotle's "Golden middle way". It proposes that a solution must be found between two extremes and can be found by conducting debates between two opposites. Here an issue appears if the opposites have different versions of the virtue considering it an only truth[95]. There may be no room for compromise, for instance, when one considers adoption of a new technology in business as a great opportunity for economy that helps to benefit all the society, another can see automatization and computerization as the cause of further unemployment[96]

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92 Belgian Drone School SPRL. (2019, July 25). Retrieved from https://www.belgiandroneschool.be

93 Reid, D. (2016). Domino's delivers world's first ever pizza by drone. The Consumer News and Business Channel. Retrieved from https://www.cnbc.com/2016/11/16/dominos-has-delivered-the-worlds-first-ever-pizza-by-drone-to-a-new-zealand-couple.html

94 Meskó, B., Hetényi, G., & Győrffy, Z. (2018). Will artificial intelligence solve the human resource crisis in healthcare?. *BMC health services research*, *18*(1), 545.

95 Cunningham, S. B. (1999). Getting It Right: Aristotle's" Golden Mean" as Theory Deterioration. *Journal of Mass Media Ethics*, *14*(1), 5-15.

Loi, M. (2015). Technological unemployment and human disenhancement. *Ethics and Information Technology*, *17*(3), 201-210.

Utilitarianism is an ethical theory developed by Jeremy Bentham and John Stuart Mill that proposes to focus on the consequences of what we are doing. [97] Good results mean good actions. Utilitarianism also insists that people should pursue happiness, but being an other-regarding theory, it says, this should be done not for ourselves, but for as many persons as possible. The principle of utility means that we should act always so as to produce the greatest good for the greatest number.[98]

Concerning the use of UAVs in city logistics, not every stakeholder might be absolutely satisfied with the way the new logistic system is adopted, but the utilitarian theory insists that each shareholder should choose the action that is the most beneficial for all the group even though it is less beneficial for the individual or produces less happiness for the individual than other alternatives. It doesn't mean that individuals must neglect their own wishes or concerns but pay more attention on the issues the others have in the way the decision is desired to be implemented. Inhabitants of one of the buildings UAVs are passing by above can be concerned by the privacy or safety reasons. Instead of fully forbidding any UAVs, they might apply to the legislators of the city to build a correct framework that does not prohibit the use of UAVs but dissipates concerns of stakeholders. On the other hand, manufacturers should invest more in order to ensure the safety or use technology that guarantees not using any private data as is dome by Flytrex which UAVs have no camera. In regards of the theory, all the actions should be done voluntarily.

5.4.6.2 Managerial framework for the change manager to act

All the stated is strictly related to management styles that set the way changes or any actions to be performed. If the polyphonic managerial style is chosen, more attention must be payed to the diversity of the interests and in order to launch the changes, regardless of technological, operational or strategical level, more soft negotiation strategies should be used[99].

[97] Anderson, K. (2013). Utilitarianism: The greatest good for the greatest number. *Evidence and Answers*.
[98] Driver, J. (2009). The history of utilitarianism.
[99] Pichault, F. (2013). Change management. Towards Polyphony. *Brussels, De Boeck*.

The polyphonic theory is made up of basic principal as following:

Contextualization of the innovation that is going to be adopted. In this regard, not only UAVs manufacturers, companies-users and legislators are going to be involved in the prosses but all the human and non-human entities.

The controversy between the entities must be characterized in order to define which parties are closer to each other in having an agreement, so problematic statements must be formulated for each group of stakeholders.

Each group of stakeholders must be legitimized by having spokespeople representing the group and being involved in the change process.

Evolution of the controversy must be represented in a graphical form making an accent on statements that can possibly increase or decrease the controversy as well as marking the parts that obliged to consider before passing to another one, e.g. if the privacy issue is among the most important, there is no option to neglect it.

After involving all stakeholders, temporary boundaries must be built and respected[100].

Implementation of a polyphonic managerial style might not go slightly and can face some natural resistance in the first phases but there are special tools as the 7 phases model by Bareil that propose specific managerial responses to individual concerns during the change process. These can be used not only as an managerial instruction but also a simplified version to help to visualize the whole process of adopting a new technology, as UAVs are, and sketching communication between stakeholders as is represented on the table 2 below[101].

[100] Pichault, F. (2013). Change management. Towards Polyphony. *Brussels, De Boeck*.
[101] Bareil, C. (2004). *Managing Resistance to Change or Readiness to Change*. HEC Montréal, Centre d'études en transformation des organisations.

Phase of concern	Description	Suggested managerial responses
1 Absence of concern	Indifference towards the project under way	Raise awareness of the need for change
2 Focus on the recipient	Awareness of the end of status quo, worrying about the impact own their position, role, status, power, etc.	Reassure, inform
3 Focus on the organization	Asking about the organization’s actual commitment to the new path and the potential impact on it	Clarify the stakes
4 Focus on change	Search for precise information about the exact nature of change, its modalities, timetable, etc.	Provide detailed information
5 Focus on experimentation	Starting to accept the new model but worried about personal skills and capacity to adapt	Support, coaching
6 Focus on collaboration	With to share experiences with others by becoming involved in implementing the change	Provide opportunities of exchange
7 Focus on improving the change	Search for new challenges and suggesting corrections or new project applications	Encourage innovations

Table 2: 7 phases model by Bareil

4.4 Supply chain operational performances

The prior desk work gave an idea about the way how the following experiment can be conducted, what the limitations are in the level of the maximal distance modern UAVs can cross and their possible payload.

It also helped to find what kind of entities are going to be considered as customers, where the distribution center is located and why operational procedures must be done in specific ways.

Since the flying range, speed and loading capacities are only reliable among the available information, in analyzing the problem, the emphasis is put on the time subject and the maximum flying range is taken as a constraint.

The Brussels-Capital Region is chosen as a virtual "test site" as it is the biggest metropolitan area in Belgium with the highest population of 1,19 million according to Eurostat[102].

The work proposes taking Brussels main hospitals as customers requiring fast and reliable delivery of urgent medical supply, blood or any other lifesaving parcels. Since some of the reviewed UAVs require launching and landing pads, the 22 biggest medical institutions having suitable facilities were selected[103][104].

The list includes only medical institutions either located aside from other buildings, having their own territory or a large roof space as is shown in figure 17. Considering the fact that yards or the roof space can be used for different purposes, for example as parking or plumbing, heating or ventilation facilities this work claims that they can be possibly reassigned.

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[102] European Statistical Office. (2018). Population: Demography, migration and projections. Retrieved from https://ec.europa.eu/eurostat/en/web/population-demography-migration-projections/statistics-illustrated

[103] The official portal of the Brussels-Capital Region (2019, June 01). Hospitals and clinics. Retrieved from https://be.brussels/living-in-brussels/health-and-safety/hopitaux-et-cliniques

[104] The official portal of the Brussels-Capital Region (2019, June 01). Le réseau hospitalier IRIS. Retrieved from http://pouvoirs-locaux.brussels/fr/acteurs/le-reseau-hospitalier-iris

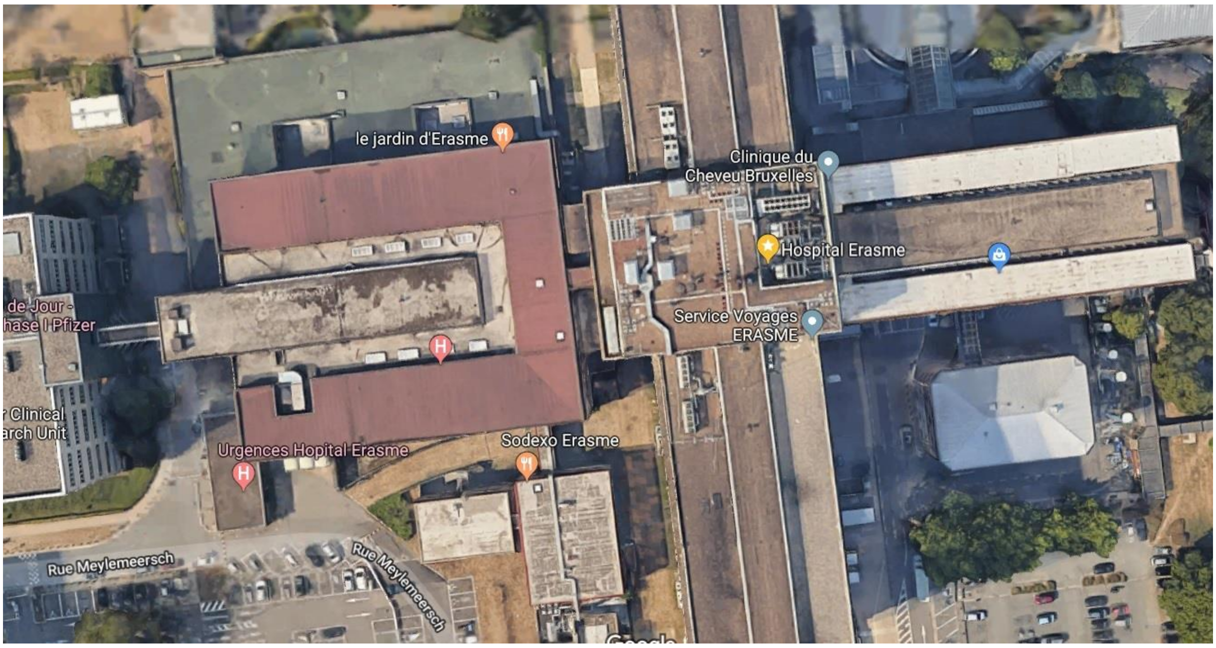

Figure 18: Hospital Erasme

The focus of the first part of this section is on a Single-depot vehicle routing problem. Since this requires a central depot that allows delivering goods to several points[105] and CHU Saint-Pierre - Site César De Paepe is located in the center-city (Brussels, 1000), this hospital is considered as the single distribution center.

The main goal of the second step is the simulation of a possible use of UAVs applying the geographical and industrial features of the Brussels-Capital Region and in order to make it application-oriented as much as possible different software types were tested. The choice was made in favor of OptimoRoute since this software has planning and scheduling functions, correctly works with Belgian addresses, supports transferring the data to google maps for further use and offers a 30-days trial free of charges[106]

After the models were built, it was important to provide a scenario of practical application, therefore, in order to simulate the real situation several distinct assumptions were made. This allowed to propose the way how the distribution center can be equipped.

Since there is no information concerning the price of UAVs, this work proposes two mathematical models that are aiming to minimize the total cost of purchasing UAVs for the

[105] G. Clarke and J. Wright (1964) Scheduling of vehicles from a central depot to a number of delivery points, Operations Research, 12 #4, 568-581
[106] OptimoRoute Inc. [Website] Retrieved from https://optimoroute.com/

virtual distribution center, analyzes them but does not propose solutions. The price of the UAVs is currently commercial secrecy.

4.4.1 One truck – one drone

As a first step to tackle the question a shipping method with only one truck and one UAV is considered. In this context, the supply must be delivered from the central depot to another 21 points; each customer must be visited only once.

For a truck it takes 80.9 km and 3h16 to reach all the delivery points and come back to the depot following the route built in OptimoRoute.

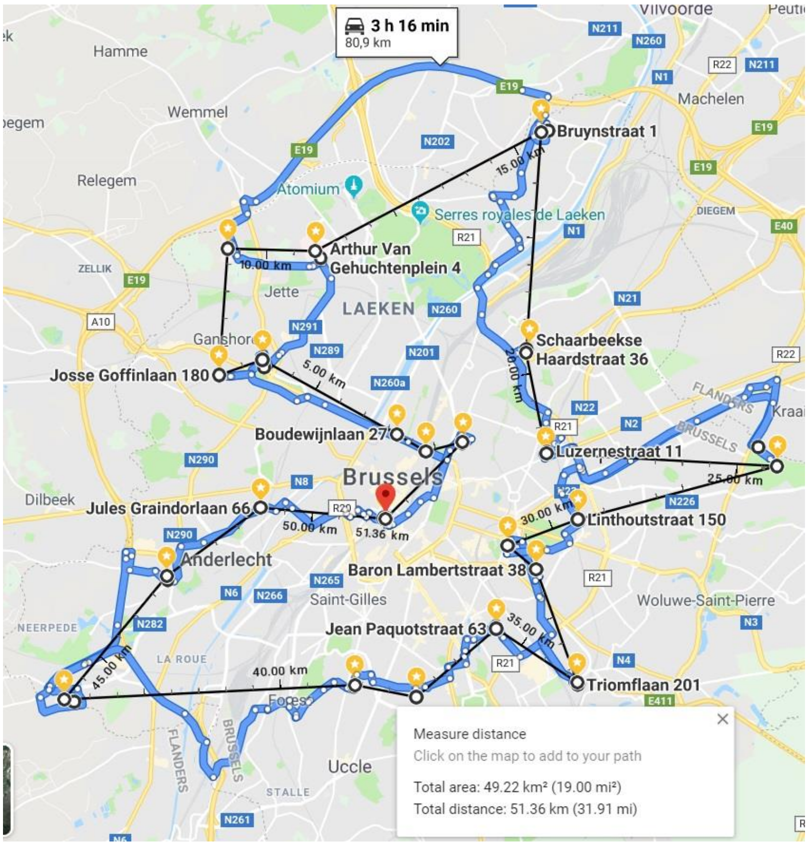

Figure 19: OptimoRoute's output for experiment 1 on the map

In the case of UAV shipping, the total distance was reduced to 51.35 km. The time required for the shipping can differ from maximal 2h34 with Flirtey flying 20 km/h to minimal 23 min with DHL Parcelcopter flying 130 km/h.

	Distance (Km)	Speed (km/h)	Time (h)	Flying dist. (km)
Truck	80.9		3h16 (196 m)	

Flytrex	51.36	29	1h46	11
Amazon PrimeAir	51.36	80	0h38	32
Flirtey	51.36	20	2h34	5
Project Wing	51.36	120	0h25	14
Zipline	51.36	100	0h30	75 - true
DHL Parcelcopter	51.36	130	0h23	65 - true

Table 3: Output of experiment 1 summarized

Only DHL Parcelcopter and Zipline with the maximum flying distance of 65 and 75 km, respectively, can cross the required shipping path.

If UAVs are used instead of a truck, the estimated time savings for DHL Parcelcopter would be 173 min (2h39) which is equal to 88.27% of all the time the truck takes for delivery, and 166 min (2h46) which is equal to 84.69% for Zipline.

The outcome shows that replacing a truck by a UAV can be advantageous since the distance and therefore time of supply delivery is decreased. However, the fact is that there is no UAV available yet that is able to cross the required distance and carry 21 objects at the same time. Nonetheless, these findings are encouraging to continue optimization with other models.

4.4.2 One truck – one drone for one sector

To solve feasibility issues, such as the encountered restrictions in flying range and payload, customers can be divided into several subsets using OptimoRoute. The objective of this is to ensure that the distance between customers in one subset is low enough compared to the distance between two subsets. It ensures that a used UAV has a suitable flying range therefore all customers can be reached. Since the distribution center is the central point of the map, the number of subsets corresponds to the primary points of the compass. The western part was neglected due to very few numbers of customers that joined the closest subsets.

For the Northern part, as illustrated in the the picture 20, for trucks it takes 35.7 km and 1.25 h. to reach 10 delivery points and arrive back to the depot following the route built in OptimoRoute

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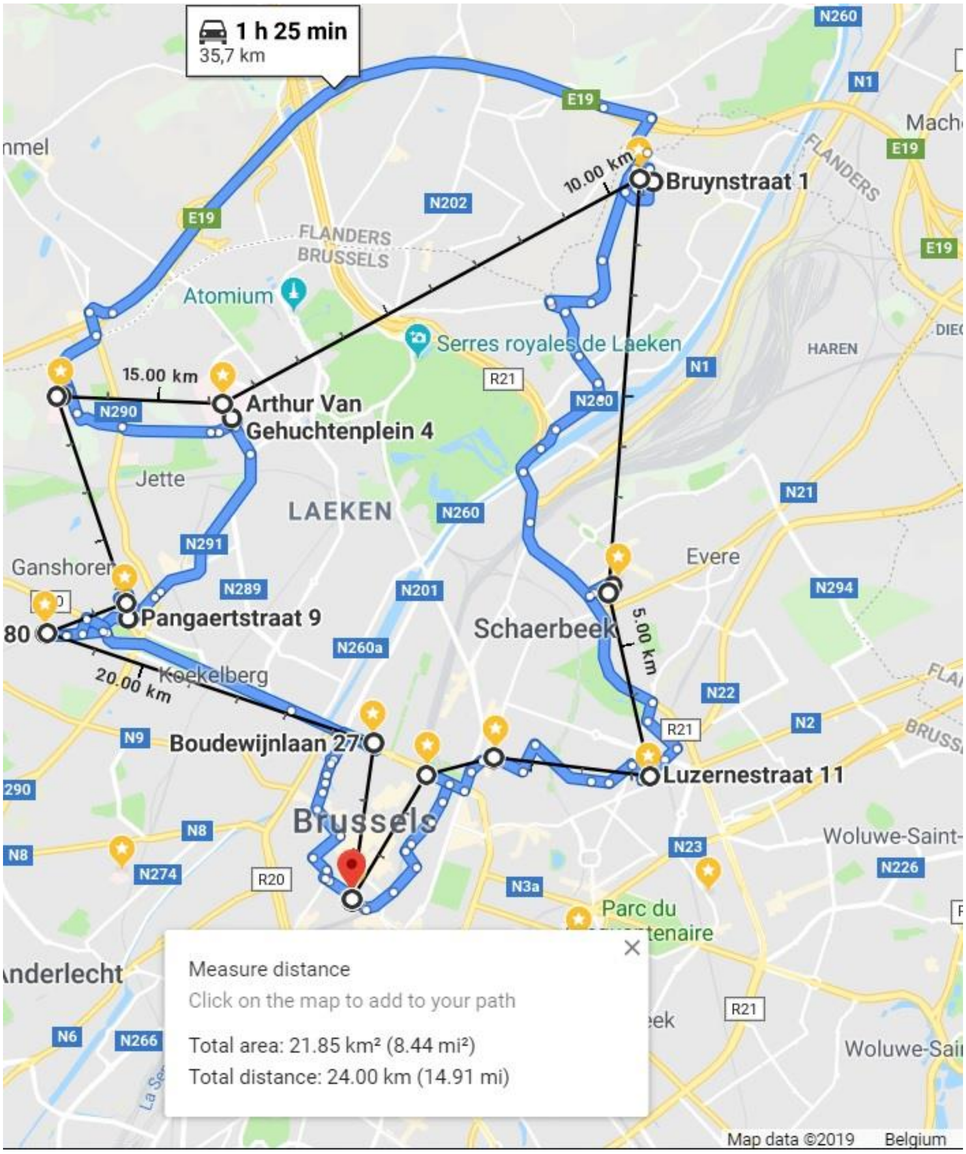

Figure 20: OptimoRoute's output for experiment 2 on the map (the North)

In the case of UAV shipping, the total distance was reduced to 24 km. The time required for the shipping can differ from maximally 1h12 with Flirtey flying 20 km/h to minimally 11 min with DHL Parcelcopter flying 130 km/h.

	Km	Speed (km/h)	Time (h)	Flying dist. (km)
Truck	35.7		1h25 (85 m)	
Flytrex	24	29	0h49	11
Amazon PrimeAir	24	80	0h18	32 - true
Flirtey	24	20	1h12	5
Project Wing	24	120	0h12	14
Zipline	24	100	0h14	75 - true
DHL Parcelcopter	24	130	0h11	65 - true

Table 4: Output of experiment 2 (the North) summarized

Importantly, only Amazon PrimeAir, DHL Parcelcopter and Zipline with the maximum flying distance of 32, 65 and 75 km respectively can cross the required shipping path.

If the UAVs are used instead of a truck, the estimated time savings for Amazon PrimeAir would be 67 min (1h07) which is equal to 78.82% of all the time the truck takes for delivering, 74 min (1h014) which is equal to 87.06% for DHL Parcelcopter and 71 min (1h011) that is equal to 83.53% for Zipline.

For the Eastern part, as illustrated in the picture 21, for trucks it takes 38.4 km and 1.22 h to reach 7 delivery points and arrive back to the depot following the route built in OptimoRoute.

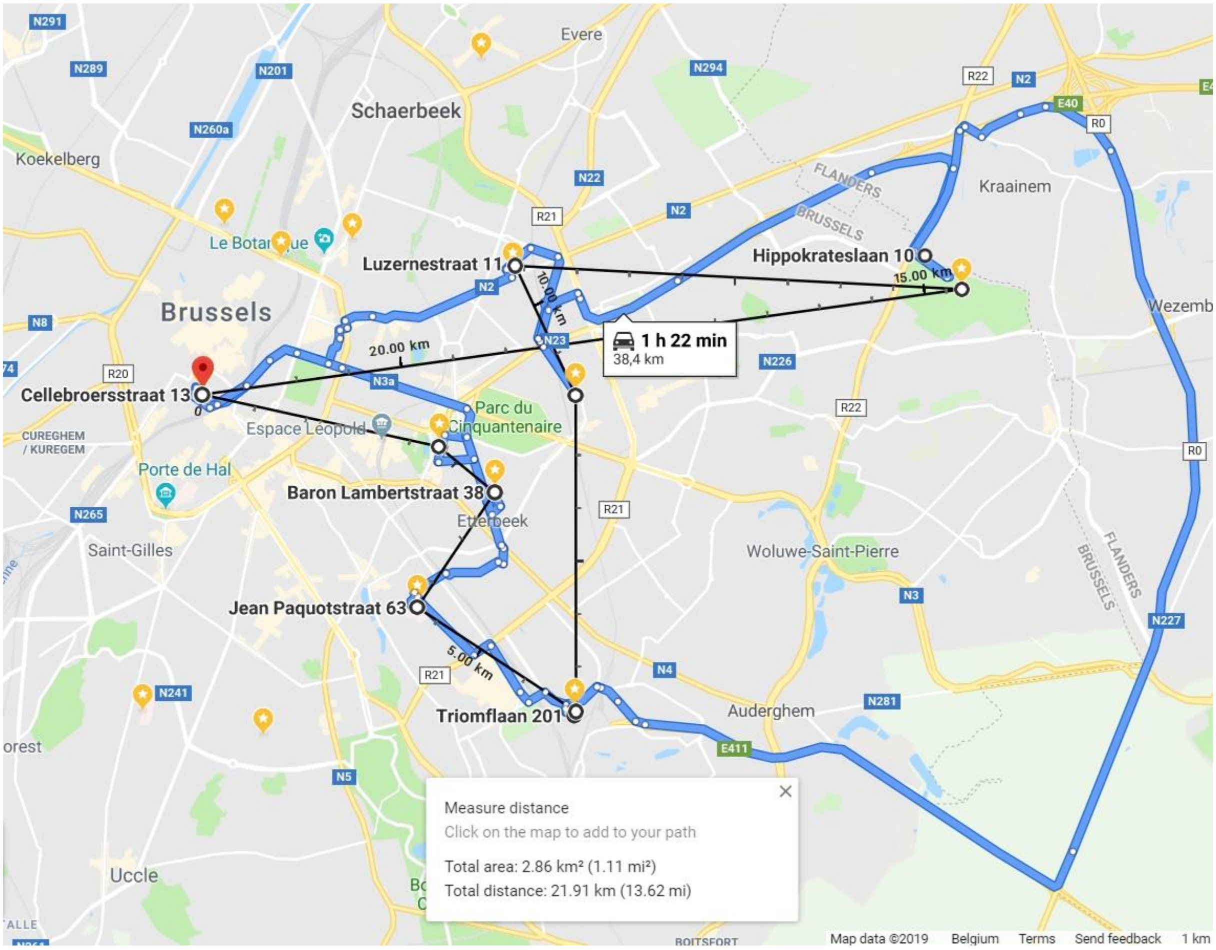

Figure 21: OptimoRoute's output for experiment 2 on the map (the East)

In the case of UAV shipping, the total distance was reduced to 21.9 km. The time required for the shipping can differ from maximally 1h5 with Flirtey flying 20 km/h to minimally 10 min with Project Wing or DHL Parcelcopter flying 120 and 130 km/h, respectively.

	Km	Speed (km/h)	Time (h)	Flying dist. (km)
Truck	38.4		1h22 (82 m)	
Flytrex	21.91	29	0h45	11
Amazon PrimeAir	21.91	80	0h16	32 - true
Flirtey	21.91	20	1h5	5
Project Wing	21.91	120	0h10	14
Zipline	21.91	100	0h13	75 - true
DHL Parcelcopter	21.91	130	0h10	65 - true

Table 5: Output of experiment 2 (the East) summarized

It is interesting to compare the example with the previous one because it shows that even if the distance for a truck is higher due to geographical or infrastructural reasons, the distance for an UAVs remains the same or can be even shorter which benefits the time savings.

In this case Amazon PrimeAir, DHL Parcelcopter and Zipline with the maximum flying distance of 32, 65 and 75 km, respectively, overcame the maximum flying distance constraint.

If the UAVs are used instead of a truck, the estimated time savings for Amazon PrimeAir would be 66 min (1h06) which is equal to 80.49% of all the time the truck takes for delivering, 75 min (1h015) which is equal to 91.46% for DHL Parcelcopter and 69 min (1h09) that is equal to 84.15% for Zipline.

For the Southern part as illustrated in the picture 22, for trucks it takes 27.5 km and 1.9 h. to reach 5 delivery points and arrive back to the depot following the route built in OptimoRoute.

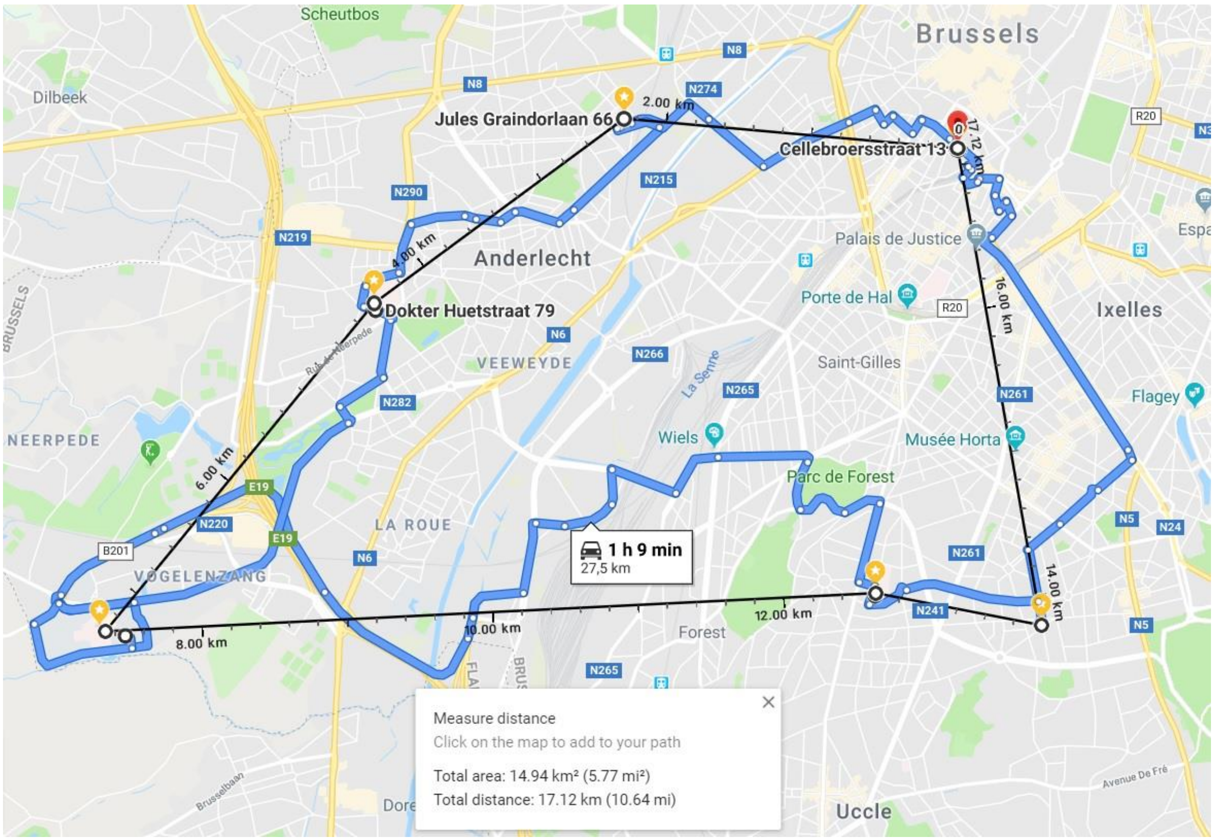

Figure 22: OptimoRoute's output for experiment 2 on the map (the South)

In the case of UAV shipping, the total distance was reduced to 17.1 km. The time required for the shipping can differ from maximally 51 min with Flirtey flying 20 km/h to minimally 7 min with DHL Parcelcopter flying 130 km/h.

	Km	Speed (km/h)	Time (h)	Flying dist. (km)
Truck	27.5		1h9 (69 m)	
Flytrex	17.12	29	0h35	11
Amazon PrimeAir	17.12	80	0h12	32 - true
Flirtey	17.12	20	0h51	5
Project Wing	17.12	120	0h8	14
Zipline	17.12	100	0h10	75 - true
DHL Parcelcopter	17.12	130	0h7	65 - true

Table 6: Output of experiment 2 (the South) summarized

If the maximum flying distance constraint applied only Amazon PrimeAir, DHL Parcelcopter and Zipline with the maximum flying distance of 32, 65 and 75 km respectively can cross the required shipping path.

If the UAVs are used instead of a truck, the estimated time savings for Amazon PrimeAir would be 57 min which is equal to 82.61% of all the time the truck takes for delivering, 62 min (1h02) which is equal to 89.86% for DHL Parcelcopter and 59 min that is equal to 85.51% for Zipline.

The outcome shows reduction of the distance and, therefore, the time the UAV needs to reach all assigned delivery points by minimally 78.82% and maximally 91.46% which can be considered significant.

On the other hand, the examples do not take into account the weight of a shipping item. To determine this, the International Federation of Red Cross and Red Crescent Societies made a list of weight to help calculating the average weight and volume of a consignment of miscellaneous medical supplies according to which the weight of one item can vary from 0.2 kg to 8 kg[107]. On the other hand, the volume of a blood product prepared for transfusing is average 200-300 ml according to the Clinical Transfusion Practice Guidelines of the World

[107]International Federation of Red Cross and Red Crescent Societies. (2019, July 28). Standard Products Catalogue: Medical weight and volume [Website]. Retrieved from https://itemscatalogue.redcross.int/medical-weight-volume.aspx

Health Organization[108]. For the blood products additional weight of packaging must be considered.

Furthermore, only the maximum flying distance constraint was taken into consideration and it was assumed that reviewed UAVs can carry an unlimited number of items. Practically, during the market research there was no UAV model found that would be able to carry multiple items, therefore, as with the previous example, it must be named as the key limitation for this part.

4.4.3 One UAV – one delivery

Taking into account the loading capacities of existing UAVs and a wide range of a possible parcel weight, another delivery method should be proposed . One UAV can visit only one delivery point as is illustrated in figure 23.

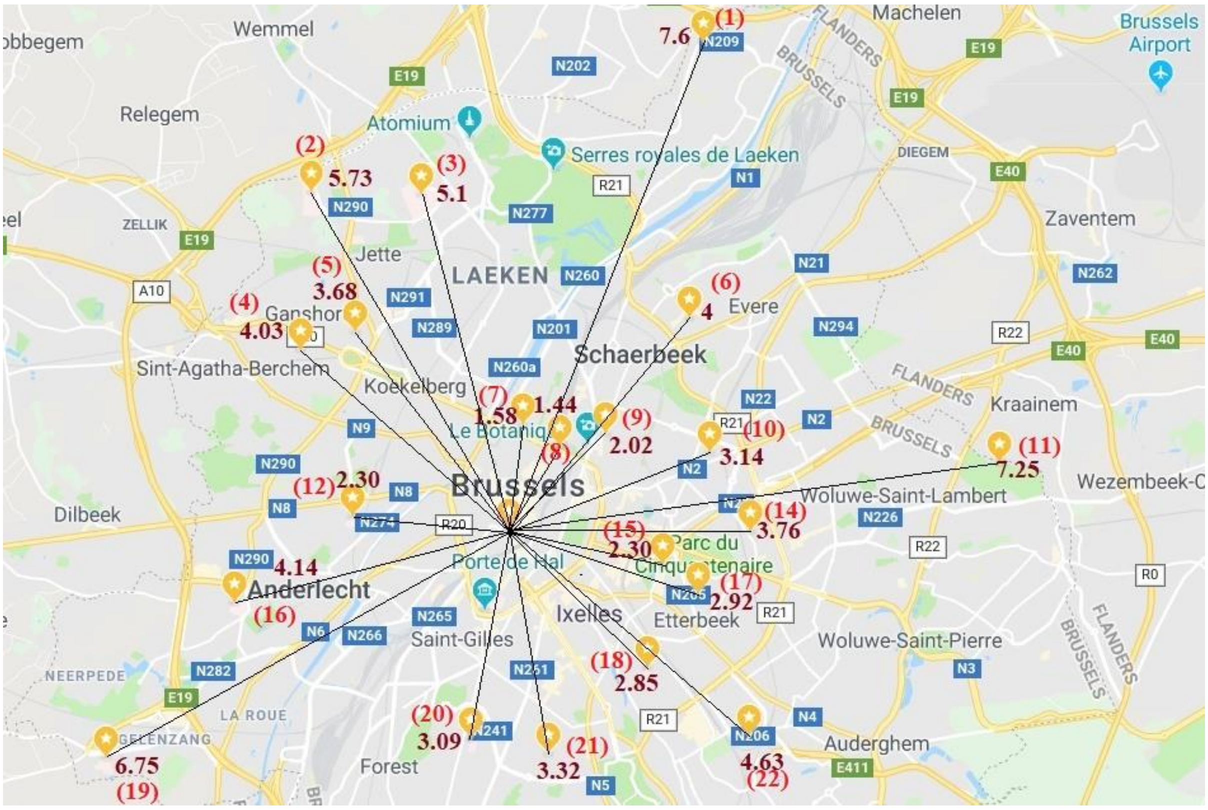

Figure 23: Distance to each delivery point

[108]World Health Organization. (2019). Clinical Transfusion Practice: Guidelines for Medical Interns. Retrieved from https://www.who.int/bloodsafety/transfusion_services/ClinicalTransfusionPracticeGuidelinesforMedicalInternsBangladesh.pdf

The distance from the distribution center to each delivery point was measured and represented by a line with a mark of the number of kilometers between them. Next, the delivery points were grouped. One group represents a model of one of the earlier reviewed UAVs and consists of the number of delivering points an UAV can access according to its flying range.

The time required for an UAV to ship an item from the distribution center to a customer and return is calculated and recapped into the appendix I.

Based on the information, Flirtey (speed 29 km/h) can potentially reach only 5 customers that are not farther than 2.5 km from the distribution center. In order to ship an item and return to the distribution center Flirtey requires minimally 8.64 (2.88 km a round trip) and maximally 13.8 min (4.6 km a round trip) within its flying range.

Flytrex (speed 20 km/h), on its turn, can reach 17 customers within a range of 5.5 km. To make a round trip within the claimed flying range, Flytrex required minimum 5.96 min for the closest delivery point and maximum 21.10 min to reach the farthest one (10.2 km) and return.

Project Wing can reach 19 customers within a range of only 7 km, although, it stands out with its relatively high speed of 120 km/h. It can reach the closest delivery point and return to the distribution center for 1.44 min and make a round trip to the farthest customer for 6.75 min (13.5 km).

Amazon PrimeAir, Zipline, DHL Parcelcopter can reach all named customers having a range of 16, 37.5 and 32.5 km respectively.

Amazon PrimeAir with the speed of 80 km/h requires 2.16 min to accomplish delivering an item to the closest customers and 11.40 min, in its turn, to reach the farthest delivery point and come back (15.20 km).

Zipline with 100 km/h can reach the closes delivery point and return having for it 1.73 min and 9.12 min for the farthest point (15.20 km).

DHL Parcelcopter as the fastest UAV among reviewed with the speed of 130 km/h delivers an item to the closest delivery point and returns to the distribution center for 1.33 min and 7.04 min to the farthest point (15.20 km).

The outcome confirms the advantage of replacement trucks by UAVs. (the outcomes were discussed in 4.4.2).

4.4.4 Possible scenario of UAVs delivery

Since the time required for a round trip delivery made by any model of reviewed UAVs is known (see Appendix I), now the work can focus on outlining a possible scenario of using UAVs in city logistics. The previously reviewed 'one UAV – one delivery's concept'(see 4.4.3) is taken as a basis, therefore, there are one distribution center and 21 customers.

The purpose of this scenario is to identify the way the distribution center must be equipped in order to successfully perform its task, in other words, which models of UAVs it requires and how many?

In order to do so, several assumptions must be made:

1. UAVs start and finish delivery at the distribution center.
2. The distribution center received requests from all 21 customers at the same time and deliveries must be performed simultaneously.
3. UAVs with shorter maximal flying range is more efficient operating on a shorter distance than those that are able to fly on larger distances regardless of their speed. In other words, it is less advantageous to operate Zipline than Flirtey, if the latter is available.

Group	Range (km)	Customers in the access zone / out of 21
Flytrex	5.5	17
Amazon PrimeAir	16	21
Flirtey	2.5	5
Project Wing	7	19
Zipline	37.5	21
DHL Parcelcopter	32.5	21

Table 7: Number of customers in the access zone per range

The outcome summarized in the table 7 shows that to be able to perform the simultaneous delivery in the Brussels-Capital Region, the distribution center must have (all assumptions are applied):

Minimum 5 units of Flitrey combined with

12 units of Flytrex combined with,

2 units of Project Wing combined with

up to 2 units of either Amazon PrimeAir, Zipline or DHL Parcelcopter.

This scenario does not consider the price while completing the distribution center. The following examples are aiming so.

Since linear programming is meant to find a decision that provides the best result, the optimum solution can be found by applying the minimization algorithm[109]. For instance, if more decision variables as, e.g. the information about the price (variable P) of UAVs was available, a mathematical model to describe the problem for the scenario would look like as follows:

Minimize Z = 12P1+X2P2+5P3+2P4+X5P5+X6P6

subject to X2+X5+X6=2

X2 ≤2

X5 ≤2

X6 ≤2

Flytrex	X1
Amazon PrimeAir	X2
Flirtey	X3
Project Wing	X4
Zipline	X5
DHL Parcelcopter	X6

The earlier stated assumptions are taken as linear constraints as well as the number of customers which is the maximum number of required UAVs since the delivery to the points is simultaneous.

This shows that assumption 3 places too strict limits on the number of UAVs, and can possibly devalidate the outcomes, therefore, if the assumption 3 is neglected but decision variables (X – number of UAVs, P – price) remain the same, the objective function will look like as follows:

109 Anderson, D.R., Sweeney, D.J. and T.A. Williams, 2000. An introduction to Management Science, Quantitative Approaches to Decision Making, ninth edition, South-Western College Publishing.

Minimize $Z = X1P1+X2P2+X3P3+X4P4+X5P5+X6P6$

subject to $X1+X2+X3+X4+X5+X6=21$

$X1 \leq 17$

$X2 \leq 21$

$X3 \leq 5$

$X4 \leq 19$

$X5 \leq 21$

$X6 \leq 21$

If the price information is available, the model will help to optimize the total cost of UAVs needed to purchase in order to allow the distribution center to carry out simultaneous delivery to 21 points.

The method where one UAV is shipping an item to only one customer overcame the main constraints –being loading capacity of currently only one item- and can be considered fairly feasible. As is shown in appendix I, this requires a relatively short time period for delivery demonstrating clear advantages compared with classical trucking delivery (discussed in 4.4.2). In an attempt to make the model as realistic as possible, a simulation of how the distribution center must be equipped was conducted and, to do so, several assumptions were made. Finally a mathematical model was proposed aiming not only to calculate but mainly minimize the cost depending on decision variables. Since the information about the UAVs price remains commercial secrecy, there is no option to solve the minimization problem, nevertheless, it is a good example of the way how a supply chain with vehicle routing with UAVs can be organized.

5. Conclusion and future perspectives

5.1 Conclusion

While legislation sees UAVs the same old way as they were many years ago, the modern UAV is not just a toy anymore but a powerful tool by means of which tasks can be performed that had earlier not been possible. Within a relatively short period, scientists "taught" them to cross long distances up to 100 km, fly with the speed of an average car, take off and land gently as a dragonfly or fast and efficient as a rocket-man. All these diverse features allow modern UAVs already today to be put in service of the good and this work demonstrates the exact way of how with the help of UAVs the system of medical supply can be improved in order to overcome the growing mobility issue. Traffic jams are not a big deal if we are talking about a pizza with double pepperoni but when it comes to lifesaving materials, it can lead not only to financial costs due to the wastage, but also be a matter of life and death.

Despite this potentially life-saving opportunity, the current legislation resembles a list of rules explaining how delivery with UAVs can be prohibited, beginning with a clear statement that transporting mails or freights is one of those activities that "ne peuvent pas être effectuées avec un drone" according to FPS Mobility and Transport. Moreover, the new data protection law is -although not really concerned about the activities with UAVs- still hovering like the proverbial sword of Damocles over them.

Against this pessimistic background, however, drone clusters and test sites promoting drones have been emerging over the last years. This can be explained by the fact the EU is developing legal documents that are going to directly cover and maybe facilitate the use of UAVs. The first implementing acts have entered into force in June 2019 and there is only one year for the UAV operators and EU member states to discuss and actualize the national regulation. Belgian Drone Port has been chosen to be a center where the EU legislation is going to be coordinated. It all, therefore, means that the future is a matter of today already.

Increasing the fundamental knowledge about UAVs is vital for being able to test whether the socio-economic and ethical concerns the society has towards the use of UAVs are justified and to correctly respond to them. This thesis showed that for most of the issues raised in this regard, there is a feature or solution the technology proposes as a decent answer. The solution proposed by Flytrex, for instance, finds a perfect answer to the privacy concern. These UAVs carry no cameras at all and instead use only GPS and sensors for navigation. Answers for some classical questions as the effect on employment cannot be provided through technological advancement, but may be found in discussions based on one of the philosophical frameworks proposed in the work. The utilitarian theory for instance proposes that each stakeholder should choose the action that is the most beneficial for the whole group even though it is less beneficial for the individual. Practically, it means that even though a truck driver can suffer from replacement of trucks by drones, he also has to consider all the benefits that the use of UAVs can bring to the society as a whole. Such benefits can include reducing greenhouse gas emissions, contributing to solving the mobility issue, fast and fragile delivery of lifesaving supply as well as creating other drone related job sectors. Moreover, considering emerging UAVs as an innovation or a change allows to apply one of the change management tools in order to correctly and more efficient communicate the change with other stakeholders.

Having a deep understanding about the state of the art of UAVs also allows to analyze supply chain operational performances using vehicle routing with UAVs and to test hypotheses on their applicability in the city logistics. This work compared the operational performance of UAVs and traditional trucks in a case study on medical urgency supply from a distribution center to 21 hospitals in the Brussels-Capital Region. The work revealed a significant reduction of the distance and, therefore, the time the UAV needs to reach all assigned delivery points by minimally 78.82% and maximally 91.46% compared to trucks. Finally, a model using only one UAV for one customer was developed. Since there is no more need to make an assumption about the payload capacities, this approach helped to overcome the constraints questioning feasibility of the former strategy. .Here, the UAVs flying ranges were analyzed and taken as a basis to define the types and quantities of UAVs distribution center should have. It is well known that people prefer following money rather than theoretical specifications, therefore, the next step was to formulate an optimization problem aiming to minimize the total cost for purchasing UAVs in order to equip the distribution center.

Overall, the review of the state-of-the-art, socio-economic and ethical considerations and analysis of supply chain operational performances provided in this work are meant to fuel the ongoing public and political debate, and hopefully will facilitate future implementation of UAVs.

5.2 Future perspectives

Consulting literature about the models it was relatively difficult to find relevant specifications. While certain manufacturers posted all the information about their product on the website, many, however, unveiled only marketing communications. A good example of this could be the new generation drone of Amazon for which a lot of pictures and videos are available, but no concrete specifications.

In many cases, video interviews with technical specialist helped in this regard but never to find an average cost of a drone. This was the reason why some aspects of this works had to be adapted to the available information, e.g. the optimization problem aiming to minimize the total cost of purchase is formulated and proposed to use when decision variables are known. The access to information is especially important since the technological progress in the area is very rapid and applications that are impossible today, might get implemented tomorrow.

There is always room for improvement by making the models more complex. So far, only one distribution center was considered, but on the other hand, more centers can be built. Zipline for example proposed a potential application of having two distribution centers within range from each other. If one of them runs out of demanded supply on its side of the country, a UAV could be loaded from the other base, fly over, land, have its battery replaced, and launched again to fly to its final delivery point[110]. Moreover, each delivery point can be used as a distribution center for different product groups.

[110] Denby, S. [Wendover Productions]. (2019, July 26). The Super-Fast Logistics of Delivering Blood by Drone [Video file]. Retrieved from https://youtu.be/bnoUBfLxZz0

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8. Appendixes

Appendix I: Time required for a UAV to make a round trip for each model

UAVs	Time required for a UAV to make a rond trip delivery / Customer name (number)																					
	1	2	3	4	5	6	7	8	9	10	11	12	DC	14	15	16	17	18	19	20	21	22
Flytrex			21.10	16.68	15.23	17.21	6.54	5.96	8.36	12.99		9.52		15.56	9.52	17.13	12.08	11.79		12.79	13.74	19.16
Amazon PrimeAir	11.40	8.60	7.65	6.05	5.52	6.24	2.37	2.16	3.03	4.71	10.88	3.45		5.64	3.45	6.21	4.38	4.28	10.13	4.64	4.98	6.95
Flirtey							9.48	8.64	12.12			13.80			13.80							
Project Wing		5.73	5.10	4.03	3.68	4.16	1.58	1.44	2.02	3.14		2.30		3.76	2.30	4.14	2.92	2.85	6.75	3.09	3.32	4.63
Zipline	9.12	6.88	6.12	4.84	4.42	4.99	1.90	1.73	2.42	3.77	8.70	2.76		4.51	2.76	4.97	3.50	3.42	8.10	3.71	3.98	5.56
DHL Parcelcopter	7.02	5.29	4.71	3.72	3.40	3.84	1.46	1.33	1.86	2.90	6.69	2.12		3.47	2.12	3.82	2.70	2.63	6.23	2.85	3.06	4.27

Appendix II: OptimoRoute's output for 21 delivery points

Date	**17.07.2019**
Driver	**Driver 001**
Vehicle	**Vehicle 001 (001)**

Stop Number	Order ID	Order Type	Location ID	Location	Address
-		-		Depot	Cellebroersstraat 13, 1000 Brussel, Belgium
1	13	Task	13	CHU Saint-Pierre - Site César De Paepe	Cellebroersstraat 13, 1000 Brussel, Belgium
2	12	Task	12	Clinic Sainte-Anne Saint-Rémi	Jules Graindorlaan 66, 1070 Anderlecht, Belgium
3	16	Task	16	Hospital Joseph Bracops	Dokter Huetstraat 79, 1070 Anderlecht, Belgium
4	19	Task	19	Hospital Erasme	Bibliothèque des Sciences de la Santé, Route de Lennik 808, 1070 Anderlecht, Belgium
5	20	Task	20	Hospital Molière Longchamp	Marconistraat 142, 1190 Vorst, Belgium
6	21	Task	21	Edith Cavell Medical Centre	Rue Général Lotz 37, 1180 Uccle, Belgium
7	18	Task	18	Hospital Etterbeek-Ixelles	Jean Paquotstraat 63, 1050 Elsene, Belgium
8	22	Task	22	Hospital Delta	Triomflaan 201, 1160 Oudergem, Belgium
9	17	Task	17	Hospital Iris Sud - Baron Lambert	Baron Lambertstraat 38, 1040 Etterbeek, Belgium
10	15	Task	15	Leopold Park Clinic	Rue Froissart 38, 1040 Etterbeek, Belgium
11	14	Task	14	Europe Hospital - St-Michel Site	Linthoutstraat 150, 1040 Etterbeek, Belgium
12	11	Task	11	University Clinic Saint-Luc	Hippokrateslaan 10, 1200 Sint-Lambrechts-Woluwe, Belgium
13	10	Task	10	Jean Titeca Hospital	Luzernestraat 11, 1030 Schaarbeek, Belgium
14	6	Task	6	CHU Brugmann - site Paul Brien	Schaarbeekse Haardstraat 36, 1030 Schaarbeek, Belgium
15	1	Delivery	1	Queen Astrid Military Hospital	Bruynstraat 1, 1120 Brussel, Belgium
16	2	Delivery	2	UZ Brussel	VUB - Vrije Universiteit Brussel Jette Bldg R, Laarbeeklaan 101, 1090 Jette, Belgium
17	3	Delivery	3	CHU Brugmann	A.Van Gehuchtenplein 4, 1020 Brussel, Belgium

18	5	Task	5	Basilique Clinic	Pangaertstraat, 1083 Brussel, Belgium
19	4	Task		Hospital Center Valida	Josse Goffinlaan 180, 1082 Sint-Agatha-Berchem, Belgium
20	7	Task	7	Polyclinic Du Lothier	Boudewijnlaan 27, 1000 Brussel, Belgium
21	8	Task	8	Clinic Saint Jean	Kruidtuinlaan 32, 1000 Brussel, Belgium
22	9	Delivery	9	Hospital Sanatia	Molenstraat 27, 1210 Sint-Joost-ten-Node, Belgium
-		-		Depot	Cellebroersstraat 13, 1000 Brussel, Belgium
View route on the map - 25 stops per link (copy-paste the links to your browser)					
https://www.google.com/maps/dir/50.84331,4.349803/50.84331,4.349803/50.84515,4.317213/50.83333,4.292844/50.81324,4.268429/50.81576,4.341704/50.81393,4.357884/50.82519,4.378763/50.81602,4.39993/50.83496,4.389228/50.83889,4.381748/50.84323,4.40013/50.85515,4.447174/50.85444,4.391912/50.87127,4.386658/50.90731,4.392292/50.88816,4.308737/50.88631,4.332828/50.86841,4.318026/50.86701,4.306336/50.85725,4.352792/50.8544,4.360381/50.85582,4.369806/50.84331,4.349803					

Appendix III: OptimoRoute's output for the North

Date	**17.07.2019**
Driver	**Driver 001**
Vehicle	**Vehicle 001 (001)**

Stop Number	Order ID	Order Type	Location ID	Location Description	Address
-		-		Depot	Cellebroersstraat 13, 1000 Brussel, Belgium
1	8	Task	8	Clinic Saint Jean	Kruidtuinlaan 32, 1000 Brussel, Belgium
2	9	Task	9	Hospital Sanatia	Molenstraat 27, 1210 Sint-Joost-ten-Node, Belgium
3	10	Task	10	Jean Titeca Hospital	Luzernestraat 11, 1030 Schaarbeek, Belgium
4	6	Task	6	CHU Brugmann - site Paul Brien	Schaarbeekse Haardstraat 36, 1030 Schaarbeek, Belgium
5	1	Task	1	Queen Astrid Military Hospital	Bruynstraat 1, 1120 Brussel, Belgium
6	2	Task	2	UZ Brussel	VUB - Vrije Universiteit Brussel Jette Bldg R, Laarbeeklaan 101, 1090 Jette, Belgium
7	3	Task	3	CHU Brugmann	A.Van Gehuchtenplein 4, 1020 Brussel, Belgium
8	5	Task	5	Basilique Clinic	Pangaertstraat, 1083 Brussel, Belgium
9	4	Task		Hospital Center Valida	Josse Goffinlaan 180, 1082 Sint-Agatha-Berchem, Belgium
10	7	Task	7	Polyclinic Du Lothier	Boudewijnlaan 27, 1000 Brussel, Belgium
-		-		Depot	Cellebroersstraat 13, 1000 Brussel, Belgium

View route on the map - 25 stops per link (copy-paste the links to your browser)
https://www.google.com/maps/dir/50.84331,4.349803/50.8544,4.360381/50.85582,4.369806/50.85444,4.391912/50.87127,4.386658/50.90731,4.392292/50.88816,4.308737/50.88631,4.332828/50.86841,4.318026/50.86701,4.306336/50.85725,4.352792/50.84331,4.349803

Appendix IV: OptimoRoute's output for the East

Date	**18.07.2019**
Driver	**Driver 001**
Vehicle	**Vehicle 001 (001)**

Stop Number	Order ID	Order Type	Location ID	Location	Address
-		-		Depot	Cellebroersstraat 13, 1000 Brussel, Belgium
1	10	Task	10	Jean Titeca Hospital	Luzernestraat 11, 1030 Schaarbeek, Belgium
2	14	Task	14	Europe Hospital - St-Michel Site	Linthoutstraat 150, 1040 Etterbeek, Belgium
3	11	Task	11	University Clinic Saint-Luc	Hippokrateslaan 10, 1200 Sint-Lambrechts-Woluwe, Belgium
4	22	Task	22	Hospital Delta	Triomflaan 201, 1160 Oudergem, Belgium
5	18	Task	18	Hospital Etterbeek-Ixelles	Jean Paquotstraat 63, 1050 Elsene, Belgium
6	17	Task	17	Hospital Iris Sud - Baron Lambert	Baron Lambertstraat 38, 1040 Etterbeek, Belgium
7	15	Task	15	Leopold Park Clinic	Rue Froissart 38, 1040 Etterbeek, Belgium
-		-		Depot	Cellebroersstraat 13, 1000 Brussel, Belgium

View route on the map - 25 stops per link (copy-paste the links to your browser)
https://www.google.com/maps/dir/50.84331,4.349803/50.85444,4.391912/50.84323,4.40013/50.85515,4.447174/50.81602,4.39993/50.82519,4.378763/50.83496,4.389228/50.83889,4.381748/50.84331,4.349803

Appendix V: OptimoRoute's output for the South

Date	**19.07.2019**
Driver	**Driver 001**
Vehicle	**Vehicle 001 (001)**

Stop Number	Order ID	Order Type	Location ID	Location	Address
-		-		Depot	Cellebroersstraat 13, 1000 Brussel, Belgium
1	21	Task	21	Edith Cavell Medical Centre	Rue Général Lotz 37, 1180 Uccle, Belgium
2	20	Task	20	Hospital Molière Longchamp	Marconistraat 142, 1190 Vorst, Belgium
3	19	Task	19	Hospital Erasme	Bibliothèque des Sciences de la Santé, Route de Lennik 808, 1070 Anderlecht, Belgium
4	16	Task	16	Hospital Joseph Bracops	Dokter Huetstraat 79, 1070 Anderlecht, Belgium
5	12	Task	12	Clinic Sainte-Anne Saint-Rémi	Jules Graindorlaan 66, 1070 Anderlecht, Belgium
-		-		Depot	Cellebroersstraat 13, 1000 Brussel, Belgium

View route on the map - 25 stops per link (copy-paste the links to your browser)
https://www.google.com/maps/dir/50.84331,4.349803/50.81393,4.357884/50.81576,4.341704/50.81324,4.268429/50.83333,4.292844/50.84515,4.317213/50.84331,4.349803

Executive summary

Mobility is an important problem today and on-road transport has reached its limit. According to the Brussels Chamber of Commerce, traffic jams cost around €511 million annually in the Brussels-Capital Region only, but when it comes to medical supply, each minute can be a matter of life and death. Meanwhile there are companies that have already successfully set up delivery systems with unmanned aerial vehicles. In Brussels and the majority of other cities in the world, the free airspace, however, remains unused and the main reason for this is the current repressive legislation caused by lack of understanding of the modern UAVs and their operational performances.

Significant headway has been made by the EU. Specifically, in June 2019 the delegated Act defining the technical requirements for UAVs operated in EU went into force and since no objections were raised, it became the start of a one-year transitional period in which drone operators and EU member states should define their future legislation. There are several socio-economic and ethical concerns that fuel the negative image of UAVs among the public and policy makers and that are directly influencing the way the legislation looks like. In addition, the lack of quantitative data on the operational performances of UAVs in specific cases is hindering a rational discussion balancing benefits versus disadvantages. To make an inclusive discussion possible, communication systems to the broad auditory should be set up, both to communicate information on the operational performances of UAVs as well as to nuance the socio-economic and ethical concerns. Only so UAVs potential application that can benefit all the society.

This work first reviews the state-of-the art of drone specifications and possible operational procedures and requirements in order to provide a solid knowledge basis. Then potential socio-economic and ethical concerns are identified and nuanced in the light of the current technological advances. Philosophical and managerial frameworks are discussed that allow to integrate seemingly opposing interests during the debate. Finally, the main body of this work makes a comparison between supply chain operational performances with vehicle routing using UAVs and traditional trucks, based on a case study of medical urgency supply to hospitals in the Brussels-Capital Region. A simulation is run to determine the quantity and types of UAVs the distribution center should have, and an optimization problem is formulated aiming to minimize the total cost for purchasing UAVs in order to equip the distribution center. This example showcases a possible application UAVs in city logistics, and it is importance in solving the mobility issues that modern cities inevitably have.