An evaluation of the potential to use drone deliveries as last-mile logistics within Jämtland, focusing on environmental benefits

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Abstract

Drones or UAV's are claimed by many companies (Google, Amazon, DHL) in the logistic sector to be a great technology for last-mile delivery, which is faced with high costs. Delivery drones promise to be cost reducing, fast and eco-friendly. There is a vast amount of research going into planning and economics of delivery drones for the logistic sector. The research on the environmental impact is limited and outcomes are highly dependent on the limitations of the study. Therefore, it is hard to analyse in which situations delivery drones can contribute to the society by lowering the environmental impact of the logistic sector, while following current trends of faster deliveries.

The purpose of this thesis is to investigate the potential of delivery drones to contribute to the logistic network (specifically the last-mile), while reducing the environmental impact, in the region of Jämtland, Sweden. This is done by making a current technological overview of delivery drones. Using this summary, it is possible to estimate the possibilities of the technology itself. Best practises are gathered and analysed since it is valuable to learn from the previous experiences. The environmental impact of drone delivery is analysed because the main reason to use drones in Jämtland, should be to reduce the overall environmental impact of the logistic sector. This is combined with the legislation and challenges drones face nowadays. Hereby it is possible to determine when drone delivery could reduce the environmental impact of the last-mile logistics.

The main findings are: the ideal case is a single light package or payload that needs to be transported, without the possibility for other packages to be delivered on the same route. Once package deliveries can be grouped in an efficient route, there are better technologies on the market nowadays. These are further developed and have a lower impact on the environment. Even if drones can be used in a way that benefits the environment and is cost-efficient, they still face challenges. More testing and scientific research is needed to prove drone delivery can be done in a safe manner, that benefits the environment while being cost-effective.

Keywords: Last-mile logistics; Drone/UAV delivery

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Table of contents

List of figures vi
List of tables vii
Abbreviations and acronyms viii
1. Introduction 1
1.1 Aim of the thesis 2
1.2 Literature review 2
1.2.1 Logistics in Sweden (Jämtland) current state 2
1.2.2 Environmental impact 6
2. Method (theory) 12
2.1 Jämtland 12
2.2 Limitations of the study 12
2.3 Method for technology overview 13
2.4 Method for best practises 15
3. Results 17
3.1 Technology: capability of drones 17
3.1.1 Payload capacity 20
3.1.2 Range 20
3.1.3 Cruising speed 20
3.1.4 Excluded variables 21
3.1.5 Type of drone 21
3.1.6 Maximum Take Off Weight 22
3.2 Best cases: general overview 22
3.2.1 Results of analysis 22
3.3 Environmental impact on Jämtland 27
3.4 Legislation 28
3.5 Challenges 30
4. Possibilities in Jämtland and discussion 32
5. Conclusion 37
References 38
Appendixes 41
Appendix 1: Best practises 41
Appendix 2: Countries of implementation 60

List of figures

Figure 1: Geographic location of Jämtland, Sweden 12
Figure 2: Theoretical serviceable range for (small) urban drones and (large) inter-city drones with the longest range 32
Figure 3: Potential serviceable range for the Wingcopter depending on the weight 34

List of tables

Table 1: Willingness to pay for same-day delivery 4
Table 2: Distance to nearest parcel representative (Konkurrensverket, 2016) 5
Table 3: Boundaries of the considered articles 7
Table 4: Companies and their mission or goal 13
Table 5: Drone technologies data collected 18
Table 6: Grouping of drones 19
Table 7: Overview companies and their main service 23
Table 8: Range Wingcopter 33

Abbreviations and acronyms

UAV – Unmanned Aerial Vehicle

VTOL – Vertical take-off and landing

EV- Electric vehicle

DV – Diesel vehicle

eGRID – Emissions & Generation Resource Integrated Database

BVLOS - Beyond Visual Line of Sight

1. Introduction

UAVs or drones are a technology that has been used for a long period of time. According to Giones & Brem (2017), the first mentioning of a drone was in the early 1900s when they were introduced by the military for practise. These drones evolved to other uses within the military such as surveillance and later on even bombing. Due to other developments of technologies, drones became popular with the general public and are currently even experiencing a boom. A drone or UAV is an Unmanned Aerial Vehicle. This means there is no actual pilot on board. It is piloted remotely or it flies autonomous. One of the main contributors to the evolution of drones in the past years is the technological progress, such as high-performing video cameras, but also "more intelligent" systems such as collision avoidance. In a short period of time, the number of applications and the industry market has grown exponentially. Around 2010, drones with cameras became popular for private people. By 2014 drones became more developed and customized. So, they were able to provide better video data and flight characteristics. Therefore, drones became interesting for the industry and commercial applications. In 2017 most revenue (60-70%) in the drone industry came from recreational use, photography, and media applications. But this is expected to be only a small part of the drone industry by 2025. Analysists predicted the near future of drones will be in infrastructure inspections, agriculture, transport, and security. This is already an important part of the drone industry nowadays. The next step where logistics companies and the drone industry are working towards, is drone delivery.

Companies (such as Google, DHL and Amazon (Kirschstein, 2020)) claim that drones have a big potential in the logistic sector. Mostly, this would be in the last-mile delivery, which has one of the highest costs of the delivery sector. Last-mile delivery is not literally the last mile, but it is the last step in a logistic network which ends at the customers home. So, from the depot or shop to the customers home. Logistic companies state that drone transportation of goods is cost reducing, fast and eco-friendly. Because of the potential of drones, technological research is investigating delivery drones in different aspects. There is research going into among others planning, economics, SWOT-analysis and the public's opinion (Kellermann, Biehle, & Fischer, 2020). However, the research on the environmental impact of the usage of drones is limited and outcomes are highly dependent on what was investigated in that particular study (Kellermann, Biehle, & Fischer, 2020). Next to the limited

environmental research, it is complicated to analyse in which situation delivery by drone can contribute to the society without having an additional burden on the environment. More research is needed on this topic and more practises performed by companies. This is where this thesis comes into place.

1.1 Aim of the thesis

The purpose of this thesis is to investigate the potential of delivery drones to contribute to the logistic network (specifically the last mile) while reducing the environmental impact, in the region of Jämtland, Sweden. To estimate what would be possible, it is necessary to have an overview of the current technological state of drones. An analysis of the current best practises is valuable in order to learn from previous experiences. Currently, there are multiple delivery drone projects and even commercial activities in practise all over the world. The environmental impact of delivery drones is analysed because the main purpose in the eyes of this thesis to apply delivery drones in Jämtland, is to reduce the environmental impact of the logistic sector. The technological overview, together with the best practises and the environmental impact combined with knowledge of current logistics system and legislation, makes it possible to propose future cases in which drone delivery or transport might contribute to the society of Jämtland by limiting the environmental impact while still following trends for faster delivery. These potential uses or cases could be further analysed in future studies.

1.2 Literature review

1.2.1 Logistics in Sweden (Jämtland) current state

As many countries in the world, Sweden is moving towards a society were more items are ordered online. Ordering online, results in the need for more commercial last-mile deliveries, instead of personal vehicle transportation needed for shopping. Items that are ordered, need to be delivered to the customers home or to a parcel representative. The retail apocalypse in rural, sparsely populated areas, occurs partly because of online shopping. This in turn results in less potential parcel representatives. Next to more online shopping, the number of inhabitants in rural regions has been declining over time, which results in less customers (Konkurrensverket, 2016). Between 2006 and 2016, E-commerce (definition: The sale of goods on the internet that is delivered to a home, to a delivery point or picked up by a consumer in a store, warehouse or parcel

representative (Trafikanalys, 2017)) in Sweden has almost four-doubled (+261%). In 2016 the turnover was close to 58 000 M SEK and by 2019 E-commerce has grown till 95 000 M SEK (Postnord, 2019). E-commerce represented 8% of the total retail in 2016 which was three times as much as 10 years before. It is a fast-growing business which could use solutions to surpass (upcoming) challenges for delivery to the customer (Trafikanalys, 2017).

Online food sales are a booming business. In 2016 there was an expected growth of 40% which would mean a turnover of about 5700 M SEK. Further fast growth is expected (Young, 2014). This type of online shopping is mostly growing in the bigger cities, and the metropolitan areas. This is due to easier home delivery then in rural areas and a larger population density. This means more customers for these relatively new businesses. A relatively new business sector is companies that make packages for meals and/or groceries for home deliveries. These enterprises commonly do not have a physical store (mat.se, Mathem, Middagsfrid…) (Konkurrensverket, 2016).

The Digital Mathandel Rapport (2015) had the following findings: 62% of the people ordering food online, want home delivery. A relatively large proportion of people in Sweden cannot buy food online, because there is no possible delivery to their home. 30% of the people living in small towns would buy online if they could have home delivery.

There is quite some potential for improving the delivery in the food delivery market because there are logistic challenges such as shipping costs and difficulties with economy of scale and financing the deliveries. Distribution of food is a challenge because of distances and because of time-limits. Some products need to be refrigerated/frozen, other products need to be delivered within a certain time to keep them warm in case the food is prepared… (Konkurrensverket, 2016). Suppliers of online food can find it difficult to cover their costs for picking and delivering. Many people expect it to be cheaper to order online, but in reality, it is a service that has a cost, especially when delivered to a customer's home. In traditional food logistics, volume is critical to be efficient and profitable (Trafikanalys, 2017).

According to a study from Yougov (2019), the willingness to pay for same-day delivery differs between age-groups. Only 21% of young people is not willing to pay for this service, while 57% of the age-group 60+, is not willing to pay for this. Overall, about 40% of the Swedish citizens are not willing to pay for same-day delivery. This of course means that about 60% of the Swedish citizens are willing to pay for same-day delivery.

When asked the question how much one would be willing to pay for same-day delivery, the results can be found in Table 1: Willingness to pay for same-day delivery.

Table 1: Willingness to pay for same-day delivery

< 25 SEK	11%
25-50 SEK	16%
51-100 SEK	12%
101-150 SEK	6%
151-200 SEK	3%
201-250 SEK	2%
>250 SEK	1%

There are some challenges and potential possibilities in the package delivery sector. Most focus is upon business to consumer (B2C) logistics, so the packages from a business get delivered to a consumer. There are big differences between the companies executing the delivery, especially in size (amount of deliveries) and where they serve customers. In Sweden, Postnord is the main mail company (Konkurrensverket, 2016). The traditional market is shifting from letters and/or newspapers to parcel deliveries because of certain business trends (Dieke, et al., 2013) . In Sweden, there are 5 national players for delivery of packages. These are Postnord, Bring, Schenker, DHL and Jetpak (Konkurrensverket, 2016).

There are big differences in the amount of online orders in different parts of Sweden. The number of packages from E-commerce to an average household during one year varies from around 6 (Stockholm, Göteborg, Malmö) to 12 packages (Storuman). Rural communities in the north have the highest number of E-purchases per household per year (Trafikanalys, 2017).

The cost of delivery is often directly payed for by the customer but not always. This depends on the store and the company responsible for delivery. If delivery is not payed for directly by the customer, it is payed for indirectly by the customer, since it is included in the prices of the products. It is an agreement between the e-retailer and the customer. It is more costly to organise delivery in sparsely populated areas, because of the longer distances and low order volumes (Konkurrensverket, 2016). E-commerce transport is heavily priced, but free shipping makes the cost of transport invisible and thus hard for a customer to value. There is a high pressure on the delivery companies, which results in a focus on price rather than quality (Trafikanalys, 2017).

37% of the packages in Sweden are sent to a delivery point, followed by mailbox deliveries with 29% and then parcel receipts at home with approximately 15% (Trafikanalys, 2017). So, it is most common to have deliveries to a delivery point or parcel representative, and not always to the door. As can be seen in Table 2: Distance to nearest parcel representative , 48% of the Swedes has the nearest package collection point at 1 km or less by road. For 89%, the distance is up to 5 km and only 4% has a distance larger than 10 km by road to the nearest collection point from their home. In Jämtland however, 42% has a package collection point at less than 1 km, 76% at less than 5 km and 11% of the inhabitants have a distance larger than 10 km to the nearest pick up station (Konkurrensverket, 2016).

Table 2: Distance to nearest parcel representative (Konkurrensverket, 2016)

	Sweden	**Jämtland**
<1 km	48%	42%
<5 km	89%	76%
>10 km	4%	11%

Last-mile delivery is the most expensive and most difficult to fulfil. Postnord has the largest existing network because they distribute mail to the whole country. So, they are better prepared to deliver individual parcels then new companies. Swedes are quite used to having deliveries from Postnord, which can take three days. For new players it is hard to enter the market with faster deliveries, because this is not really expected (Konkurrensverket, 2016). However according to Postnord's E-barometer (2016), about 29% of the customers would like to have an ordered item through e-commerce delivered on the next weekday and demands for faster deliveries are increasing, especially among young people. Delivery on the same day or even within the hour is starting to become a phenomenon in Sweden, mainly in the big cities.

The national official statistics on the parcel market for delivery from B2C are not extensive, mainly because not all delivery companies share their data. It is currently not possible to make good estimates of the market. Most calculations and percentages are based upon statistics from mainly Postnord (E-barometern) (Konkurrensverket, 2016). There are few Swedish studies measuring the amount of transport and/or the environmental impact of transport in E-commerce (Trafikanalys, 2017).

1.2.2 Environmental impact

There are studies looking into costs and time savings and how the actual planning could be done, such as Ulmer & Thomas (2018) which analysed how to combine drones with regular delivery vehicles to improve same-day delivery performance; Dorling et al. (2017) looked upon routing problems for drone delivery; Boysen et al. (2018) analysed drone scheduling for given truck routes; … According to Kellerman et al. (2020), which made a literature review upon drones for parcel and passenger transport, most studies focus upon the economic benefits (49,3%) and the private sector & macroeconomic effect of technology introduction. Only 20,2% focused on benefits that can be anticipated for the (urban) population and 11,3% focused upon the environmental impact.

There are two main differences in the literature, some articles look at stationary systems and others investigate dynamic systems. In a stationary system, there is a UAV hub that works as a depot for UAV delivery trips to start and end. Dynamic systems use mobile hubs, such as delivery trucks, as a depot for the UAV. All studies have differences in their results depending on what they considered. It is important to outline the factors considered for each study. The studies can be found in Table 3: Boundaries of the considered articles, which explains the type of study, the functional unit considered and the boundaries or limitations. The most important results are summarized in this chapter. These studies will be further analysed upon the situation of Jämtland in chapter 3.3.

Table 3: Boundaries of the considered articles

Article	Type of study	Functional unit	Boundaries of study
Chiang et al., 2019	Impact of vehicle routing optimization with drones	Delivery system with X customers	- UAV: serviceable range of 16 km; payload capacity 2,26 kg; One delivery at a time - Dynamic system, drone in combination with van delivery (simultaneous) - Weighted average emission rate of vehicles 0,7831 kg/km; CO_2 emissions at power generation is 3,773 x 10^{-4}; average energy requirement of UAV is 2,0712 Wh/km - Urban
Figliozzi, 2017	Comparative LCA (energy use and CO_2 emissions)	One package delivered	- UAV: serviceable range of 25 km; payload of 5 kg (21,6 Wh/km); One delivery at a time - Compared to diesel vans (Ram ProMaster 2500 – 1016 Wh/km), electric truck (760 Wh/km), electric vans (205 Wh/km) and tricycles (30,24 Wh/km) - Energy used in transportation considered + emissions for production electricity/fuel + production vehicle/drone - One-to-one: one package to one customer - One-to-many considered that one vehicle can carry more packages then the other; several customers grouped in one tour for road vehicles - Energy use related to CO_2 by GREET and eGRID databases - Urban
Goodchild & Toy, 2018	Comparison primary energy & CO_2 emissions	One delivery tour	- UAV: no specific model but energy use instead (6,21 Wh/km – 62,14 Wh/km); One delivery at a time - Compared to diesel van (Medium heavy Fedex express step vans) - 50 recipients per zone up till 500 (330 zones) - Average distances travelled per package were 16,38 km for the drone and 0,26 km for the diesel van. - Vans use road network – drones fly in straight line - Energy used in transportation considered + emissions for production electricity/fuel - Urban (Los Angeles)
Kirschstein, 2020	Comparison primary energy & CO_2 emissions	One delivery tour	- UAV: serviceable range of 9 km; 5 min of hovering/delivery; One delivery at a time

			- Delivery tour van off: 100-200 customers; 50-150 km - Numbers of customers/stop: 1,1-2 - Radius of delivery tour (circle with depot in middle): 2-8 km - Wind considered - Compared to diesel truck and electric truck, no combination of technologies - Urban (Berlin) - Energy used in transportation considered + emissions for production electricity/fuel
Koiwanit, 2018	LCA (11 impact categories)	One package delivered / km	- UAV: 30 min flight time; 5 kg payload; One delivery at a time - LCA: cradle-to-gate or from mining till drone use phase - Data from Thailand - Lifespan drone 5000 h/ 250 000 km - Li-ion battery only
Park et al., 2018	LCA (CO_2 and PM2.5)	A single pizza delivery	- UAV: 45 min flight time; average speed of 12 m/s; serviceable range of about 15 km; One delivery at a time - Compared to motorcycle and electric motorcycle - Urban (26463,6 inhabitants/km²) and rural (27,6 inhabitants/km²) - Energy used in transportation considered + emissions for production electricity/fuel
Stolaroff et al., 2018	Comparison primary energy & CO_2 emissions	One package delivered	- UAV: serviceable range of 4 km; payload capacity 4,5 kg; One delivery at a time - Compared to diesel truck (Class 4; 6350-7257 kg) delivering 0.94 packages/km tour is 160 km - Energy used in transportation considered + emissions for production electricity in US + emissions by upstream battery manufacturing + additional urban warehouses - Urban

An article by Chiang et al. (2019) investigated the sustainability of drones in a dynamic system. According to their computational results, there is a strong support for the notion that using UAVs (in tandem) for last-mile logistics is not only cost-effective, but also environmentally friendly. Their investigation shows that shifting smaller package delivery from trucks to drones would result in savings of the overall energy used. If adequately deployed, UAV delivery would cut down energy use and CO_2 emissions. There is an average emissions reduction possible by over 20% even without a reduction in the number of vehicles. However, they state that the current technology of battery-powered delivery UAVs limits the range and payload capacity so further research is needed to alternative power sources.

Figliozzi (2017) made a lifecycle modelling and assessment of unmanned aerial vehicles CO_2 emissions. The results for one-to-one routes show that UAV's are 47 times more efficient in energy use than a delivery van. Additionally, the energy consumed by the drone is 22 times cleaner than energy consumed by the van, so the UAVs CO_2 emissions per unit of distance is in total 1056 times lower than the diesel van. In the one-to-many scenario (explained in table), it is considered that a van can carry up to 378 more cargo, then the van gets more energy efficient (up to 8 times better) but the GHG emissions for UAVs remain lower (about 2,8 times). Furthermore, if an electric van is used and there is a possibility to group at least 10 customers on 1 route, drones are less efficient. An electric tricycle is likely to be more CO_2 efficient than an UAV, but can only be used in areas where a tricycle is economically feasible such as dense urban areas. UAVs can fill in a niche and substantially lower the energy use and emission per service when the payload is relatively small. If multiple consumers can be grouped there are other, more efficient technologies. The researches see potential in other drone types such as fixed wing and VTOL models since they would considerably lower the energy demand.

Goodchild and Toy (2018) made one of the first studies looking into reducing CO_2 emissions in the delivery service industry by using UAV technology. They calculated the maximum of energy a drone can use to emit less CO_2 than a delivery truck, for each distance and the number of stops considered. Out of this, some conclusions can be made. In broad terms for the considered boundaries, drones with an average energy use of 25Wh/km or lower will have a net positive impact but drones with an average energy use of 50 Wh/km or higher will not. They found that drones tend to have lower CO_2 emissions than truck in service zones that are either closer to the depot or have a smaller number of recipients or both. If CO_2 emissions are a weighing factor, there is a

plausible market in these closer service zones or the zones with smaller numbers or recipients. In the zones that are far away and have a high number of recipients the delivery trucks have lower CO_2 emissions then UAVs. Their results suggest that, within an environmental framework, a blended system, combining both technologies would perform best, or in other words emit the least CO_2.

A study by Kirschstein (2020), investigated the energy use of UAVs compared to road vehicles. The scientist concludes that drones use more energy than diesel vehicles (DV) or electric vehicles (EV) when customer density is high (2 customers/stop) in a rather small area (2 km). For low to medium traffic congestion, DVs use about 40-50% more energy than EVs and for high congestion this goes up to 80-90%. Drones use a comparable or even slightly smaller amount of energy than (electric) trucks in the more rural setting with large areas (8 km) to cover and a lower customer density (1,1 customers/stop) if wind conditions are calm or moderate. For medium to high wind conditions UAVs use more energy than electric vehicles (3-10x). There are quite some critical discussion topics mentioned by the author himself, such as the drone energy consumption model; one exclusive type of vehicle is used for all deliveries (combination of technologies is more realistic and possible better energy wise); drones flown in straight line and the type of primary energy is important since it changes the results.

An analysis made by Koiwanit (2018) investigated the environmental impact of drone delivery on 11 impact categories by an LCA (CML2001). The dominant contributor to all environmental impact categories is the parts operation which exists out of 3 main groups which are coal mining, electrical generating station operation and parts production. Coal mining and electricity generating station operations were the main contributors to global warming, abiotic depletion (ADP elements and fossil), acidification air, eutrophication, ozone layer depletion and photochemical ozone creation impact categories. Parts production, especially the carbon fibres production (which is the raw material for the cargo box) and Li-ion production (which is the main input for the battery), is the main contributor to the human toxicity, freshwater aquatic ecotoxicity, marine aquatic ecotoxicity and terrestrial ecotoxicity impact categories. In the drone operations themselves there is little impact on the environmental impact categories.

A study by Park et al. (2018) looked upon the environmental benefits of drone-based delivery services in urban and rural areas. Their results indicate a CO_2 emission per 1

km by drone that is one-sixth of that of a motorcycle delivery. The particulates produced by drone delivery are half the amount of a motorcycle delivery. The environmental benefits could be greater in the rural area where the delivery distance is relatively longer then in the urban area. The electric motorbikes scored better than the combustion engine motorbikes for CO_2 emissions. However for small particulates, the emissions from the electric motorbike were higher than the combustion engine motorbike due to the technologies used for electricity production. Sustainable energy production systems could increase the environmental benefits of a drone delivery system.

An article by Stolaroff et al. (2018), examining the energy use and life cycle greenhouse gas emissions of drones for commercial package delivery has the following results. They see the use of drones in the near-term future to be for short distance, same-day deliveries and build on the existing transport or logistic network. They found that, because of their small size, when solely comparing the energy use required per km of distance travelled, electric drones are far more efficient than trucks, vans, larger gasoline drones, and passenger cars. In their comparison between a small drone, delivering 0,5 kg, and a diesel truck (considering the truck to do more deliveries during one tour) the emissions were reduced with 54% in California and 23% in Missouri. For bigger drones with a package of 8kg the results are mixed and less favourable for drones. They conclude with stating that the focus of drones should be on light packages, while the heavier packages should be left for ground vehicles. Next to these results, the scientist stated: The potential for improved energy efficiency through hybrid designs is clear. A pure fixed-wing design uses about half of the energy per distance travelled compared to a quadcopter. Hybrid or VTOL technology will not match the efficiency of a classic fixed-wing UAV. But the potential for improvement over a quadcopter drone is there. Greener energy production will result in lower CO_2 emissions for the electric vehicles and drones.

2. Method (theory)

2.1 Jämtland

The study is done in the Jämtland county, Sweden. It has a surface of 48 935 km² and 130 810 inhabitants in 2019. Hereby the area is considered rural. The biggest city in the county is Östersund with a population of 63 779 in 2019 (SCB, 2019). It is located in the middle of Sweden as can be seen on figure 1. It has a subarctic climate, so it is cold during the relatively long winter and temperate the rest of the year. The region can also be defined as a Dfc climate which means it is a cold land climate with precipitation during the whole year (Köppen, 1918).

Figure 1: Geographic location of Jämtland, Sweden

2.2 Limitations of the study

The study of the technologies focusses at UAV systems that are battery powered. Other systems, such as internal combustion engine drones, are not considered. The study does not go into piloting systems, so no differentiation is made between remotely piloted systems or autonomous systems. The drones considered in the study are specifically designed to carry payloads and to function as delivery drones. Other drones, such as for cinematography work, are not part of the study. Although the way of electricity production influences the environmental benefits, no UAV systems are excluded because of the use of polluting generation methods of electricity.

2.3 Method for technology overview

There are many different technologies used in the drone sector. It is necessary to make an analysis of the current technologies available for delivery drones that are battery powered. There is a Drone Delivery Market Map 2019 made by Drone Industry Insights (Insights, 2019). This map gives an overview of all current players in the drone delivery market. However, it only shows the actors on the market. Based upon this map, all drone delivery companies in Table 4: Companies and their mission or goal, were considered and contacted by email with questions about their current technology (and best practises).

Table 4: Companies and their mission or goal

Company	Mission/Goal
Antwork (Antwork, 2019)	Tech company working on large-scale robotics, wanting to make delivery more convenient, 'just make a wish' is their vision.
Arone (Arone, 2019)	Revolutionizing delivery in Africa, building drones for fast delivery of medical supplies to and from clinics, hospitals, labs and health facilities.
Doks (doks, 2020)	Working on drones for digitization of stocktaking and inventory processes ass well as transportation of goods over short distances (within factory).
Drone delivery Canada (canada, 2020)	Becoming a key player in the drone delivery industry by commercializing their technology. Connecting remote communities in Canada.
Drone Volt (volt, 2020)	Drone manufacturer.
Dronistics (Dronistics, 2018)	Developing a personal and human-friendly drone delivery system for last centimetre delivery.
Ehang (Ehang, 2020)	Safe, autonomous, and eco-friendly air mobility accessible for everyone (Airtaxi).
Fli drone (FliDrone, 2020)	Not a manufacturer, but drone logistics company. Utilize the latest and greatest drones for their applications, transporting all kind of goods in the Bahama's.
Flirtey (Flirtey, 2020)	Mission is to save lives and improve lifestyles by making delivery instant for everyone. Pioneering an industry, working on healthcare and food delivery.
Flytrex (Flytrex, 2020)	Make drone delivery (food) a reality.
Manna (Manna, 2020)	Making 3-minute air delivery a reality, whether you want food, medicine, or anything you need in your local community.
Matternet (Matternet, 2020)	Make access to goods as frictionless and universal as access to information.
Rigi tech (tech, 2020)	Faster, easier, and eco-friendlier deliveries, enabling universal access to goods for communities, governments and private businesses.

RPS Aerospace (Aerospace, 2020)	Drone manufacturer.
Skyports / Volocopter (Volocopter, 2019)	Mobility company developing and operating landing infrastructure for the electric air taxi revolution. Aims to become the leading urban air mobility service provider worldwide.
Moog (Moog, 2020)	Advancing MOOG's position as a developer and integrator of flight critical systems.
Swoop Aero (Aero, home, 2020)	Transform the way the world moves essential health supplies. Providing an aeromedical logistical service and moving medical supplies on-demand.
Volansi (Volansi, 2020)	Drone manufacturer – reimagining the logistics of supply chain management to deliver what you need, where you need it.
Wing (Wing, 2020)	Autonomous delivery drone service aiming to increase access to goods, reduce traffic congestion in cities, and help ease the CO_2 emissions attributable to the transportation of goods.
Wingcopter (Wingcopter, 2020)	Drone-manufacturer - design innovative, high-performance drones that are operated all over the world in commercial and humanitarian operations. Their drone technology saves and improves lives every day.
Workhorse / Moog (Workhorse, 2020)	Electric delivery vehicle manufacturer, also developing drones for goods and personal transport.
Zipline (Zipline, 2020)	Provide every human on Earth with instant access to vital medical supplies.

Communication with the industry has been hard. The contacted companies were not willing to share a lot of detailed information. So, data was mostly collected through the websites of the companies or from information they released when doing pilot projects or tests. From the data collected, a table was made that can be found in chapter 3.1. In total 22 relevant companies were included, with even more drone models since some producers have multiple models being made (3 companies that are working on personal transport were added, but are not considered in this technology overview, since this is entirely different technology). Two drone models from companies included in the table, were excluded since they were driven by fossil fuels. Since not all companies on the market provided the data requested it is not possible to draw conclusions for the whole industry, however enough data is gathered to have some results. These are presented in chapter 3.1.

There are multiple characteristics important to estimate the capabilities of drones. The characteristics that were collected are:

- Payload capacity (weight and volume); to get knowledge about the kind of packages that can be transported by drone
- Range (empty, loaded and service range); to get knowledge on how far drones can fly and deliver their package, and how the payload influences the range
- Cruising speed; to get knowledge on how fast a drone can deliver its package
- Time of flight; if range is not given, the time of flight can give some indication on how far the drone can fly if the speed is known as well
- Battery capacity; to get knowledge on how much energy a drone uses and what is possible with batteries nowadays
- Price; to get knowledge on how expensive it is to use drones for drone delivery
- Type of drone; drones can be either fixed wing / VTOL or quadcopter / hexacopter or similar. Certain types can have certain advantages and disadvantages
- Dimensions of the drone; important for use in cities
- MTOW (maximum take of weight); is related to the legislation needed for the drone
- Weight of the empty drone; in case the MTOW is not given, this gives an indication about the MTOW

2.4 Method for best practises

Based upon the same companies in the market as the technologies the best practises were gathered and analysed. 19 of the 22 companies, represented in the technology part, are analysed. The three excluded companies do not have any practises yet in the field of delivery of goods. There is an additional company added that is not considered in the technology overview because they use drones from another company.

The following information was gathered:

- General information
    - Company and website
    - Mission of the company

  - Country of the company and where they perform the best practises
  - Their main service or product
  - The used technology

- Best practises
  - What is being done now
  - The phase the company is in: testing; pilot projects; ongoing operations

Out of these best practises of the companies the most important results will be discussed in chapter 3.2.

3. Results

3.1 Technology: capability of drones

In Table 5: Drone technologies data collected, the most relevant collected data of the drone companies can be found. Out of the information gathered, Table 6: Grouping of drones, was made. This table differentiates between two groups of delivery drones and gives an overview of the gathered information. All drones are different from each other, some have a longer action radius, while others can carry more. Since drones are designed with a specific function in mind, it is possible to split them up into two groups. There are drones made for urban use. These are commonly smaller and have a shorter range, while the other type has a longer range. Those can be used for rural good delivery and transportation over longer distances. This is sometimes called inter-city transport, which means these drones are not just used within the same area or city, (the current maximum for this technology is about 80 km of serviceable range). Next to this type of drones there is one type which will not be further discussed in detail, the drones for personal transport.

Table 5: Drone technologies data collected, shows which drones belongs in which category by colour code. The yellow models (15) can be considered as urban drones with a shorter range. The blue (8) ones have a longer range and can be considered inter-city drones or drones for more rural delivery. The green ones (3) are the passenger drones which have completely different characteristics.

Table 5: Drone technologies data collected

Producer	Model	Payload capacity (kg)	Payload capacity (l)	Range (empty)	Range (loaded)	Service range	Cruising speed (m/s)	Type	MTOW
Antwork	Jetgo TR7	7	N/A	N/A	30	N/A	N/A	Hexacopter	N/A
Arone	Not made yet (design)	5	N/A	N/A	200	N/A	N/A	VTOL	N/A
Doks	N/A	4.5	N/A	N/A	4.5	N/A	N/A	Quadcopter	N/A
Drone delivery Canada	Sparrow X1000	4.5	N/A	30	N/A	N/A	65	Quadcopter	25
Drone delivery Canada	Robin X1400	11.3	N/A	60	40	N/A	65	Quadcopter	34
Drone volt	Hercules 10	7.5	N/A	N/A	N/A	N/A	N/A	Quadcopter	20
Drone volt	Hercules 20	15	N/A	N/A	N/A	N/A	N/A	Quadcopter	33
Dronistics	Packdrone	0.5	N/A	N/A	N/A	2	N/A	Quadcopter	N/A
Ehang	Passenger drone	220	N/A	N/A	N/A	N/A	130	N/A	600
Flirtey	Eagle	N/A	N/A	N/A	N/A	N/A	N/A	Quadcopter	N/A
Flytrex	Flytrex Mule (DJI M600 Pro platform)	N/A	N/A	N/A	11	5,6	51.5	Hexacopter	15.5
Manna	N/A	4	N/A	N/A	N/A	6.4	N/A	N/A	N/A
Matternet	M2	2	4	N/A	20 (1 kg) 15 (2 kg)	10 (1kg) 7,5 (2kg)	N/A	Quadcopter	13.2
Rigi tech	Rigione	3	15	N/A	80	40	N/A	VTOL	N/A
RPS Aerospace	Discovery TRN	3.5	N/A	3.7	N/A	N/A	50	Hexacopter	10.3
RPS aerospace	Discovery EXP	5	N/A	38.9	N/A	N/A	59	Hexacopter	15
RPS Aerospace	Discovery LTF	5	N/A	38.9	N/A	N/A	74	Hexacopter	15
Skyports	Volodrone passenger	200	N/A	N/A	40	20	80	N/A	900
MOOG	SureFly	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Swoop aero	Kookaburra	2.5	N/A	N/A	120	N/A	100	VTOL	N/A

Vayu	X5	N/A	N/A	N/A	N/A	N/A	82.8	VTOL	23
Volansi	Voly C-10	4.5	N/A	80	N/A	N/A	N/A	VTOL	N/A
Wing (alphabet)	Wing	1.5	N/A	N/A	19.3	10	113	VTOL	N/A
Wingcopter	Wingcopter 178 heavy lift	6	13	120	110 (2kg) 85 (4kg) 45 (6kg)	51 38.5 18.5	100	VTOL	16
Workhorse	HorseFly	5	17	N/A	N/A	N/A	N/A	Quadcopter	N/A
Zipline	Fixed-wing aircraft	1.77	9.29	N/A	160	80	101	Fixed wing	21

Table 6: Grouping of drones

	Amount of 23 drone types that provided this data	**Urban drone**	**Inter-city drone**
Payload capacity weight	21	0,5-15 kg; Average 5 kg	
Payload capacity volume	5	4-17 l	
Serviceable range	9	Max +/- 10 km	Up till 80 km
Most common type of drone	22	Quadcopter/hexacopter	VTOL/fixed wing
Cruising speed	13	60 km/h	100 km/h

3.1.1 Payload capacity

From the 26 relevant delivery drones, 21 provided data about the payload capacity (weight). It differs between 0,5 kg up till 15kg. The average capacity is 4,95kg. The volume of the payload was only mentioned by 5 of the drone models. This has two reasons. Not all of the drone models are designed to take the payload inside of the drone. There is a reasonable number of models that use a hanging system, so the volume is not limited by the available place. The second reason is that not every producer reveals this value. From the 5 provided answers we can see that the smallest volume is 4 l and the biggest 17 l.

3.1.2 Range

The range of many models is unclearly communicated. There is no standard or rules on how the range should be tested. This is a shortage that can be exploited by the manufacturers. Drone producing companies might hide the real-world range because they want to attract customers. The range of a drone is highly dependent on the weight. The more a package weighs, the more it reduces the available range. Next to the weight, there are other factors that play a role on the range, such as aerodynamics and weather conditions. The maximum range is not equal to the distance at which packages can be delivered since in most cases, especially without an existing network, the drone needs to fly back to its starting point.

From the results that were gathered, it is possible to see in Table 5: Drone technologies data collected, that some drones which were defined as the first group (urban drones), have a serviceable range of about maximum 10 km (payload 1,5 kg). While the drones for rural or inter-city transport currently have a maximum serviceable range of about 80 km (payload 1,77 kg). As said before, this is for a certain payload. If the payload is heavier, the range gets reduced.

3.1.3 Cruising speed

The cruising speed is relevant, since it is related to the time needed for delivery. As will become clear in chapter 3.2, a main benefit of drones is the speed at which they can deliver. The cruising speed is mostly dependent on the drone type. Quadcopters or hexacopters, which is the standard for drones used in other applications, have lower cruising speeds. Fixed wing models and VTOL models, which combine fixed wings with vertical take-off and landing, have higher cruising speeds since they are more aerodynamic and use less energy to achieve these speeds. The average cruising speed for the quadcopter and/or hexacopter models in the analysis is 60 km/h. This is based

upon data of 6 out of the 14 quadcopter and hexacopter drone models since the others did not share their cruising speed. The average speed for the VTOL and fixed wing models is 100 km/h. This is based upon data of 5 of the 8 fixed wing and VTOL models, the others were not included since they did not provide this information.

3.1.4 Excluded variables

It is not possible to share relevant results about the time of flight, battery capacity or the price because of a lack of data. The time of flight is less relevant, if the service range and the cruising speed is known. Not many actors share this information probably for this reason. Time of flight is, just as the range, highly dependent on a variety of characteristics. In this work, the focus was on the range of the drone, since this gives more information. For example, if the manufacturer states 30 minutes of flight, while not giving any information about the speed or weight, it is impossible to predict how far the drone could fly. The battery capacity and the price of delivery drones is almost never publicly available. Part of the reason some drone manufactures don't share their prices is, because they sell a service and not the actual drones. Another potential reason is that the prices of the drones is so high that they are not commercially viable in comparison to alternatives.

3.1.5 Type of drone

The type of drone (quadcopter/hexacopter or VTOL/fixed wing) has both advantages and disadvantages. Quadcopters and hexacopters are quite common in the drone business. They are already well developed and used in other sectors/services. They have the advantage that they can hoover and hereby land or take-off anywhere. But in comparison to VTOL or fixed wing drones, they are less efficient with their energy. VTOL combines the best of both types; the drones can take off and land vertically. During their flight, they use the principles of a fixed wing drone which are similar to an actual airplane. Fixed wing drones are more efficient and can fly longer distances, but if they are not VTOL, but a pure fixed wing design, they need to be launched and landed with a special infrastructure. VTOL drones are commonly bigger, since they are used for longer distances and have a more airplane kind of design. Quadcopters can be relatively big as well, depending on the payload they are designed for. It is clear by Table 5: Drone technologies data collected, that most models classified as inter-city or for rural transport of goods are VTOL or fixed wing drones, while most urban drones are quadcopters or hexacopters.

3.1.6 Maximum Take Off Weight

The Maximum Take Off Weight (MTOW) is important to know, since it can change the kind of license you need to fly the drones. In chapter 3.4 of this thesis, the legislation on drones will be explained in depth.

3.2 Best cases: general overview

3.2.1 Results of analysis

19 out of the 22 companies from chapter 3.1 will be further analysed for their best practises. The remaining 3 companies are most likely also performing tests, but information is not available or the information available is not concerning good delivery/transportation. Each company has a unique and different mission or goal, which influences the kind of projects the company is working on, these were presented in Table 4: Companies and their mission or goal.

There is a limited amount of companies which have commercially active drone projects for the delivery of goods. Companies still performing tests or pilot projects mostly raise money by investors. The amount of services currently done or being tried out by the drone delivery sector is fairly limited. As can be seen in Table 7: Overview companies and their main service, 12 out of the 19 companies are working within healthcare. 8 out of 19 work on e-commerce or package delivery and 7 on food delivery by drone. A smaller amount works on passenger transport and industrial or parts delivery respectively 3 and 5 companies.

There are 3 different development stages the companies can be in: testing, pilot projects and ongoing operations. Testing, pilot and ongoing operations as used in this thesis are defined as: A test of a drone is an experiment to discover whether and/or how well something works, or to find out more information about it. A pilot project is an initial small-scale implementation that is used to prove the viability of a project idea. Often used for new ideas or concept. It does not need to be new to the entire industry to be a pilot project, any new kind of drone or application tested within an organisation can be a pilot project. A pilot project enables an organisation to manage the risk of a new idea and identify any deficiencies before substantial resources are committed. Ongoing operations is continued work on the business activity/delivery drones. This is for businesses that are further then testing or pilot projects. It is an activity without a certain end date in which the company uses its already gathered skills to contribute in real-world activities. In the industry, different terms are used by the actors. Some

call a project commercial testing or do not even define the stage they are in. In Table 7: Overview companies and their main service, the current stage of each company can be seen by colour code (explained in the legend).

Table 7: Overview companies and their main service

	Healthcare	E-commerce (package delivery)	Food delivery	Passenger transport	Industrial / parts
Antwork	X	X	X		
Doks					X
Drone delivery Canada	X	X	X		
Dronistics	X		X		
Ehang				x	
Fli drone	X	X			X
Flirtey	X		X		
Flytrex			X		
Manna			X		
Matternet	X	X			
Rigi tech	X	X			X
RPS Aerospace	X				
Skyports / Volocopter				X	
Swoop Aero	X				
Volansi	X				X
Wing		X	X		
Wingcopter	X	X			X
Workhorse / Moog		X		X	
Zipline	X				

Legend:

Testing
Pilot projects
Ongoing operations

More than half of the companies involved in drone delivery practises are international (10 out of 19). It is a sector where the regulations change, depending on the country or region. It's challenging to work in more than one country, because the drone and the operations need to comply with the regulation of each country. Companies that now work in several countries to perform pilot project could have more experience in a later stage, which might make it easier for them to develop their business. Three out of the nineteen companies work in the more northern regions of the world. A potential

reason for this is that cold weather brings specific challenges to drones. Not all drones are designed to fly in (extreme) cold weather, it could potentially shorten the range because of a smaller battery capacity. (More information about the countries of implementation can be found in Appendix 2: Countries of implementation)

Based upon Table 7: Overview companies and their main service, the three companies which have ongoing operations nowadays and the two companies which are the furthest in their pilot projects are selected for a deeper focus. These are: Zipline, Swoop Aero, Wingcopter, Matternet and Wing. This does not mean that the other companies have lower potential. A summary of the best practises of each company can be found in Appendix 1: Best practises.

3.2.1.1 Zipline

Zipline is currently the biggest drone delivery company on the market. Their main focus is in healthcare. They have made over 35 000 commercial deliveries. The ongoing operations nowadays, are in Ghana and Rwanda. In Ghana, they make over 600 drone deliveries per day and they have the capacity to make even more. They are the only drone delivery company (considered in this study) that works with fixed wing drones. So, there is an installation needed for the launching of these drones and to retrieve them to the ground. The packages with medical supplies are dropped with a parachute. This is possible for Zipline since they do not only take care of the transport, they have a central "warehouse" as well. In Ghana and Rwanda, they have made a deal with the government to help them in delivering medical supplies. They started off with blood. They oversee a central warehouse where the blood can be stored and transported to where it is needed in a short time. The central storage helps with storing the blood in a sufficient way and it only goes to where it is needed. Hereby less blood is wasted. Their drones fly autonomously. Currently, they have more medical supplies than just blood and deliver these all over the country to more than 2500 healthcare facilities. A new partnership is announced in India, where they will have a similar service as in Ghana or Rwanda. They see a possible future in healthcare in America, especially in the delivery of medication from pharmacies, but this is not in place yet. Presumably because of harder drone laws than in developing countries. Next to the harder drone laws, other factors could play a role such as the limited road network in Africa which creates possibilities for drones, especially for fragile products such as blood, which is highly needed.

3.2.1.2 Swoop Aero

Swoop Aero has a similar mission as Zipline. They want to provide healthcare and improve the way the world transports essential health supplies. They performed projects in Vanuatu, Congo, Malawi and Mozambique. They work together with several other actors on the market. This is important in order to share knowledge, but also for future business opportunities with possible the same companies such as: UNICEF, Village Reach, UKaid and the USaid Global health supply chain project. There is not much public information available about the drone they use, but it has a payload of about 3kg and a serviceable range of 60km. It is a VTOL drone, which could have an advantage that it can land in location and if needed it can carry payload on the way back to the central. Because of VTOL technology, it does not need additional infrastructure. The drones of Swoop Aero fly autonomously.

The following information was obtained from a summary that complements a final report of UNICEF about the achievements of Swoop Aero in Vanuatu. The summary is used since the final report is not published (yet). Only the most important insights and challenges will be mentioned, since not everything is relevant for possible applications in Sweden (Aero, 2019).

- Scheduling is often interrupted by various factors such as communication, medical supplies, weather circumstances …
- It is important that the upstream supply chain is taken care of. The materials that need to be transported need to reach the last-mile delivery step.
- The drones are used for other items then medical equipment (for example payslips). It is important to keep the drones available for high priority deliveries.
- Because of inexperience, more equipment was deployed then necessary. This caused higher costs, in the future this can be done cheaper.
- In this specific project, generators on petrol were used. This is not sustainable, so in the future they want to use solar energy.
- Complex information needs to be exchanged for the planning and receiving/departure of goods. There were problems with communication during this project, such as: changing phone numbers, no telecommunication possible, no reports/paperwork.

The focus of this company is health and all cases so far are in developing regions. This is probably because of a less developed infrastructure in place. This means there is an

opportunity for drone deliveries to fill in these gaps. Easier legislation could play a role as well.

3.2.1.3 Wingcopter

Wingcopter is a company with a main focus on engineering and designing of the drone itself. They build a VTOL drone with a payload of up to 6kg, it can fly longer distances (18 km serviceable range with 6 kg payload). So, it is an inter-city drone. For most of their current best practises, they work together with other companies. They have worked together with Merck for delivering laboratory samples between two production facilities. They flew 25 km beyond the visual line of sight (BVLOS) and over highways, state roads, power lines and industrial infrastructure. This was done in Germany. Their other projects were performed in developing countries. They had a project in Vanuatu: medical deliveries of vaccines on demand. The average packages contained 3,5kg of payload and had a delivery time of about 20 minutes. They supplied 19 villages through one central hub. They did a project in Tanzania with DHL, to deliver medical supplies over a long distance. They have now entered a partnership with UPS Flight Forward to develop UPS's drone fleet for parcel delivery.

3.2.1.4 Matternet

Matternet partnered up with UPS flight forward in the USA. (UPS partnered up with both Matternet and Wingcopter. They do not see this as a problem because the drones of both companies have different purposes and possibilities; urban/inter-city). In the US, they deliver laboratory samples on the campus of WakeMed in North Carolina. These flights take place within the visual line of sight because of drone laws in the USA. In Switzerland, Matternet has a cooperation with Swiss Post. They fly between hospital locations over a short distance, but still longer than in the US. The flights in Switzerland are about 2,5 km in urban areas. Their main goal is to be faster than road transport in delivering laboratory samples. They invest in so called stations. These are secure locations, where the drone can land and the receiver can come to pick up his or her package. These stations would be able to exchange batteries and automatically provide a new payload to deliver. The stations are currently focussed on hospital campuses. In contrast to the previous discussed companies, the projects of Matternet take place in the developed world. where they face limitations because of legislation.

3.2.1.5 Wing

Wing is a company that originated from Alphabet inc., the company behind Google. Their main focus is on food delivery. They are currently performing pilot projects in Australia, Finland and the USA. Their drone is a VTOL drone but developed for shorter distances with payloads on a hanging system. They made reports stating profits for both customers and businesses. These profits could be monetary, but also time could be saved. More information about these potential profits can be found in the report itself, but is not presented here because it is not relevant to the situation of Jämtland (AlphaBeta, 2019).

3.3 Environmental impact on Jämtland

The articles discussed in chapter 1.2.2 have different outcomes, depending on the factors they considered. Some general conclusions can be made for the situation in Jämtland. Drones are a technology that can benefit the environment if their implementation is well considered.

- It does not make sense to replace delivery vans if their tour has many deliveries on a short distance. It is better to electrify the vans if possible (Kirschstein, 2020); (Stolaroff, et al., 2018); (Figliozzi, 2017); (Goodchild & Toy, 2018).
- Drones in combination with a delivery van have some potential in benefiting the environment, if this is well planned. This could potentially save costs (Chiang, Li, Shang, & Urban, 2019).
- A flight by drone is better for the environment than driving to pick up a package with a personal vehicle (if the transportation is only done for the pickup) (Stolaroff, et al., 2018); (Park, Kim, & Suh, 2018).
- If only one item or package needs to be delivered to a certain place, which is often the case in food deliveries, drones are a better option for the environment than motorcycles or other road vehicles. This is even the case if electric vehicles are used (Stolaroff, et al., 2018); (Park, Kim, & Suh, 2018).
- Since the considered drones work on electricity, their environmental impact is dependent on the used production technologies. If the electricity production becomes more sustainable, so do electric vehicles and drones. Therefore, it is advisable to use sustainable energy production systems such as solar, wind or waterpower.

- Next to the energy used in the usage, it is important to keep the impact of the production of the drones itself in mind. The production of the drones itself has an impact, especially batteries and carbon fibre materials have a negative impact. (Koiwanit, 2018); (Figliozzi, 2017).

To determine more about how drones can contribute to the environment and in which cases they have the most impact, more research is needed. Most of the research nowadays, is focussed on urban areas and on the comparison with delivery vans. New research is needed in different directions, such as rural areas. It would be wise to compare with technologies that are used in case there are fewer recipients. Out of the current published articles, it's possible to conclude that the focus should mainly be on delivery routes that have a low number of recipients, which is often the case in more rural areas.

3.4 Legislation

UAV (Sw. *obemannade luftfartyg*) have certain rules that are monitored and controlled by the Swedish Transport Agency (Sw. *Transportstyrelsen*). UAV's are split up in 5 different categories:

- Category 1: Unmanned aerial vehicles with a maximum take-off weight of less than or equal to 7kg, which are flown solely within sight of the pilot.
- Category 2: Unmanned aerial vehicles with a maximum take-off weight of more than 7kg, but less than or equal to 25kg, which are flown solely within sight of the pilot.
- Category 3: Unmanned aerial vehicles with a maximum take-off weight of more than 25kg, which are only flown within sight of the pilot.
- Category 4: Unmanned aerial vehicles that are certified to be able to fly and be checked out of sight of the pilot.
- Category 5: Unmanned aerial vehicles used for special types of flights, not applicable to any other category, divided into subcategories 5A; 5B; 5C.

Category 5 is especially for being exempted from the requirements of category 1 to 3. 5A is to fly higher than 120 meters. 5B is to fly beyond the visual line of sight of the pilot, but still within the visual line of sight of one or several observers. 5C is to fly beyond the visual line of sight or higher than 120 meters in a special area. The category 5 can be used for testing of delivery drones, but are in general limited in their use and

geographical area. For the commercial application of drones for the delivery of goods, it is necessary to fly beyond the visual line of confirmation.

For most of the operations in drone delivery, the rules of category 4 are the ones to comply to. However, in the statutes of the Swedish Transport Agency (TSFS 2017:110), the transportation of goods and passengers is only mentioned once. It states: For transportation of goods and passengers, special permission is required by Transportstyrelsen. Depending on the category, at least the rules for category 4 will apply if a company want to transport goods and persons beyond the visual line of sight of the pilot, since these are the strictest rules in the regulations. The regulations regarding category 4 has 113 sections, so it is quite long and rather complex. There are many items that need to be addressed before a company can receive the permit for this category. There are air operational regulations, such as the need for a business manager who assigns two organizational side persons with responsibilities. The names of this persons are the flight manager (Sw. *flygchef*) and the technical manager (Sw. *Teknisk Chef*). The persons which have organizational roles, need to be approved by the Swedish Transport Agency. For this need, they must state with documents that they are able to perform the necessary tasks. There is also a need for an operation manual, which needs to measure up to certain requirements. There are requirements for the equipment, regulations for maintenance…

The instructions for applying for a permit category 4 exist out of 3 parts: the general information, an aeronautic organisation and a maintenance engineering organisation. The process of getting the category 4 permit is not easy, but for well-grounded reasons. It is important that, when drones are implemented into society, this can happen safely. There are several countries were flying beyond the visual line of sight is completely illegal. In Sweden it is possible, once the (hard) permit process is completed. There are companies which have obtained a permit for flying BVLOS, such as Everdrone which obtained a 5C category permit for test flight BVLOS. Smartplanes has performed tests with BVLOS flights in Sweden as well. All companies agree that the legislation is one of the hardest challenges to overcome for BVLOS flights in Sweden.

There is a certain cost involved with confirming to the legislation. The cost for applying is not publicly available, but the annual permit fee is 95 000 SEK. Next to these annual fee and administrational cost to the Swedish Transport Agency, each company has internal costs to make their drone and organisation conform the regulations. The true

cost for obtaining a permit is difficult to know, but a company certainly needs a certain budget.

3.5 Challenges

Even if drones would benefit the environment and be commercially viable, there are still challenges that need to be overcome. Drones have already been established for some time, but the usage of delivery drones is still relatively new. The cases nowadays, in which drones are used in the developed world, are seriously limited.

Due to the colder climate in Jämtland as described in the method, the drones need to be intensively tested. For drones to be able to fly in this region during wintertime, a protection against ice formation is necessary. This is stated in the regulations from the Swedish Transport Agency as well. They need special approvement to fly in these icy conditions and the pilot needs special training for this. Next to the protection against ice, the cold could influence the technology. Batteries (Li-ion batteries) are affected by the outside temperature. Colder weather could reduce the energy output of the battery and hereby the possible range. Most of the best practises nowadays are in warmer regions. Some companies fly in regions where it could be colder, so they might already have experience with these problems (Drone Delivery Canada, Wing in Finland, Flytrex in Iceland). Some regions in Jämtland can have strong winds. This is something that also need to be taken into consideration while testing.

The regulations themselves are a second challenge. The regulations for drones in Sweden are not simple or easy, but it is possible to overcome them, since other companies (not directly related to drone delivery) have done this. Everdrone is one of the first companies in Sweden that has performed a beyond visual line of sight flight (and autonomous). All flights done up to date are test flights. So, the regulations allow to perform certain flights, but commercial activities still need further development. Then the Swedish Transport Agency can consider BVLOS and autonomous flights for prolonged operations, that might be commercial. Changes in regulations might be needed as delivery drones further develop but this should not compromise safety. The regulations as they are nowadays are certainly not beneficial for the development of drone delivery.

A third challenge that is currently not addressed in the regulations is privacy. The regulations have a focus on safety, but privacy is not mentioned. Privacy is a concern for possible customers and people that are affected by the drone flying over their

property. It is especially a problem in rural areas, where most people live in detached houses. A drone might deliver in their inner space or yard, or fly over their yards. For them this is a bigger worry than for city-people. In cities, delivery drones could use a drop-off point. (Yoo, Yu, & Jung, 2018) Some delivery drone companies are already paying attention to this matter. They develop drones without actual camera's. The drones are equipped with different technology. This way the drone can still be aware of its position without making photographic images that might affect the privacy of the general public.

A further challenge could be security or risk of crimes. Since the drones would be able to fly to remote locations and drop of light weight but possibly valuable items, there is a certain risk for crime. People might steal the delivered packages or damage the drones. This is currently addressed by some of the drone delivery companies, by using certain technologies. Examples of this:

- No landing of the drone. the drone makes the delivery by dropping the package.
- The use of applications so that the customer needs to verify that he or she spots the drone and is ready to pick up the package.
- Use of delivery stations where the packages are dropped off at a secure location.

4. Possibilities in Jämtland and discussion

The potential range of drones is easier to fully understand, once visualising it. To know how far a drone can fly from Östersund Figure 2: Theoretical serviceable range for (small) urban drones and (large) inter-city drones with the longest range; was made. Keep in mind, this is all assuming a drone would be allowed to fly in a straight line. Figure 2: Theoretical serviceable range for (small) urban drones and (large) inter-city drones with the longest range shows the map of Östersund and its surroundings. There are two circles on the map. The smaller one is the potential serviceable range (10 km) for smaller drones, which were classified in chapter 3.1 as urban drones. The bigger circle is the maximum serviceable range of the electrical drone with the largest serviceable range (half of the max. range), that is in use nowadays (Zipline 80km). This kind of drone was classified in chapter 3.1 as an inter-city drone. As can be seen in Figure 2: Theoretical serviceable range for (small) urban drones and (large) inter-city drones with the longest range, an urban drone would be able to fly from the city centre to most of the urban area of Jämtland. So, the whole city centre of Östersund can be served by an urban drone. An inter-city drone however, would be able to connect more distanced places to Östersund. For example: Östersund-Bydalen-Östersund; Östersund-Bräcke-Östersund would be possible.

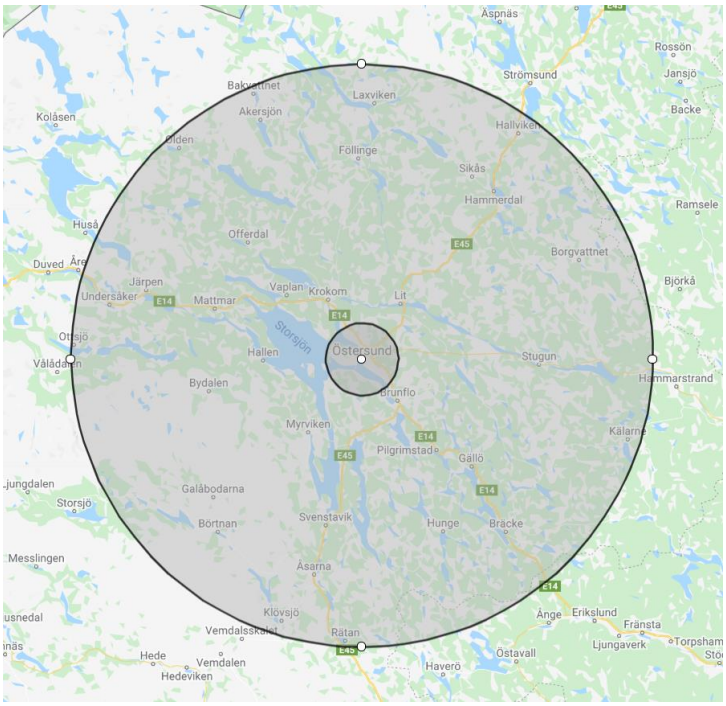

Figure 2: Theoretical serviceable range for (small) urban drones and (large) inter-city drones with the longest range

Wingcopter is specifically open about their possible range. This could be seen in Table 5: Drone technologies data collected. They share information about their range, depending on weight, with battery reserve and the energy used for landing and take-off. Table 8: Range Wingcopter is an extraction from table 5 for an easier overview.

Table 8: Range Wingcopter

Drone	Maximum range (payload weight)	Serviceable range
Wingcopter	110 (2 kg)	51
	85 (4 kg)	38.5
	45 (6 kg)	18.5

Based upon Table 8: Range Wingcopter, Figure 3: Potential serviceable range for the Wingcopter depending on the weight, was made. How far their serviceable range brings them from Östersund can be seen on this figure. Both maps have the city centre of Östersund as a central point. Of course, this could move depending on where the drones are launched (possibly Frösön). The smallest circle (heaviest payload) is big enough to reach the whole city centre of Östersund and most of the urban areas around it, including Frösön. The drone with a lighter payload of about 4 kg (second circle), would be able to fly anywhere in the kommun of Östersund. This has a total population of 63 773 people (SCB, 2019), which is about half the population of Jämtland. The scenario with the lightest payload has the largest serviceable range (third circle). This could serve even more inhabitants, but the number will not increase drastically since most population is concentrated in Östersund.

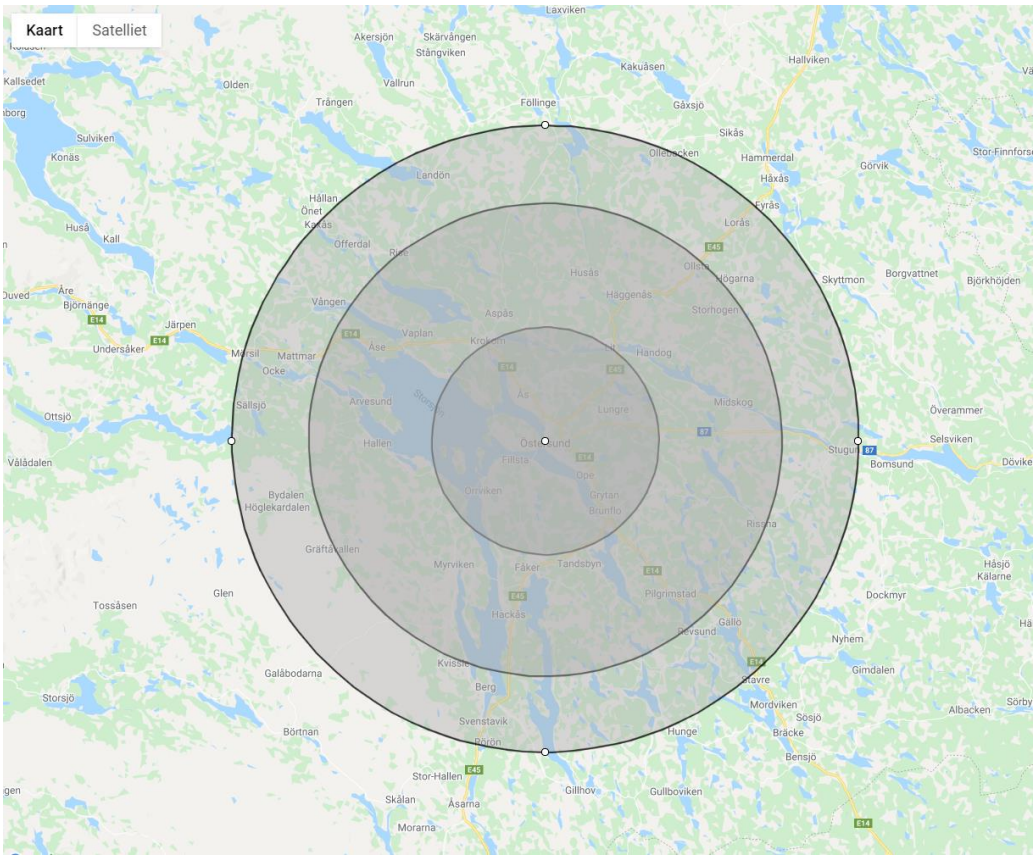

Figure 3: Potential serviceable range for the Wingcopter depending on the weight

So even though the range of drones is limited and heavily influenced by the weight they carry, there are some possibilities since most of the inhabitants of Jämtland are concentrated around Östersund. If drones are allowed to fly in a more or less straight line, their limited range can still take them reasonably far. Out of the previous chapter about the technology, the best practises and the environmental impact, some important factors to take into consideration can be summed up.

- The package or payload that needs to be transported by drone must be light
- The average maximum payload is about 5 kg. This limits the range; lighter packages can be transported further.
- One of the reasons to use drones is the potential positive impact on the environment, compared to other logistic or transport methods.
- There is absolutely no reason to replace existing logistic methods if they are more efficient than a drone transportation system.
    - Delivery vans can work efficiently
    - There are other technologies available for delivery routes with many customers (electric vans)

    - There might be a possibility for vans in combination with drones in a dynamic system
- Inefficient transportation, such as almost empty delivery van tours, nowadays can be replaced by UAV delivery technology.
- Drones would be ideal for fast, on-demand delivery. However, we need to consider if this is always necessary. As mentioned in the current state of logistics in Sweden, fast delivery is not expected. From an environmental standpoint it is not always better to be faster.
- Healthcare/medical supplies are the main service of most drone delivery companies. Reasons for this:
    - Time is of the essence
    - Often smaller packages (laboratory samples; blood; …) need to be transported
    - Most projects nowadays however are in developing countries
- Food delivery is a second service that creates possibilities
    - There are no ongoing operations nowadays in food delivery with drones, only pilot projects.
    - Östersund is sub-urban, so almost no deliveries are done by bike which is the most environmental option. Most are done by car
    - For a single package, drones are better for the environment than motorised vehicles, delivery cars, motorcycles or even electric motorcycles
    - The cost of a drone delivery system in Östersund or Jämtland, compared to the possible profits is extremely hard to estimate. No drone delivery companies have ongoing operations for food delivery and results from pilot projects are not publicly available
    - Drones could result in a larger serviceable area then the technology used nowadays. This would give restaurants more customers and customers more choice
- Same-day delivery of goods is a third sector which could benefit from delivery drones
    - There is willingness to pay, which is growing within younger generations, for same-day delivery
    - For people unable to go to the stores
    - If small items are needed, it can be more environmentally friendly to transport it by drone than a personal trip to the shop

Research and testing on many scenario's or practises are being done. But before any commercial drone activities can be done in Jämtland, more testing is needed to overcome the challenges still faced.

5. Conclusion

Although it is unlikely (because of problems still faced) that commercial drone delivery activities will take place in the region of Jämtland within the near future (2 years), there certainly is potential to contribute to the society by more sustainable delivery. The last-mile delivery of goods is a market which has certain challenges and is faced with high costs (especially in rural areas). This gives opportunities to new technologies and ideas if these can be cost-effective.

The technology used for drone delivery, can be split up into two categories. There are drones for urban use with a serviceable range of about 10 km and inter-city drones which have a current maximum serviceable range of 80 km. The payload on average can weight about 5 kg, but a heavier payload results in a shorter range and vice versa. Most drone delivery companies are currently testing and performing pilot projects. The amount of companies having ongoing operations is very limited. The companies that do have ongoing operations, are mostly located in developing countries. There they benefit from bad infrastructure and more lax regulation. Companies need to perform more tests and further develop their technology, so they can continue to commercial ongoing operations, as the market is today it is not mature.

Ideally, drone delivery should only be used in cases where it can benefit the environment. By this, the potential is limited. The ideal case is a single light package or payload that needs to be transported without the possibility for other packages to be transported on the same route. Once package deliveries can be grouped in an efficient route, there are better technologies on the market nowadays which are further developed and will have a lower impact on the environment.

Even though drone applications have been on the market for some time, the drone delivery section of the market is relatively new. This results into a variety of challenges to overcome, even if a certain practise can be environmentally friendly and cost-effective. These challenges are cold weather conditions and wind; hard regulations; privacy concerns and security issues.

It is now most important that the drone delivery technology can be tested in Sweden to prove drone delivery can be done in a save manner, within the regulations from the Swedish Transport Agency, and be beneficial for the environment while being cost-effective. Further scientific research on the topic is needed.

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Appendixes

Appendix 1: Best practises

Appendix best practises

Company	Matternet (https://mttr.net/)
Mission	Make access to goods as frictionless and universal as access to information. Our products enable organizations around the world to build and operate drone logistics networks for transporting goods on demand, through the air, at a fraction of the time, cost and energy of any other transportation method used today.
Country of company and practises	USA Switzerland
Main service / products	Healthcare E-commerce
Technology	Quadcopter with payload capacity of 2 kg
Best practise(s)	- USA: (cooperation with UPS) Healthcare delivery service at WakeMed, over 1000 deliveries have been completed. Results in quicker test results. (in line of sight). - Switzerland: (Cooperation with Swiss Post) Transportation of laboratory samples. Ticino hospital group in Lugano, preformed over 2000 flights between Ospedale Italiano and the Ospedale Civico. (Distance of 3.4 km by car) Because this is in the middle of the city, a drone can be up to 45 minutes faster. In Zurich, transportation is done between the University Hospital and the University. The drone flies 4 minutes over 2,5 km. Compared to a road carrier, this is twice as fast. (Started December 2018) In Zollikon transportation is done between the Hirslanden Hospital and the central laboratory. This is done in 7 minutes, which is up to 5 times faster than a road courier.
Stage	Ongoing operations

Company	Zipline (https://flyzipline.com/)
Mission	Provide every human on Earth with instant access to vital medical supplies
Country of company and practises	USA company Ghana; Rwanda; (India; Australia)
Main service / products	Healthcare
Technology	Fixed wing with payload capacity of 1,77 kg and a serviceable range of 80 km. (Needs to be launched and caught, drops load with parachute)
Best practise(s)	- Over 35 000 commercial deliveries have been made by Zipline. - In Ghana over 600 on demand deliveries are made per day, using 4 different distribution centres. Each distribution centre has the capacity to make 500 flights per day. 65% of the blood supply outside of the capital is delivered by Zipline. - In Rwanda and Ghana together, there are now 6 distribution centres. They serve over 2500 health care facilities, which in turn serve close to 22 million people. - They are expanding the medical products they deliver. Started purely with blood deliveries,now they deliver another 169 medical products (vaccines, medical supplies…). - Tested by the US military in Australian (life-fire) wargames for delivering medical supplies to the front line (381 drops were made and 461 flights). - New partnership/location has been announced. They will start flying in India, in one of the provinces. There are plans for a total of 10 distribution centres and there are 120 million citizens living in the province of Maharashtra. (The project was planned to start in early 2020)
Stage	Ongoing operations

Company	Flirtey (https://www.flirtey.com/)
Mission	Our mission is to save lives and improve lifestyles by making delivery instant for everyone. We're the first drone delivery service in the world and we're pioneering an industry, not just a company.
Country of company and practises	USA
Main service / products	Healthcare Food delivery
Technology	Quadcopter
Best practise(s)	- Test of medical deliveries such as a delivery of AED (Automated external defibrillation). - Test projects with Domino's, 7-eleven for delivery of food.
Stage	Testing

Company	Drone Delivery Canada (https://dronedeliverycanada.com/)
Mission	Our vision is to become a key player in the Drone Delivery Industry by commercializing our technology to create new and innovative logistics platforms for retailers and government agencies.
Country of company and practises	Canada
Main service / products	Connecting remote communities in Canada (Medical supplies, food, clothing, essential goods)
Technology	3 drones currently in use, 2 are battery powered. Unique designs specified for goods, not much information released about them
Best practise(s)	- Moose Cree First Nation Community, is one of the first commercial projects for DDC. They use drones to deliver various goods to an island (Moose Factory Island), which is situated close to the city of Moosonee. There is no bridge to the island. It is only accessible by boat in the summer and an ice road in the winter. But when this is not possible, a helicopter is used. There is a 2,5-million-dollar contract signed, to supply medicine, food and mail from the mainland to the island. There will be payloads of about 5 kg. It is about a 10 minute journey to cross the river to the island. In comparison to a helicopter, drones are less expensive. They are designed to be more affordable and quicker. Lower costs were not the only reason for this project, it also creates new jobs in the region.
Stage	Pilot project

Company	Flytrex (https://flytrex.com/)
Mission	Make drone delivery a reality
Country of company and practises	USA, North Dakota Iceland
Main service / products	Food delivery
Technology	Hexacopter, based upon DJI M600 Platform, payload capacity of 3 kg with a service range of 5,6 km.
Best practise(s)	- Flytrex is currently operating in Iceland where they cooperate with AHA which is Iceland's largest e-commerce company. They want to help make food delivery quicker, cheaper, safer and more environmentally friendly in the city of Reykjavik. Over a thousand flights are logged. But there is not much information about the flights and pricing. - In North Dakota, the drones of Flytrex are used to deliver refreshments on a golf course (King's walk golf course). This is replacing the "beverage cart", that is used conventionally.
Stage	Pilot project

Company	Wing (https://wing.com/sv_se/)
Mission	Wing is an autonomous delivery drone service aiming to increase access to goods, reduce traffic congestion in cities, and help ease the CO_2 emissions attributable to the transportation of goods. Wing is also developing an unmanned traffic management platform that will allow unmanned aircraft to navigate around other drones, manned aircraft, and other obstacles like trees, buildings and power lines.
Country of company and practises	USA, Virginia Finland (Helsinki); Australia (Canberra and Logan)
Main service / products	Food delivery In USA also packages (FedEx) and deliveries from pharmacy (Walgreen)
Technology	VTOL, rather light weight packages and short distances
Best practise(s)	- Wing is testing out minute food-delivery in Finland, USA and Australia. They have a report stating big possibilities in this sector. They assume they can create more customers, since they would be able to deliver to people living further away in less or the same time as traditional delivery.
Stage	Pilot projects

Company	Wingcopter (https://wingcopter.com/)
Mission	We are an aviation company. We, at Wingcopter, design innovative, high-performance drones that are operated all over the world in commercial and humanitarian operations. Our drone technology saves and improves lives every day.
Country of company and practises	Germany Ireland; Vanuatu; Tanzania
Main service / products	Healthcare E-commerce
Technology	VTOL with a payload capacity of up to 6 kg and rather high serviceable range of about 18,5 km with 6 kg or 46 km with 2 kg.
Best practise(s)	- UPS and Wingcopter are working on a new drone fleet for UPS to deliver parcels, only announced in end of March 2020. - Pilot project: delivery of insulin to an Irish island. - South-island of Vanuatu: They set up an on-demand vaccines supply. They supplied 19 villages from one central hub. The average package contained 3,5 kg of medical payload with a delivery time of about 20 minutes. - In cooperation with Merck and the Frankfurt University of Applied Sciences, they preformed a beyond-visual-line-of-sight flight between two production facilities. Laboratory samples were flown over a distance of 25 km. The flight went over highways, state roads, power and rail lines and industrial infrastructure. - In Tanzania a project was done in cooperation with DHL. More then 180 take-offs and landings found place. A total of over 2200 km was flown. During the 6 months project, the drone was flown to an island 60 km away, in an average time of 40 minutes. If it lands on the destination (not always needed if packages are “dropped”), it could take payloads in both ways. For example, supplies there and laboratory samples on the way back.
Stage	Pilot projects

Company	Antwork (https://www.antwork.link/build/pages/ours_en.html)
Mission	Antwork is a tech company devoted in providing large-scale robotic delivery network solution. We believe our innovation will not only help to make delivery more convenient, but also save human couriers from tough labours. More importantly, our technology will provide best delivery service to every consumer. 'Just make a wish' is our unchangeable mission.
Country of company and practises	China
Main service / products	Healthcare E-commerce Food delivery
Technology	Hexacopter with a payload capacity of 7 kg and service range of less then 15 km
Best practise(s)	- Test projects for medical delivery, food delivery, emergency response (carrying AED) and parcel delivery with the Chinese post.
Stage	Testing

Company	Fli drone (https://flidrone.com/)
Mission	Fli Drone is not a drone manufacturer, we are a drone logistics company. Since we are not tied to a single aircraft, we utilize the latest and greatest drones for our applications. We are constantly at the cutting edge of unmanned aerial systems capabilities.
Country of company and practises	The Bahama's
Main service / products	Healthcare; parts; perishable and/or packages
Technology	Drone logistics company does not make drones itself, uses "best" technology, multiple drones are used, one example is the drone of Volansi
Best practise(s)	- Their plan is to develop in the upcoming months and to have 2 main hubs that can deliver to more then 70 locations. - They did test flight from an airport to a company which took 28 minutes and in total covered about 80 km. Previously both a car and ferry would have been needed. - Their plans are to deliver last-mile, inter-island and also to yachts.
Stage	Testing

Company	Skyports / Volocopter (https://skyports.net/) (https://www.volocopter.com/en/)
Mission	Skyports is a mobility company developing and operating landing infrastructure for the electric air taxi revolution, as well as operating cargo drone deliveries. Volocopter aims to become the leading Urban Air Mobility service provider worldwide. With our innovative technology, products and services, we will support cities in sustainably transforming their mobility concepts. Volocopter saves time, is extremely safe, emission-free, and quiet. At Volocopter, we are developing the complete ecosystem including aircraft, take-off and landing infrastructure, and integration into air traffic management systems. We bring Urban Air Mobility to life.
Country of company and practises	Germany Dubai; Helsinki; Singapore
Main service / products	Passenger transport/air taxi
Technology	Drone designed for passenger transport and this concept was used to make a drone that can carry goods up to 200 kg. The passenger drone is a sort of VTOL system.
Best practise(s)	- Over a 1000 testflights. - Permits to fly in manned or unmanned configurations for pioneering test flights in Germany, Dubai, Helsinki and Singapore. - Received design organisation approval by EASA (European Aviation Safety Agency). - Sees other possibilities such as medical, logistics and e-commerce solutions with drones but not much has been realized in this.
Stage	Testing

Company	Workhorse / Moog (https://workhorse.com/index.html) (https://www.moog.com/innovation/aircraft/SureFly.html)
Mission	As an American original equipment manufacturer, we design and build high performance battery-electric vehicles including trucks and aircraft. Workhorse develops cloud-based, real-time telematics performance monitoring systems that are fully integrated with our vehicles and enable fleet operators to optimize energy and route efficiency. All Workhorse vehicles are designed to make the movement of people and goods more efficient and less harmful to the environment.
Country of company and practises	USA
Main service / products	Package delivery Personal transport
Technology	2 different drones: Horsefly for packages and Surefly for personal transport. Not much information about the drones is released.
Best practise(s)	- Test together with UPS: the horsefly was combined with an electric delivery van. UPS believes drones can help to reduce last mile delivery costs. Their project, called ORION, predicts that a reduction of just one mile per driver per day over one year can save them 50 million dollars. They focus on rural delivery routes since these are the most expensive to run. During the test the driver continued the road to make another delivery. - Workhorse is partnering with USOG (Unmanned Systems Operations Group). They are working on unmanned mobile medical delivery logistics and will launch a pilot drone delivery program in the San Diego area. More information is not available since the project is quit recently (8 October 2019).
Stage	Testing

Company	Manna (https://www.manna.aero/)
Mission	At Manna, we are making 3-minute air delivery a reality, whether you want food, medicine or anything you need in your local community.
Country of company and practises	Ireland
Main service / products	Food delivery
Technology	Not much information is known about the drone(s) they use
Best practise(s)	- There first real case tests were planned for 2020. They were going to deliver food in a partnership with Just Eat. But because of Covid-19 these plans are postponed. - However, they are testing drone delivery services in Moneygall Ireland. They are delivering medicine to vulnerable people locked in their homes, due to Covid-19. They have plans for a possible further rollout in Ireland in case of successful tests. The drones deliver prescription orders for medicine to about a dozen households. Because of the use of drones, a zero human contact delivery is possible.
Stage	Testing

Company	RPS Aerospace (http://www.rpsaerospace.com/index.php?lang=en)
Mission	Drone manufacturer
Country of company and practises	Italy
Main service / products	Healthcare
Technology	Hexacopter equipped with a box for temperature-controlled transport.
Best practise(s)	- The Flyn'ICE project together with Anemocyte. Their aim is to contribute to the Cell and Gene Therapies (CGT). They want to use drones to transport new drugs from the pharmaceutical production site to clinical centres. These medicines need to be transported fast and are tailored to individual clinical needs. Temperature during transport needs to be controlled. The quality of the transport of these products is important. They aim to ensure the raw materials from the patient, to produce personalised medicinal products, arrivals at the production site under optimal conditions. It is currently in an advanced testing phase.
Stage	Pilot project

Company	Rigi tech (https://www.rigi.tech/)
Mission	Rigi Technologies is a pioneering drone technology company developing next generation logistics vehicles for faster, easier and eco-friendly deliveries, enabling universal access to goods to communities, governments and private businesses. We are dedicated to create a fully-integrated, easy to use and reliable inter-city drone delivery solution.
Country of company and practises	Switzerland
Main service / products	Healthcare E-commerce; industrial & spare parts and emergency & humanitarian
Technology	VTOL drone for longer distance with a serviceable range of about 40 km and payload capacity of 3 kg.
Best practise(s)	- Plans for a first flight route between two cities in Switzerland for medical services transportation such as blood and laboratory samples. They are currently waiting on permits from the Swiss authorities.
Stage	Testing

Company	Swoop Aero (https://swoop.aero/)
Mission	At Swoop Aero, our mission is to transform the way the world moves essential health supplies. We provide an aeromedical logistics service. Moving medical supplies, on-demand; is our bread and butter.
Country of company and practises	Australia Vanuatu; Congo; Malawi; Mozambique
Main service / products	Healthcare
Technology	VTOL, not much information is known about the drone, but it can carry a payload of 3 kg and has a serviceable range of maximum 60 km.
Best practise(s)	- In Vanuatu they deployed an autonomous two-way air transport network (2018). They delivered vaccines on a commercial contract. They were able to show that transformation of the health supply delivery in these regions is possible by providing on demand delivery of vaccines, pharmaceuticals, test kits… They delivered oxytocin, which could be live saving for mother suffering from postpartum haemorrhaging. - In the Democratic Republic of Congo, they deployed an autonomous air transport network (2019). Hereby, they supported the regional vaccination program, supported by the Ministry of health and VillageReach. They received ongoing funding and will be entering enduring operations. - In Nkhata Bay, Malawi, Swoop Aero took over the operations on the USAID Global health supply chain project (2019). They operated from the district hospital and expanded existing operations, serving 3 times more health centres then previously. There are up to 10 long range flights made per day, with multiple aircrafts airborne at once. They facilitate cold chain deliveries, medication drops and collection of blood samples for HIV/aids testing. - In Nsanje & Chikwawa, Malawi (2020) they started a multipurpose drone operation. They will perform long range deliveries with an ability to assist with flood mapping and disaster response. This will strengthen the health supply chain and improve access to healthcare during the flood season for about 500 000 residents living in southern Malawi. The project is supported by funding of UNICEF and UKAID. - In Mozambique (2020) they commenced operations together with VillageReach. They conduct an average of 10 to 12 flight a day, covering several geographical locations, including flights over populated areas. About 600 km is flown per day. They transported tuberculosis sputum samples, for urgent testing. In a previous project for these tests (without drones), 67% of the samples were lost before reaching the lab. The distribution rates of essential medication and supplies increased by 203%.
Stage	Ongoing operations

Company	Volansi (https://flyvoly.com/)
Mission	We've reimagined the logistics of supply chain management to deliver what you need, where you need it. Volansi's all-inclusive delivery solution utilizes user-friendly mobile platforms, automation and UAVs to revolutionize the way your materials are delivered to increase equipment up-time, shorten critical delivery times, and save on unnecessary warehouse inventory.
Country of company and practises	USA Bahamas, Texas, Puerto Rico
Main service / products	Healthcare, Industrial
Technology	Volansi makes long range VTOL drones. They have multiple models, some are battery powered and others are powered on gasoline (not always clear for the tests which was used).
Best practise(s)	- Pilot in the Bahamas. Testing the capability for long-range delivery of temperature-dependent medicines and vaccines by drone. This pilot was developed in collaboration with Direct Relief, Merck and Softbox. The drone flew over open water between several islands of the Bahamas, beyond the operator's line of sight. Volansi built and operated the all-electric drone. - Test in Texas. They completed a 160 km long transportation of a robotic component weighing 2.13 kg. Because there was no permit for flying beyond the visual line of sight, they followed the drone by car. The test was done in 2017, they didn't share which drone was used, but if looked upon their current available drones the drone was probably not battery powered. - In Puerto Rico they did a test in 2018, a year after a hurricane passed through. Researchers showed that most death from the hurricane were not because of water or wind but the loss of access to medicines, since the people couldn't go to the health centres. No details about the test were released, except for that it went over different terrains and beyond the visual line of sight.
Stage	Testing

Company	Doks (https://www.doks-innovation.com/?lang=en)
Mission	Founded in 2017 in Dortmund, near the Fraunhofer Institute for Material Flow and Logistics IML, Doks. innovation accelerates the digitization of stocktaking and inventory processes, the management of master data as well as the transportation of goods over short distances. The solutions are based on years of research and development, unite machine and deep learning, artificial intelligence and automation approaches. Since January 2018, we operate out of our headquarters in Kassel and develop solutions that help logistics and industrial companies to automate and digitize warehouse and stocktaking processes. Proprietary algorithms for gathering and analysing different types of sensor data, let you create a digital twin of your warehouse with a wealth of actionable information that helps you make better decisions. Combining machine-learning algorithms and automated data processes, we process your data to relevant information and thus offer you advantages in the planning and design of your processes.
Country of company and practises	Germany
Main service / products	Industry
Technology	Quadcopter for shorter distances
Best practise(s)	- No test or pilot projects publicly available yet. - Unique concept of using drones to take inventory of a big/high warehouse. This is their main focus, but also the possibility to use drones to transport something from one side of the warehouse to another if needed. They see this as a way to unlock more potential in already busy warehouses/industrial buildings.
Stage	Testing

Company	Dronistics (https://dronistics.epfl.ch/)
Mission	Dronistics is developing a personal and human-friendly drone delivery system for last centimetre delivery
Country of company and practises	Switzerland Dominican Republic
Main service / products	Food Healthcare
Technology	Quadcopter with small range and small payload capacity but unique since it is built in a sort of cage. It is safe to land in your hands. They focus on safety and what they call last-centimetre delivery.
Best practise(s)	- In the Dominican Republic, the healthcare system is not optimized. There is a small amount of pharmacies and hospitals. It is a region with mountains and not optimized roads. Drones can travel a shorter distance then vehicles travellingby road. They tested delivery of medication in this area. - During the open-days of EPFL ((L'Ecole Polytechinque Fédérale de Lausanne), they flew around the college campus with ice-cream.
Stage	Testing

Company	Ehang (https://www.ehang.com/ehangaav)
Mission	Our mission is to make safe, autonomous and eco-friendly air mobility accessible to everyone. EHang provides customers in various industries with AAV products and commercial solutions: air mobility (including passenger transportation and logistics), smart city management and aerial media solutions. As the forerunner of cutting-edge AAV technologies and commercial solutions in the global Urban Air Mobility industry, EHang continues to explore the boundaries of the sky to make flying technologies benefit our life in smart cities.
Country of company and practises	China Norway; Spain; USA; the Netherlands, Qatar; Austria
Main service / products	Passenger transport
Technology	Special design for passenger transport
Best practise(s)	- Testflights in many countries such as US, North Carolina. - Pilot projects in Spain. - Actual information about the characteristics of each flight or agreement is not available.
Stage	Pilot projects

Appendix 2: Countries of implementation

	Australia	Canada	China	Congo	Dominican Republic	Dubai	Finland	Germany	Ghana	Iceland	Ireland	Italy	Malawi	Mozambique	Rwanda	Singapore	Switzerland	Tanzania	The Bahamas	USA	Vanuatu
Antwork			X																		
Doks								X													
Drone delivery Canada		X																			
Dronistics					X												X				
Fli drone																			X		
Flirtey																				X	
Flytrex										X										X	
Manna											X										
Matternet																	X			X	
Rigi tech																	X				
RPS Aerospace												X									
Skyports / Volocopter						X	X	X								X					
Swoop Aero	X			X									X	X							X
Volansi																			X	X	
Wing	X						X													X	
Wingcopter								X			X							X			X
Workhorse / Moog																				X	
Zipline									X						X					X	