Drones in last mile delivery services

Master thesis with an estimation of delivery drone potential in the last mile of delivery traffic in the Netherlands, and a qualitative analysis about the opportunities and limitations for drones as delivery vehicles

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Preface

Writing a thesis is a long and challenging progress. Especially in a time like the Covid-19 pandemic the repetitiveness days can make it hard to keep the focus on this work. Fortunately many people have helped me during this process, whom I would like to thank for this.

First of all I want to thank Dr. Ir. Tillema, my supervisor, for his input and advice that helped me write this thesis. By asking the right questions and keeping me critical he prevented this research from getting stuck, as all steps were thought through multiple times. Although conversations via video call will never beat a discussion in person, these calls were still really helpful to keep the progress going.

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Lastly I want to thank all respondents for taking the time to participate in the interviews. Without their cooperation writing this thesis wouldn't be possible.

Abstract

In recent years a new delivery method has appeared on headlines of news articles, as well as in scientific literature. This delivery method is delivery by drone. Although drone development is still in an early stage, there are more and more fields and applications where drones are being implemented as part of a business strategy. However it is also clear that there are quite some changes to current delivery drones necessary before widespread drone implementation will become a reality. Therefore it remains ambiguous if drones will actually be implemented into delivery systems, or if the future of delivery drones is limited to a small number of functions. This is what this research aims to find out; to what extent will delivery drones be implemented as part of last mile delivery traffic in the Netherlands in the coming decade? In this research an estimation of the current potential of delivery drones has been created by using a framework with several aspects identified in the theoretical framework. With this information it is found out that drones will need major technological upgrades and space to operate before widespread implementation as part of a delivery chain is realistic. With current weather resistance and limitations by no-fly areas drone operations are often not a possibility. Apart from this framework this research also includes an analysis of semi-structured interviews with companies that have been experimenting with drones, as well as experts in the field of transportation research and drones. With the information from these interviews it becomes clear that there are still major barriers in drone technology and regulations that prevent the first delivery drones from being implemented at this moment in time. However as time progresses some of these barriers will diminish, making the first commercial delivery drone flight realistic. For some functions, such as in the medical field and in high value high priority deliveries, drone delivery has great potential for the near future in the Netherlands. Widespread implementation in parcel and food delivery is however very unlikely for the short term, and to an extent also for the long term. This is because public acceptance for drones in these functions is likely to be low, and other methods, such as delivery by vans, driving robots or bikes, are likely to be more economically viable in a large majority of deliveries.

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1. Introduction

1.1 Societal relevance

In the last decade delivery traffic has increased rapidly in the Netherlands, often with over 10 percent per year (Doole, 2020). Because of the increasing popularity of e-commerce, it can be expected that this delivery traffic will continue to increase the coming years (Yoo & Chankov, 2018). This delivery is done mostly by trucks or vans. In this delivery system, the last mile has become the bottleneck of the parcel delivery process. This is due to its high costs and the lack of progress to realise more efficient transport here (Zhang et al., 2018). The challenge about delivering in the last mile is the fact that this last part is often done in dense living environments. Because of this delivery companies have to take a lot of rules and other traffic into account here, making this part of the delivery process the least reliable and efficient (Yoo & Chankov, 2018), which also limits the sustainability of this part of the delivery process. New technology might be a solution for these problems. In some cities bikes and driving robots have been tried as a solution (Hoffman & Prause, 2018), but the most spectacular effort is trying to use drones to deliver packages.

Ever since 2013, when Jeff Bezos, the founder and CEO of Amazon, revealed plans for drones as a possible delivery vehicle, drone delivery has gained wide attention (Kellerman et al. 2020). As a result a lot of experiments have been conducted by more and more companies. These experiments have been conducted all over the world, with already the first operational networks being present for medical purposes, such as Zipline in Africa (Gangwal et al., 2019). The usage of drones for deliveries is not limited to medical goods however. The companies that are responsible for the most delivery traffic, the parcel and food deliveries, have been exploring what the potential for drones for their delivery functions can be (Di Puglia Pugliese et al., 2020). The first operational drone delivery networks in these fields have yet to be created however.

It should be noted here that this research focuses on drones with delivery purposes. A drone is an unmanned aerial vehicle, a vehicle that is controlled by a pilot on the ground, or a robot that is able to fly autonomously. The delivery purpose includes all drones that are able to carry goods with them. A lot of attention is paid to parcels in particular, as these comprise a potentially large amount of volume, and an implementation in this field would result in a very high impact on the economy and society. Drones that transport people, so called taxi drones, are not included in this analysis.

An advantage of using drones for deliveries is their independence from current infrastructure. Drones can traverse cities as a crow flies, giving a whole new dimension to the traveling salesman problem (Marinelli et al. 2018). Because of this they can travel a much shorter route than regular road traffic. This, combined with the fact that drones are not limited by congestion, can make drones very efficient (Ulmer & Thomas, 2018). Drones are also fast and reliable. Although there is a wide variation in speed between different types of drones, most delivery drones can reach up to 65 km/h (Yoo et al., 2018). Drones do have some disadvantages as well, that might limit their usage. An obvious first is the noise they produce. Drones also can cause privacy issues because they are usually equipped with a camera (Lidynia et al., 2017). With these cameras previously private environments become visible for others. Another prominent disadvantage is safety. Because of the fact that they are largely out of

sight, a drone that suddenly comes down can cause big problems on the ground. Drones also have the potential to be used for criminal purposes or even terrorism (Aydin, 2019). This can cause governments to be reluctant to allow drones to fly in inhabited environments. These are some well-known advantages and disadvantages of drones usage. Of course, this is far from a complete overview. But it already shows that many of the issues concerning drones are very place specific, and largely dependent on the way drones will be implemented.

The Netherlands is one of the countries where several drones experiments have been conducted in the last few years. These experiments include, among others, dropping a parcel on a moving ship (Port of Rotterdam, 2020) and flying a medical drone between two predestined points, one on an island and one on shore (Omrop Fryslan, 2018). Although there is not an operating network in the Netherlands yet, there are still tests being done to find out for which purposes using drones as a delivery tool can be an addition to improve efficiency. And as of 2021, new U-space regulations can provide a more complete framework for this implementation, as the Netherlands has become part of European wide regulations. This framework is created to provide an EU wide system for drones to operate in (Barrado et al. 2020). Still U-space is only a part of Dutch drone regulations. Other, national and regional drone regulations are also in place in many locations. These provide extra obstacles for wider implementation and ensure that commercial drone operations remain limited to groups that have the necessary permits to operate.

The reason why companies are eager to test with drones is that drones have a lot of potential to increase efficiency (Ulmer & Thomas, 2018). The impact of drones however, will mainly depend on how they can be used. This usage is limited by regulations, and as a result drones are not able to achieve their potential. This research can contribute to limit the gap between drone potential and legislative limits, because it can inform policy makers about the main barriers that are found by both the companies that are eager to implement drones and experts in the field. With this information they can create policies that better suit the needs of future drone delivery companies. But also for companies and groups that consider implementing drones this research can be informative about what other companies and experts their experiences with drones are. Scientific literature doesn't provide insight on the views of these groups yet, even though these views are crucial to find out what the impact of delivery drones is likely going to be in the coming years (Nentwich & Horváth, 2018). With the information from this research it will become clear what important barriers need to be overcome before delivery drones can be implemented wider, and whether it is likely that these barriers will be overcome or not.

1.2 Scientific relevance

The last few years have seen a large number of publications on drone delivery, especially in the academic field (Kellerman et al., 2020). This attention has been increasing as time progresses. Kellerman et al. (2020) note a focus on economic benefits of delivery drone usage, whereas societal impact and environmental impact of drones are described much less definitively in most scientific literature. Many researches are indeed focused on comparing different delivery models, where a range of different vehicles is compared with drones in terms of economic efficiency (Di Puglia Pugliese et al., 2020; Marinelli et al., 2018). There is also some interest in comparing different delivery vehicles in terms $C0_2$ emissions (Goodchild & Toy, 2018). These researches often create several models of different scenarios of real world

implementation to test the potential for delivery drones in a wide array of functions, such as delivery of parcels (Di Puglia Pugliese et al., 2020), in health care (Scott & Scott, 2017) or food delivery (Pinto et al. 2020). To what extend delivery drones will actually be implemented is an issue that varies widely in literature, with some reports expecting only a niche role (Kennisinstituut voor Mobiliteitsbeleid, 2017) for drones in last mile delivery, where other see opportunities for drones to become widely integrated, with potentially thousands of drones flying over just one city (Doole et al., 2020). Of course, the fact that there aren't yet any operating drones networks makes this hard to estimate.

Aurembout et al. (2019) and Doole et al. (2020) provide estimations on the total number of deliveries that could be delivered by drones for certain countries, but their analyses lack the incorporation of typical characteristics of the places their drones operate in. This research enhances their approaches to find out what the potential of delivery drones is for last mile traffic by taking these characteristics into account. With this approach this research identifies the effects that several factors can have on drone delivery.

As mentioned by Kellerman et al. (2020), a focus merely on technical and economic potential is not enough in a discussion about drone implementation. With this information many drone models, such as Ulmer & Thomas (2018) or Doole et al. (2020) are very promising in an abstract sense. But a development that looks very good on paper might be less suitable in the reality of operating outside a conceptual space. After all, delivery drones are yet to be implemented in operating networks. A first scenario of application of delivery drones results in several questions that can only be answered within an in-depth examination (Nentwich & Horváth, 2018). This research aims to give such an examination by taking a new approach in this field; taking interviews with companies that are the most likely to implement drones as delivery vehicles, as well as experts in the drone delivery field. With this information a more realistic view on when and for what functions drones are likely going to be used can be given. With these interviews this research creates an insight in especially the short term prospects of drone delivery in the Netherlands.

1.3 Problem analysis

Drones have the potential to become an iconic technology of the 21st century (Kellerman et al. 2020), but there are still many barriers that could limit their impact in the end. It will take some time before widespread use of delivery drones, if at all, is going to be more common however. Because of this fact it is not possible to know definitively to what extent drones will be implemented as part of the last mile transportation system. This will largely depend on how drones develop technologically, if the public opinion is in favour or against drones, and if an implementation of drones in a certain region for a certain function is economically viable (Aydin, 2019; Kennisinstituut voor Mobiliteitsbeleid, 2017). When the first drone deliveries were proposed, such as by Jeff Bezos in 2013, it was expected that drones would be operative by now. Developments however, have apparently not been as fast as expected, as wide implementation is still quite far from reality. This certainly doesn't mean that drone development has come to a standstill. Internationally delivery drones are used for more and more applications, and in the Netherlands, there are several new tests being done to find out what the perspective of this piece of technology is. Meanwhile, as time progresses, the

abilities and legislation concerning drones usage are becoming more clear. New EU wide U-space regulations provide a new environment for tests and business models to operate in (Rijksoverheid, 2021). With this information the question arises to what extent delivery drones will be implemented.

1.4 Research goal

The goal of this research is to find out to what extent delivery drones will be implemented as part of last mile traffic in the Netherlands. This research will add interesting information for the Netherlands in particular, since a lot of the issues related to drone implementation are place and regulation specific. By creating a model of several factors and conducting interviews with experts and delivering companies, this research gives an accurate view of what the most limiting factors on drone delivery are at this moment in time. These factors will then be used to estimate for which purposes drones are likely to become part of a delivery network. Of the purposes that are identified as the most likely, an overview will be created to find their potential in the coming years.

1.5 Research questions

To reach the research goal, the following central question for this research is:

- To what extent will delivery drones be implemented as part of last mile delivery traffic in the Netherlands in the coming decade?

In order to answer this question, the following sub-questions need to be answered:

1. What is the potential to implement drones in last mile delivery traffic?
2. Where do companies and experts perceive opportunities to implement drones, and where are limits?
3. What is the potential for drones in the areas and functions that, according to the interviews, are likely to see delivery drones implemented in the coming years?

1.6 Methodological approach

The sub questions each have their own methodological approach. For the first question the technical and legislative possibilities are discussed, by exploring different limitations, identified by Doole et al. (2020), on the total parcel value that would be suitable for drone delivery in the Netherlands. There are four different limitations identified, and by using secondary data and a GIS analysis the effect of each limitation is calculated. This results in a final number of parcels that would be suitable to be delivered by drone. The method used here has certain limits in its predictive capability, as just technical and legislative possibilities are not the only aspects that affect drone delivery (Kellerman et al., 2020). Still this estimation can provide interesting information about the main factors that currently limit drone usage. The second part of the methodology focuses on finding the motives of companies that operate drones. In order to find these motives this research takes a qualitative approach, namely by interviewing those companies that have been experimenting with delivery drones. This gives the opportunity to find out if the potential and limitations of delivery drones that are mentioned in the literature are perceived similarly or differently by the companies that try to implement drones as part of their business strategy. By interviewing the companies that have been experimenting with drones, knowledge is gained from the groups that are the most likely

to implement drones first. This can then give a good view on the near future of drones implementation (Nentwich & Horváth, 2018). By adding the views of experts as well, a critical reflection on these developments is given, and more insight from different perspectives is gained. In the third question the results from both methods are combined, to reflect on the findings and find where the locations and functions are where it is most likely that drones will be implemented in the coming years.

1.7 Reading guide

This research starts with a scientific overview on delivery traffic and the potential for drones in this regard in chapter 2. The main concepts that impact the potential for drones in delivery traffic are identified, and brought together at the end of this chapter, in paragraph 2.8, in the conceptual model. Based on the concept the research gap is further explored in this paragraph as well. Then the methods to gain this knowledge to fill this gap are discussed in chapter 3, with first the methodology describing the framework of different aspect drone delivery needs to take into account, followed by the method for the qualitative analysis, and the methods of the combined analysis. The result of these analyses are discussed in chapter 4. Then the main findings of this research are again revisited in the conclusion in chapter 5. This conclusion ends with recommendations for further research and a reflection. After the conclusion the sources are listed, followed by the appendixes.

2. Theoretical framework

2.1 Introduction

In order to find out for what areas of transportation drones are being proposed as delivery vehicles, this research starts on a description of last mile delivery traffic in section 2.2. After the problems that arise here have been identified section 2.3 will then discuss some potential new last mile delivery methods. These new delivery methods are compared and the focus narrows to delivery by drones. However before drones can be fully implemented developments in a number of fields are necessary. First technological development will be discussed in 2.4 as these developments will determine for the most part how the drone will operate (2.5). This is followed by a discussion of several scholars on the societal acceptance (2.6) of drone implementation. After this the legislative part in 2.7 describes the current regulation where drones need to operate in. This part narrows the focus to the regulations that are applied in the Netherlands. After the different aspects have been identified it becomes clear that there is still a lot of knowledge lacking in order to find out how drones are likely going to be implemented in the Netherlands. In the final part of this chapter, 2.8, these gaps will be identified. After that a conceptual model is created to close the gap between the knowledge currently available from scientific literature, and the areas where this knowledge is still lacking.

2.2 Last mile issue

The last mile of delivery is likely to receive more traffic as the delivery demand increases. Such an increase is likely as more people are eager to have parcels delivered to their house. Doole et al. (2020) estimate that the amount of parcels delivered in the Netherlands was over 400 million packages in 2017. These number of parcel deliveries increased with 12 percent from 2015 to 2016, and the authors estimate around 15 percent increase from 2016 to 2017. In neighbouring countries, similar increasing numbers are found. According to the Autoriteit Consument & Markt (2020) the number of parcels delivered in the Netherlands has increased in 2018 and 2019 as well, again with over 10 percent each year. This growth in the number of parcels is a worldwide trend, and largely a result of the increasing popularity of e-commerce (Yoo & Chankov, 2018). With growing numbers of online shoppers, more and more delivery traffic is necessary, as most of the goods purchased online are delivered directly to customers (Aurembout et al. 2019).

With an increase in delivery traffic more pressure will be put on the parcel delivery sector, as more parcels will need to be delivered in the same amount of time. This parcel delivery is part of a broader system of urban logistics, a study field in itself. Cardenas et al. (2017) divide urban logistics in three geographical scopes. The macro level, that they call the city logistics, that concerns the actors and laws between cities, and the relation of cities towards each other. The meso level, where they refer to as urban goods distribution. This level concerns the delivery up until the first location in an urban area. Then there is the last scope, the micro scale, called the last mile. In parcel delivery, the last mile of a delivery of a good often takes place in congested urban environments as most people in highly developed countries live in urbanized areas. In such cities there are complex systems of traffic with many different actors

and interests. Such congestion lowers the efficiency of transportation traffic (Perboli & Rosano, 2019). This issue of a lower efficiency is an often discussed topic in logistics and transportation economics (Li et al., 2019). Although compared to the other scalar levels the distance travelled in the last mile scope is minimal, the transport cost can be as high as 28 percent of the total (Cardenas et al., 2017). Delivery traffic can be both to households, as well as freight to companies.

Delivery traffic is disturbed by the many actors in the last mile, but the delivery itself also causes disturbance on the place they deliver goods to. Often delivery traffic requires more space as a result of loading and unloading, storage and packaging (Dablanc, 2007). Visser et al. (2014) note that an increase in delivery traffic doesn't necessarily result in an increase in total traffic, since it also replaces a lot of traffic from consumers to stores. Although people can buy multiple goods in one trip to the store, a delivery vehicle can deliver to multiple addresses in proximity to each other. So if an increase in e-commerce leads to more or less traffic is not entirely clear in the literature. The effect of more e-commerce at the cost of retail commerce might actually be positive on a city scale. Especially in a more spread-out city a decrease in traffic to the busy city centre and an increase in traffic in the empty neighbourhoods could be desirable. However in many situations this parcel delivery traffic doesn't go to the spread out neighbourhoods. When this delivery is done by trucks or vans this can cause congestion problems, as many houses where goods are being delivered are not suited for loading and unloading (Hammami, 2020). A great number of these loading and unloading operations are done in an illegal way, for instance while blockading a road. In Spain over 70% of these operations are done illegally, and in France similar numbers have been found (Hammami, 2020). The increase in delivery traffic will put extra pressure on the delivery systems. Especially in a densely populated country such as the Netherlands this can lead to more disturbance in traffic flows. These traffic flows aren't only from company to consumer, or between companies. One of the most overlooked parts in research concerning package delivery is the large amount of packages that get returned shortly after delivery. The Netherlands is the country in Europe with the highest percentage of packages being returned at 13 percent (DPD, 2020). This number is growing both in the Netherlands as in other European countries. DPD (2020) notices that 29 percent of Dutch people find a free return option the most important consideration when buying a product. This causes again a traffic flow.

Not all people are equally likely to buy products online. According to Beckers et al. (2018) especially well educated men in their thirties are the most likely to buy goods online. Beckers et al. (2018) note that population density appears to have a negative effect on e-shopping in urban areas, and a positive effect in rural areas. They explain that this is mainly related to where the more wealthy residents live. Farag et al. (2006) also note a difference between rural and urban areas in the kind of products they buy online. In rural areas goods that are not as easily available as in urban areas, such as clothing or videos, are bought more online whereas urban residents are more likely to buy travel tickets online. Seeing how delivery has developed in the last decade it is questionable if these conclusions are still true. Even then the differences between urban and rural areas were not large (Farag et al. 2006). Noted should be that in the research of Beckers et al. (2018) and Farag et al. (2006) the data is from Belgium and the

Netherlands, countries with a very high population density, where a rural area would be defined as urban in other countries. This might explain the small differences between rural and urban areas.

The lack of efficiency in the last mile is likely to become an increasingly important issue in the coming years in the Netherlands. If this part of delivery becomes more efficient this can result in large economic gains. Next to that more efficiency can also decrease congestion, and therefore the disturbance caused by increased delivery traffic. For this reason there is a lot of research about optimizing last mile delivery traffic. Most delivery traffic, both to cities or rural areas, goes over roads, with a small number of places being supplied by water (Ranieri et al. 2018). For this reason most research is focused on improving delivery over roads. Several models have been created to describe an efficient delivery system, such as the traveling salesman model. Although new models might still slightly improve delivery systems, years of experience have made delivery via vans or trucks very efficient already. Therefore several new innovative methods are tried, such as parcel lockers and service points, to limit the amount of traffic necessary (Autoriteit Consument en Markt, 2020). Such solutions however, are less convenient for consumers then home delivery. As consumer convenience is an important goal for delivery companies, innovative delivery methods are gaining attention as large gains can be expected from new technology (Ranieri et al. 2018). This will be discussed in chapter 2.3.

2.3 New delivery methods

Paragraph 2.3 provides an oversight of new delivery vehicles that are gaining attention in scientific and popular media. These include delivery via driving robots, bikes and drones. Of these methods several advantages and disadvantages towards each other are discussed. At the end of this paragraph the attention switches to just drone delivery, and its advantages and disadvantages compared to traditional delivery traffic.

In Estonia a company called Starships technology is testing with driving robots that are driving around with small packages (Hoffman & Prause, 2018). Such vehicles have fewer emissions, as they only carry the parcel, and no personnel. As these driving robots could operate in an on-demand system, their arrival time window can also be made to match the demand of the customer. Poeting et al. (2019) show the dependence of this kind of technology on current infrastructure in order to be economically viable. If this infrastructure is poor, implementation of this kind of technology will be hard to realise. After all such robots would share the pedestrian paths. In places where this path is already congested this leads to acceptance problems by the public as well (Hoffman & Prause, 2018). This has already led to laws that strictly limit the usage of such robots in for instance San Francisco. The extent to which new technology can be implemented depends on a combination of their technical possibilities, the extent to which the public will accept it, regulations and their added value.

Using driving robots is not the only modern solution for the last mile issue. Zhang et al. (2018) for instance discuss the effectiveness of using bicycles for inner city parcel delivery. In their research this kind of delivery is proven to be more efficient for short range traffic than delivery by trucks. For delivery companies this is interesting, as it is a cheaper option. For the city a lower amount of emissions is also beneficial. Zhang et al. (2018) find that in Berlin an effective system could be installed. Sheth et al. (2019) also find that in inner cities in the US bicycles

could be a good solution for the delivery of light cargo. Delivery of parcels using bicycles would be interesting in the Netherlands due to its extensive bicycle network. This already has resulted in several delivery services in the Netherlands that use bikes as their primary vehicle, like Cycloon and Fietskoeriers.nl (NOS, 2020). An increasing role for cycling for parcel delivery is therefore a likely future scenario.

Both bikes and driving robots have in common that they depend on current infrastructure in order to operate. Another new technology, the unmanned aerial vehicle, doesn't have this limit. Drones have been suggested by some authors and companies as a possible solution for the last mile issues in the last few years. In the next part the possible role of the unmanned aerial vehicle, in this research referred to by its more commonly known name; the drone, in delivery traffic will be discussed.

Drones

Drones have only caught recently the attention of companies and groups in the field of goods distribution (Kellerman et al. 2020). Drones are vehicles that were first primarily used for military purposes (Ranieri et al. 2018). For a few years however, drones are being used for an increasing number of civil and public functions. Drones can be a solution for the last mile delivery problem, since they are not limited by congestion of other traffic. They are also not limited to following any current infrastructure. Because of this they can travel a much shorter route than regular road traffic and therefore they have the potential to be more efficient. Drones are more predictable in arrival time, which can decrease the number of missed deliveries (Aurembout et al, 2019). Another potential advantage of drone delivery is, when drones are able to operate autonomously, that there is not an operator required, resulting in lower personnel cost (Kennisinstituut voor Mobiliteitsbeleid, 2017). The fact that drones are able to ascend and descend vertically makes that they can operate in many environments. Drones could also be used to return packages, as long as they can be operated by consumers. It is however questionable if this would be desirable for the delivery companies. The delivery company DPD (2020) argues that one of the reasons that Dutch people return a relatively large number of packages might be related to the fact that Dutch people, compared to other Europeans, perceive returning packages as easy. If drones can return packages easily it would remove the barriers consumers might feel to return a product, and therefore result in even more return packages back to delivery companies and web shops.

The aspect of drones that they are not limited by current infrastructure is theoretically the case, but this doesn't mean that drones would be able to fly over every location below. Doole et al. (2020) however, find that in the future drones delivery is a much cheaper way of delivery than bike delivery, especially in larger cities. Most of the costs of delivery is in the costs of hiring personnel, and here autonomous drones or driving robots would have a clear advantage. Full autonomy would however be required before such a scenario can become realistic.

Although drones, robots and bikes can diminish the amount of traditional delivery traffic, so by vans or trucks, they cannot substitute it completely. After all, there is a limit to what a drone, robot and bike can carry. Still a large majority of delivered products fall within the margins that these vehicles can carry (Doole et al. 2020). Although delivery via bike or driving

robot can be profitable in certain environments, drones would be crucial in order to reach the lowest delivery time possible (Perera et al. 2020). However if drones need to be able to live up to their potential some technological progress needs to be made first.

2.4 Technological developments of drones

Although it doesn't reach the news highlights on a day to day basis, remotely controlled and self-flying drones are being used for more and more functions every year. In this paragraph first the companies that show interest in adopting drones will be discussed, followed by a discussion of the drone supply market. In this discussion delivery companies their decision to implement drones is discussed, as these companies will lead the technical development. The paragraph ends with a few technological gains discussed in scientific literature that are presumed to be necessary in order for drones to function in a delivery network.

Drones implementation

A wide array of companies is interested in the potential for drones as delivery vehicles. This ranges from experimental start-ups, to some of the largest companies globally, such as Uber, Amazon and Airbus. The large number of interested parties likely ensures that drones will become more and more capable, as these groups can all innovate the drone to suit their specific needs. Firms incorporate new technology when the profits from this new technology are expected to be larger than when using extra labour (Greatz & Michaels, 2018). These profits are determined by the added value that drones provide minus the cost of capital that incorporating drones would cost. When drones become more widely available and their prices drop, it will become more profitable for many companies to use drones. Often new technology becomes cheaper as its producing industry mature, and this is likely to happen as well for drones.

Although the parcel delivery market in the Netherlands allows for competition, the market is dominated by two companies. These are PostNL, with 60 to 65 percent of the market turnover and DHL, with 25 to 30 percent of market turnover (Autoriteit Consument & Markt, 2020). The amount of competition between firms is often calculated using the Herfindahl-Hirschman index (Brezina et al., 2016). According to this index the Dutch delivery market had a score of 4,153 which indicates a very strongly concentrated market (Autoriteit Consument & Markt, 2016) with large power asymmetries. This gives these companies considerable power in terms of market control.

The drones delivery companies are currently experimenting with a wide array of drones, each suitable for different kinds of packages. Amazon Prime Air, one of the largest companies experimenting to use drones, says that they still are experimenting with new types of drones for specific delivery (Amazon, 2020). Other major investing companies in the US are UPS and Alphabet. Looking globally the Chinese Shenzhen DJI Science and technology company is by far the largest civil drone producing company, producing around 70 percent of drones worldwide, and 85 percent of the professional drones in the Netherlands (Dronewatch, 2019). As the drone market is growing rapidly more companies are likely to invest in drones, but as the production market matures only few producers are likely to remain (Smolka, 2016). The drone delivery market is likely to be dominated by the same companies as those that dominate the delivery market right now. This is due to the fact that the delivery market is highly

concentrated, or oligopolistic (Autoriteit Consument & Markt, 2016). Such markets are characterized by entry barriers (Sloman & Garratt, 2013). These barriers can make it hard or even impossible for new players to enter the delivery market. A disruptive innovation has the potential to shake up such a market (Chevalier-Roignant et al., 2019). Although Perera et al. (2020) explicitly call delivery drones a disruptive technological innovation, it is doubtful if drones will indeed shake up the market, as the implemented drone has to meet many preconditions, and might take long due to its strict regulation. In fact, when permits are necessary to commercially fly drones, which currently is the law in the Netherlands, this can even act as an extra entry barrier when only given to existing companies. Due to the high demand for safety and privacy a scenario where implementation of drones would not result in a change in market shares between the delivery companies in the delivery market seems the most likely.

Necessary improvements

With technological development some aspects are especially relevant for delivery drones. Murray & Chu (2015) have identified a few of the main aspects of drones that need to improve in order to make commercial drone delivery realistic. First of all this is improvement of the battery capacity of drones to ensure longer flights. Secondly would be the addition of a redundant flight system for safety in case the normal flight system doesn't work anymore. Thirdly is improving the GPS communication of drones, as the normal 10 meter accuracy isn't good enough to fly in many urban environments. Improving on the GPS is also necessary to combat deliberate efforts to disturb the drones. Technical progress doesn't only need to be made on the drones themselves, but also to anti drone defence, since drones can be used for criminal and terrorist purposes (Kennisinstituut voor Mobiliteitsbeleid, 2017).

Another aspect that would make drones more suitable would be the capability to deliver multiple packages during a single trip (Doole et al., 2020). Such a development would lead to an increase in efficiency and would limit the number of flight movements. Doole et al. (2020) also mention the weather conditions as a possible problem for drone deliveries. Kennisinstituut voor Mobiliteitsbeleid (2017) mentioned three different weather aspects that play a role; extreme temperatures, precipitation and wind. Doole et al. (2020) however expect that the improvements on drones will limit the days that drones aren't able to operate to an insignificant number. They do not support this claim with any data however.

Perhaps the most important aspect that drones need to develop is reliable autonomy in their operations. As long as drones are not able, and as a result allowed, to operate autonomously a drone network is much more costly than any of the previously mentioned delivery methods. This autonomy needs to be of very high quality, as a failing drone would cause much more trouble in a congested environment than a failing bike, van, or a driving robot. Therefore drones need to have reliable sense and avoid technology (Kennisinstituut voor Mobiliteitsbeleid, 2017), which is currently not good enough yet. As drones operate in air space they will have to apply by rules of the aerial authorities. This connotes that drones have to apply to very strict regulations, as will be further explained in paragraph 2.7.

2.5 Schematic drone operations; possible models for implementation

One of the aspects of drone delivery is the major effect it has on the route good delivery companies have to follow. After all drones no longer have to follow the same routes as the traffic that has to stick to the roads. In their paper Marinelli et al. (2018) consider a delivery system where drones don't go forth and back to the same place but instead fly from a delivery vehicle, like a truck, and while this truck continues to drive further the drone does the delivery, and then returns to the truck on its new location. This will give a whole new dynamic to the traveling salesman problem. As a result, a novel adaptation is called for, the traveling salesman problem with drone, TSP-D in short (Marinelli et al. 2018). In this new system locations that are distant from the other delivery location can be supplied by drones resulting in a much more efficient delivery system. This is visualized in images 1 and 2.

Image 1: Route with vans.

Image 2: Route with vans and drones incorporated.

Two features that make the route a lot longer will get their goods delivered by drones. These drones can depart and land while the delivery car is unloading another package. Although it is very promising in terms of efficiency such a system would require some significant technological improvements, as efficiency is only gained when the drones are able to fly autonomous to the far locations. It is therefore not very likely that the first drones implemented will be operating in such a system.

Using a vehicle that is driving around is one of the possibilities how drones can be implemented. Another option often mentioned in scientific literature is the creation of a certain hub where goods get delivered to (Aurembout et al., 2019; Goodchild & Toy, 2018). From these hubs, or beehives as Aurembout et al. (2019) call them, a hinterland can be supplied with packages. Such an hinterland needs to have a relatively large number of addresses in their proximity to be economically competitive, and therefore it is expected that urban areas are more suitable for drones operating from a hub (Doole et al, 2020; Aurembout et al. 2019). Such a hub is visualized for the same neighbourhood in image 3. Vans supply goods to a hub, and from that hub goods get delivered to their final destinations. The size of such a hinterland is largely dependent on the distance drones can fly on a battery charge, making its potential largely dependent on this aspect. Such a beehive system can also be combined with traditional delivery trucks, where the trucks still deliver to the houses that are conveniently located for a route, while the drones supply the other locations (Murray & Chu, 2015). Such a method will combine the large load capacity and long endurance of trucks with

the high travel speed and uniform access of drones (Kitjacharoenchai et al., 2020). Note however that the travel distance is much longer in image 3 then in images 1 and 2, and even more increased when realizing that drones need to travel back and forth for each package.

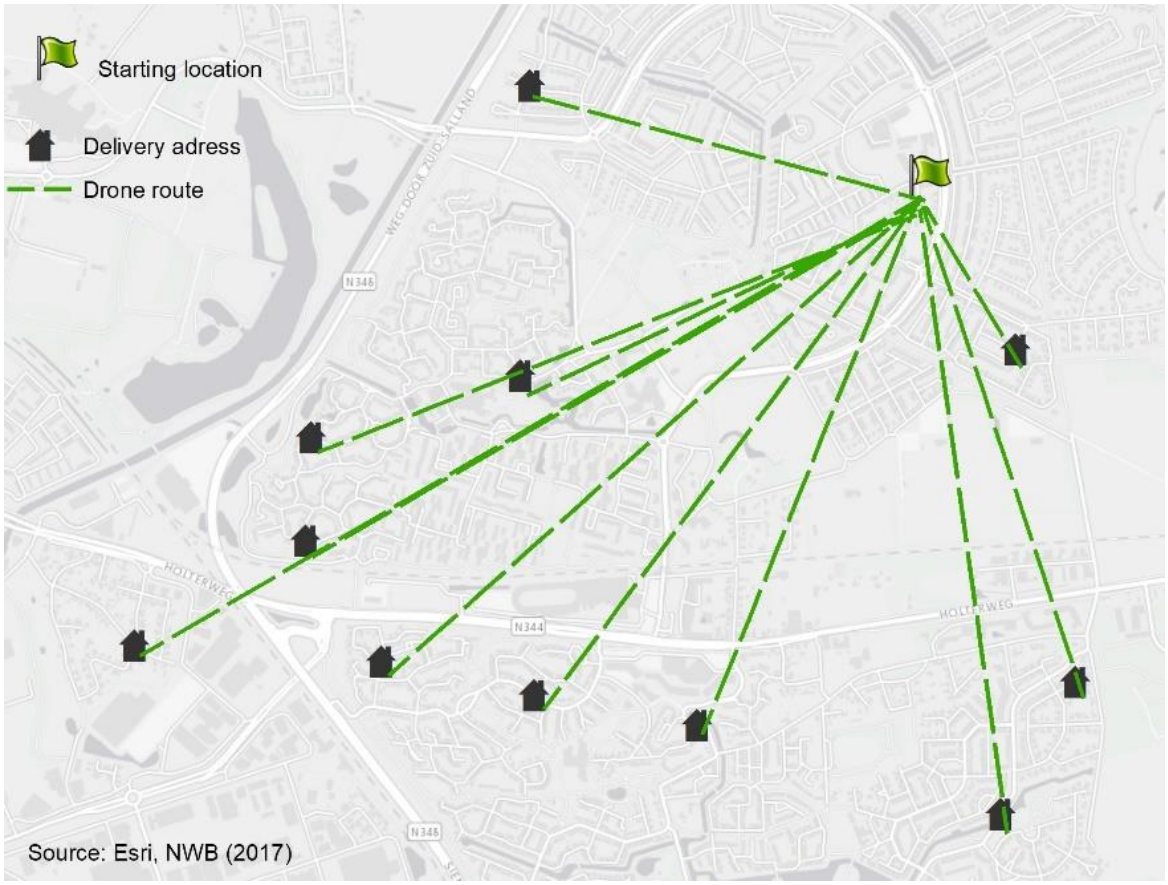


Image 3: Drone delivery using a hub system.

Not all packages are suitable for drone delivery. Doole et al. (2020) assume that current drones are able to deliver packages up to 2.2 kg. This number is based on several tests by possible drone delivery companies such as Amazon Prime Air, Matternet and Flirty. 86 percent of packages delivered by Amazon would suit drone delivery based on this criterion. Based on their criteria Doole et al. (2020) expect that in 2019 there would have been around 220 million packages suitable for delivery in Dutch urban areas. Both Aurembout et al. (2019) and Doole et al. (2020) assume that drone delivery traffic will be focused in urban areas. This is because they expect that a drone transportation system should be quite dense in order to be profitable, as a result of the longer distance drones in a hub system would need to travel. The number of possible packages clearly indicates a huge economic potential for drones as delivery vehicles.

Drones can influence parcel delivery as well. If drones only deliver up to a certain weight or size, this can encourage producers to create products that fall inside these margins. Demand for such goods can also increase then. Amazon Prime Air projects a large role in the ambition for drones to deliver goods in their future ambition to deliver goods everywhere in the world in 30 minutes (Amazon, 2020). Such goals are very ambitious, and as Perera et al. (2020) notice, these goals for maximum efficiency are unlikely to be cost-effective, although Ulmer

& Thomas (2018) expect that a combined system is more efficient. As long as technology continues to provide new opportunities it is likely that drones will be used for more purposes. In order to reach their economic potential however, restrictions by drone unfriendly legislation would first need to be addressed. Such legislation is likely to be created, or will remain in place, when drone operations receive large public backlash.

2.6 Public acceptance of drones

It doesn't require much imagination to realise that an increase in the number of drones has a major impact on the living environment of people. In this paragraph will be discussed how people view this potential change to their living environment. This paragraph will begin with a discussion of acceptance of drones in general, followed by a discussion on drones specified as delivery tools. As acceptance is largely dependent on an understanding of the necessity, the paragraph ends with a discussion in which situations drone delivery would be perceived as a proportional method to deliver a good.

Research has shown that acceptance for most usage of drones in the Netherlands is high (Kennisinstituut voor Mobiliteitsbeleid, 2017). This is especially the case for safety, inspection and research purposes. Acceptance for drones as parcel deliveries is much lower, with 49% of people perceiving it as a very good or good thing, and 21% percent as a bad or very bad thing. These percentages are the lowest of any purpose measured by the Kennisinstituut voor Mobiliteitsbeleid (2017). The low results are mainly a result of concerns about safety and violation of personal living environment. In the USA public acceptance is also high for safety and research purposes, although Aydin (2019) generally finds much lower results. The public acceptance for drones here also differs widely between the different usages of drones. A usage that can be expected to be used first are drones that fly with a medical purpose, as for this purpose acceptance is very high (Kennisinstituut voor Mobiliteitsbeleid, 2017). Such drones could also be used during mass events, where a lot of people come together (Robakowska et al., 2019). If there is plenty of supply of capable drone pilots, something that can be expected in the coming years, this will result in a significant improvement in safety against reasonable cost (Robakowska et al., 2019).

These results show that for many purposes an implementation of drones will be perceived well by most people. Clothier et al. (2015) expects that the general attitude towards acceptance of drones will change a lot in the future, because there is lack of public knowledge about safety issues and disturbances, but also about added value and benefits. Therefore it remains important that drones will continue to operate with the consequences on the ground in mind. Incidents with negative consequences could alter a public opinion against drones (Kennisinstituut voor Mobiliteitsbeleid, 2017). The limits in drones usage will be set by society, so accidents could be devastating to drones development. Privacy is also an important aspect of drone acceptance. Recreational drones are already causing privacy problem when they are equipped with camera's (Nentwich & Horváth, 2018). Lidynia et al. (2017) finds that privacy is, at this stage, the most important concern of non-drone users. The idea that a remotely controlled object is able to locate and observe anyone makes some people nervous, but there are some indications that privacy concerns will disappear as drones become more common. Ramadan et al. (2017) compare the privacy concerns of drones with the data mobile

telephones share. Consumers also share very personal information with phones, fully aware that these can be hacked and tracked. Ramadan et al. (2017) see this as a sign that consumers are willing to hand over privacy in return for efficiency and convenience. A difference here is that giving up your own privacy when you get something in return is different. When a neighbour gets a parcel delivered via drones, you might perceive not to get any benefits from this, and therefore not appreciate the disturbance caused by the drone.

In the previous paragraphs the increase in parcel delivery has been discussed, and the effects this might have on cities in the Netherlands. It was found that the increase in extra delivery traffic might not lead to an increase in total traffic. Therefore, the extra congestion caused by delivery traffic might be limited, and the other negative aspects of delivery by van, such as inefficient transport and pollution, might be not urgent enough for people to see it as that much of a problem, that requires a radical solution. This is especially true when pollution is limited when delivery vans start driving on electricity as well. Drones could be perceived as such a radical solution. This fact can contribute to aversion towards drones in places where they are a cause of nuisance. This will be especially the case in inner cities and residential areas. This can be a problem, since the places that drones will cause the most nuisance are also the places where they are likely to have the highest added value (Aurembout et al, 2019). The inner city of the future is likely to be much less suitable for cars (Stout, 2015), with a larger focus on pedestrians, cyclists and public transport. If an operating drone causes the same disturbance in terms of noise or blockages, it will not be accepted as a delivery option.

The eagerness to adopt such new technology might also be limited when this technology results in a major loss of jobs (Aurembout et al., 2019). Graetz & Michaels (2018) find that for robots, an inclusion of new technology doesn't necessarily lead to a loss in jobs in that specific sector. This could count for drones as well. When goods produced become cheaper consumers are inclined to buy more and this new demand will offset some of the jobs lost. If drones make delivery more efficient and cheaper, cost for delivery can drop as well. Combined with the fact that delivery is still growing rapidly it is unlikely that drones would lead to fewer jobs in delivery companies.

Drones have a lot of aspects that make them quite promising to play a role in future delivery traffic. However there are some clear indications it still might take a while before drones can really play a major role in delivery traffic. Drones aren't reliable enough to be profitable, and many people are not eager to have drones flying around their house. Public acceptance will be necessary before legislation will be adjusted to make drone operations possible.

2.7 Drone regulation in the Netherlands

Drones are not yet used for the delivery of commercial goods. Still, there are many drones in the Netherlands already. These drones are used for both private purposes as commercial purposes. Using delivery drones commercially however, is very hard with the current regulations. As a result most commercial used drones are used in fields like inspection or photography. In this paragraph both European and Dutch drone regulations will be discussed first. The paragraph will end with a conclusion about these regulations.

Since 2021 the European air space has been subdivided into new areas with different flight regulations, the so called U-space (Rijksoverheid, 2021) This U-space is created to facilitate the integration of drones on a low altitude air space. Because the European Union expects drones to provide economic growth it tries to facilitate this development (SESAR Joint Undertaking, 2017). U-space is also an effort to integrate low altitude air traffic with other traffic. The approach of the European Union to support drone development, and to create an environment where drones can operate in harmony with the other actors of society shows that the European Union sees great potential for drones. In the Netherlands special permits were necessary in order to fly drones with a commercial purpose until 31 December 2020. Since then however, the Netherlands has become part of new EU wide regulations, and some commercial purposes no longer require permits. For any drone to operate however, either one of the observers or the pilot needs to have a flight license (Rijksoverheid, 2021). The exclusion to this rule are drones that have been identified as toys, who are excluded from the analysis in this paper.

As mentioned, since 2021 there are new regulations regarding drones usage. These divide all drone flights in three different categories, low risk, medium risk and high risk (Rijksoverheid, 2021). These categories are also referred to as the open, specified and certified categories (EASA, 2015). The rules for low and medium risks categories are already known, but for the high risk category these still have to be defined (Rijksoverheid, 2021). The main rule differences are listed in table 1 below. Delivery drones could fit in the medium or high risk category, as they need to drop something, and may need to fly in inhabited environments. Therefore delivery drones do not fall in the category of commercial drones that can be used openly.

	Low risk	*Medium Risk*
it is allowed to fly above people	No	Yes
flights near aerodromes are permitted	No	Yes
it is allowed to fly with drones above 25 kilos	No	Yes
it is allowed to fly within the inhabited environment	No	Yes
it is allowed to fly higher than 120 meters	No	Yes
drones are allowed to drop something	No	Yes
flying is allowed out of direct sight (BVLOS)	No	Yes

Table 1. Main rule differences between Low and medium risk drone operations

It may seem somewhat counterintuitive that drones that have a higher risk are allowed to do more. This is because of the fact that being allowed to do more makes drones operations in this category riskier. Of course, the extra permissions also mean that medium risks flights have to have much stricter conditions. Although regulations are EU wide, permission for such operations are granted by national agencies. Also regulations about defining where it is allowed to fly drones are made on a national or regional level. Such no fly zones can be a limitation on the potential for drones as delivery vehicles (Aurembout et al., 2019).

In a concept of operations suggested by Barrado et al. (2020) U-space is divided into three different volumes X, Y and Z. In X volumes no conflict resolution is offered, and the remote pilot carries the full responsibility of the safety of the operation (Barrado et al. 2020). In these areas there are relatively few other actors, such as electricity cables or buildings, that use the

air space in the altitudes where drones operate, so the risks are relatively low. An example of such an area could be a rural region. In Y volumes only strategic support is offered. An example of an Y area could be a national park, or an industrial area. In such areas there is still a relatively low density of operation, but risk avoidance is necessary due to the ground situation. In Z volumes in flight confliction detection is fully offered. These can be applied in the most congested urban areas. It is the responsibility of the national flight agency to define which volumes are designated to which categories, and where the borders are drawn (Barrado et al. 2020). Such a concept provides an interesting insight for this research concerning future drones operations. After all, drones in the low risk category are not allowed to operate in very large parts of the country. Even in the areas where they operate strict regulations apply, making it that delivery drones don't fall within this category, but instead either in the medium or high risk drones operations. For these categories there aren't any no fly zones however. These are not necessary because in order to do a flight, the operator of this flight would need a risk analysis checked. As such the government is still able to keep drone operations out of congested or higher risk areas as long as it perceives the risks of these operations as too high. This fact makes that, although U-space allows a little more freedom in terms of operations of commercial drones, the regulator still determines the speed of implementation.

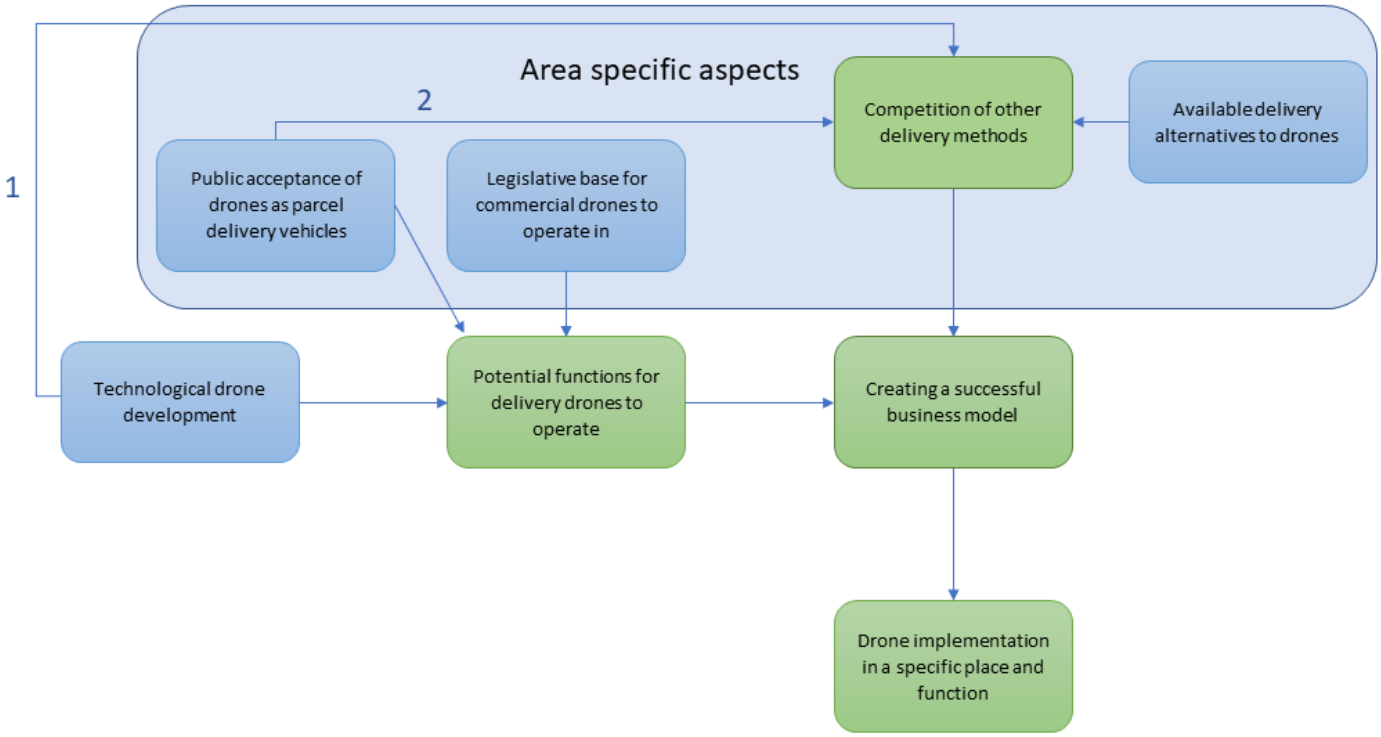
As such the regulations currently in place ensure that in the Netherlands commercial usage of delivery drones is highly regulated. In order to successfully implement drone these regulations would need to be relaxed in due time. Whether or not such changes are only likely to happen will most likely depend on the public acceptance towards drones (Aydin, 2019), as well as technological development that limit safety risks, privacy violations and disturbance. After all, in a country such as the Netherlands drones will have to function in congested environments. This will make it an even harder challenge to operate drones here.

2.8 Conceptual model

From the theoretical framework it has become clear that there is quite some academic knowledge regarding the advantages and disadvantages of using drones as delivery vehicles. In some of the papers several models have been discussed that explore how drone delivery could function (Goodchild & Toy, 2018; Aurembout et al., 2019), and what limitations are caused by public acceptance (Aydin, 2019). As was learned from paragraph 2.6, public acceptance differed substantially for different functions of delivery drones. As a result this also affects the potential for the different function to become a reality. Paragraph 2.7 has shown that regulations are currently a main limitation of wider drone implementation. These regulations make drone implementation very place specific, as no fly zones and rules over flying above people are also dependent on the purpose of delivery. In Barrado et al. (2020) for instance, legislation in urban areas would make several drone deliveries much harder to realise than in rural areas. Technological development is also important for the implementation of drones. Certain functions can only become a reality when improvements are made. In regard to delivery traffic especially higher autonomy is an important factor to make widespread implementation realistic (Kennisinstituut voor Mobiliteitsbeleid, 2017). Technological developments also determine for what kind of parcels a drone would be suitable. A more capable drone would be able to carry a heavier parcel, or even multiple parcels at once (Doole et al. 2020).

Technical development, public acceptance and a legislative base are in the blue boxes on the left side of the conceptual model below, and together these areas determine where drones would be able to operate, and also what kind of parcels a drone would be able and allowed to transport. These are then the potential delivery functions for drones. Public acceptance and legislation can differ sharply between different locations for different functions, and therefore these aspects are in the model identified as area specific. If drones are a business rational choice then drones will need to give economic gains compared to other delivery methods. Such gains will only be there when there isn't a more efficient and cheaper alternative. This is shown in the blue box to the right. If such an alternative is present largely depends on the infrastructure of the place where drones could be implemented (Poeting et al., 2019). Whether a drone will be the best delivery option when there is competition of other delivery methods is dependent on the technical capabilities of the drone, as well as if people will accept the drone for that function, as is visualized in the conceptual model by arrows 1 and 2.

If there isn't a more suitable alternative for a specific function where drones would be able to operate in a certain area, then it is likely that drones will be implemented in that function. A drone operating company would then need to create a suitable business model. When it is learned how such a business model could operate, it becomes clear how a drone can be implemented for a certain function in a specific place. This is the final box of the conceptual model, and will in the end make it clear where the potential for delivery drones in the Netherlands is in the coming years.



Model 1: The conceptual model, with the input factors in blue and the results of these inputs in green.

In the theoretical framework several aspects have been identified within these categories that could play a role in delivery. By creating a framework with several of these aspects it becomes possible to see what the effect of these identified aspects on the total number of possible drone deliveries in the Netherlands is. This framework is created in paragraph 3.2.

After the framework has been created the second part of this research focuses on a qualitative approach to the model. By taking the perspective of possible drone delivery companies, this research provides new insight in how drone implementation will likely develop in the Netherlands. These companies can provide answers about the implementation of drones. As they are currently exploring how to implement drones in delivery traffic, they are dealing with the limitations caused by the first technological progress, societal acceptance and legislative adaptation. But apart from this the companies are also exploring where drones can possibly be implemented, and what the potential for drones can be in the coming years. With this experience they can estimate for what purposes drones are a valuable asset, and what are currently the main obstacles preventing wider implementations. Taking other delivery vehicles into account is crucial here, as companies will not incorporate drones into a business strategy if there are more convenient alternatives. By asking them these questions following the structure of the model this research is able to answer the question to what extent delivery drones will be implemented as part of delivery traffic in the Netherlands in the coming decade.

After this the results of both analyses are combined to find out in what functions and areas the implementation of drones, the last box in the conceptual model, the first drones will be implemented, and how many drones this potentially can include.

3. Methodology

3.1 Overview of the methodology

The methodology of this thesis describes the way this research aims to answer the question to what extent can delivery drones be implemented as part of last mile delivery traffic in the Netherlands in the coming decade. From the literature it has become clear that there are several technical aspects, as well as regulation, that could limit the usage of drones as delivery vehicles. In the first part of the methodology, paragraph 3.2, these aspects are addressed. By looking at the current delivery numbers, an estimate will be made which part of current delivery could potentially be delivered by a drone. Paragraph 3.2 goes through these aspects step by step, which will allow to see the effect of individual actors, as well as the overall picture. This overall picture is an interesting result, however it does not delve into two other components identified in the conceptual model, the public acceptance and the competition by other delivery methods. In order to get information on these aspects eight interviews have been conducted with experts and companies that have been experimenting with drones. Apart from these questions, the interviews also provide a reflective insight on the respondents' view on the limitations on delivery drones, identified in the theoretical framework. With the limitations taken into account, the respondents then provide their views on implementation of delivery drones in their companies business strategy, and the potential for delivery drones in last mile delivery in general. The final part of the methodology describes how the estimation results are combined with the findings of the interviews to find an answer to the question of what the most likely functions and locations are where drones will be implemented.

3.2 Estimation of delivery drone potential via a framework

The first part of the methodology is focused on the question: What is the potential to implement drones in last mile delivery traffic? This question is also discussed in Doole et al. (2020), who have estimated the change in delivery traffic in a few European countries as well. They, however, used the same factors for all countries. Since this research is only focused on the Netherlands it is possible to use more specific data that is provided by several sources. The goal is to give an overview of the delivery market to find where potential for drones is. This paragraph gives insight in several aspects identified in the literature that could affect the usage of drones as delivery vehicles. By comparing the different aspects this paragraph also makes clear which are the main obstacles that prevent a drones delivery network from being created.

The model here is largely based on Doole et al. (2020), but it differs in a few parts.

- This model also includes rural areas as possible areas suitable for drone delivery. After all seeing the results of the experiments done in the Netherlands it is unlikely that drones should focus on one specific area.

- This model doesn't take economic viability into account. Such an analysis would need to take other costs of delivery methods, such as vans, bikes and driving robots into account but this data is not available.

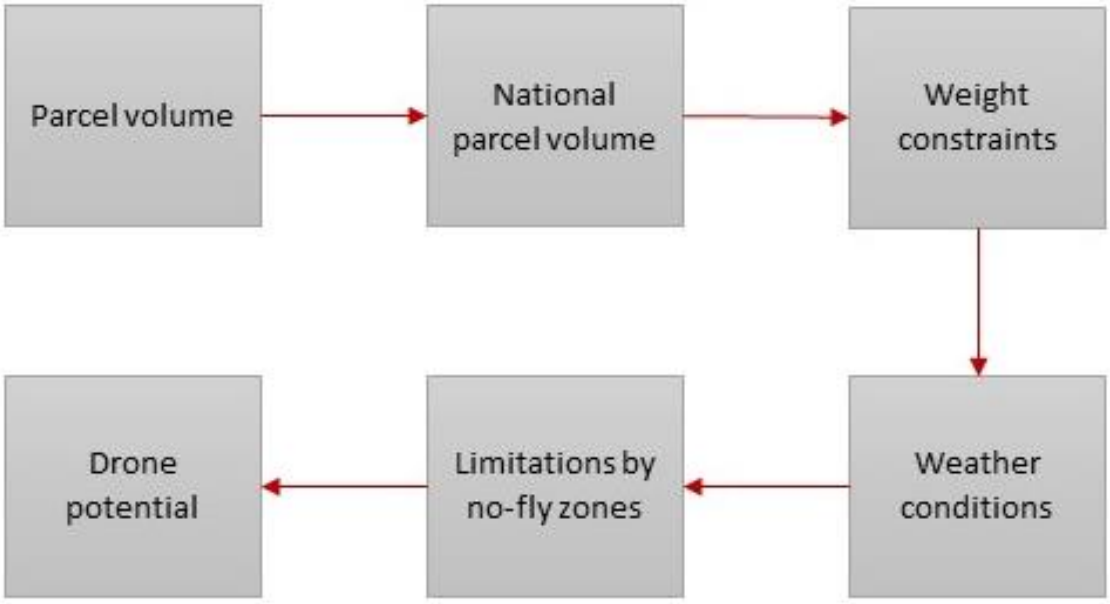
- This model also looks at current Dutch drone legislation, and areas where drones operations are allowed and where not. This is already briefly touched upon in 2.7, and will be expanded here.

- This model doesn't take developments in the growth of the parcel volume into account. It should be noted that the number of domestic parcels has been increasing with over ten percent every year since 2015 (Autoriteit Consument & Markt, 2020) and this trend can be expected to continue in the coming decade. According to PostNL the coronavirus has led to even higher demand for home delivered goods (PostNL, 2020). There are some indications that long term effects of COVID-19 are indeed an even higher percentage of goods being delivered. The extent of these long term effects are still very much uncertain. As an estimation of future delivery is therefore impossible to estimate this research will focus on the hypothetical potential of drones in 2019. In reality the number of parcels will be much higher in the coming years.

The result of this analysis will show the potential that drone delivery has in terms of number of deliveries. This potential is however hypothetical, as current drone regulations and technology make widespread delivery by drones at least a far future scenario. As a result of the fact that drones can't operate in the Netherlands yet, it is hard to find the exact potential that drones have now and in the coming years based on the potential this measure gives. The interesting aspect of this analysis is therefore not necessarily the combined number that is calculated, but especially the separate results of the different limitations that are shown in Model 2. When these results are compared to results of the other estimations, such as from Doole et al. (2020) and Aurembout et al. (2019) typical aspects of drone delivery in the Netherlands will become clear as well.

Where is the potential for drones in the current delivery traffic?

The increase in e-commerce puts extra pressure on the last mile of delivery (Yoo & Chankov, 2018). The extra pressure can be an incentive to try new delivery methods, such as drones. By adding information about the parcels that are being delivered it becomes possible to estimate which parcels are suitable to be delivered by drones. This is not an estimation of the number of parcels that will be delivered by drones, as alternative delivery methods are not taken into account here. Instead it is an estimation of how many could potentially be delivered by drones.



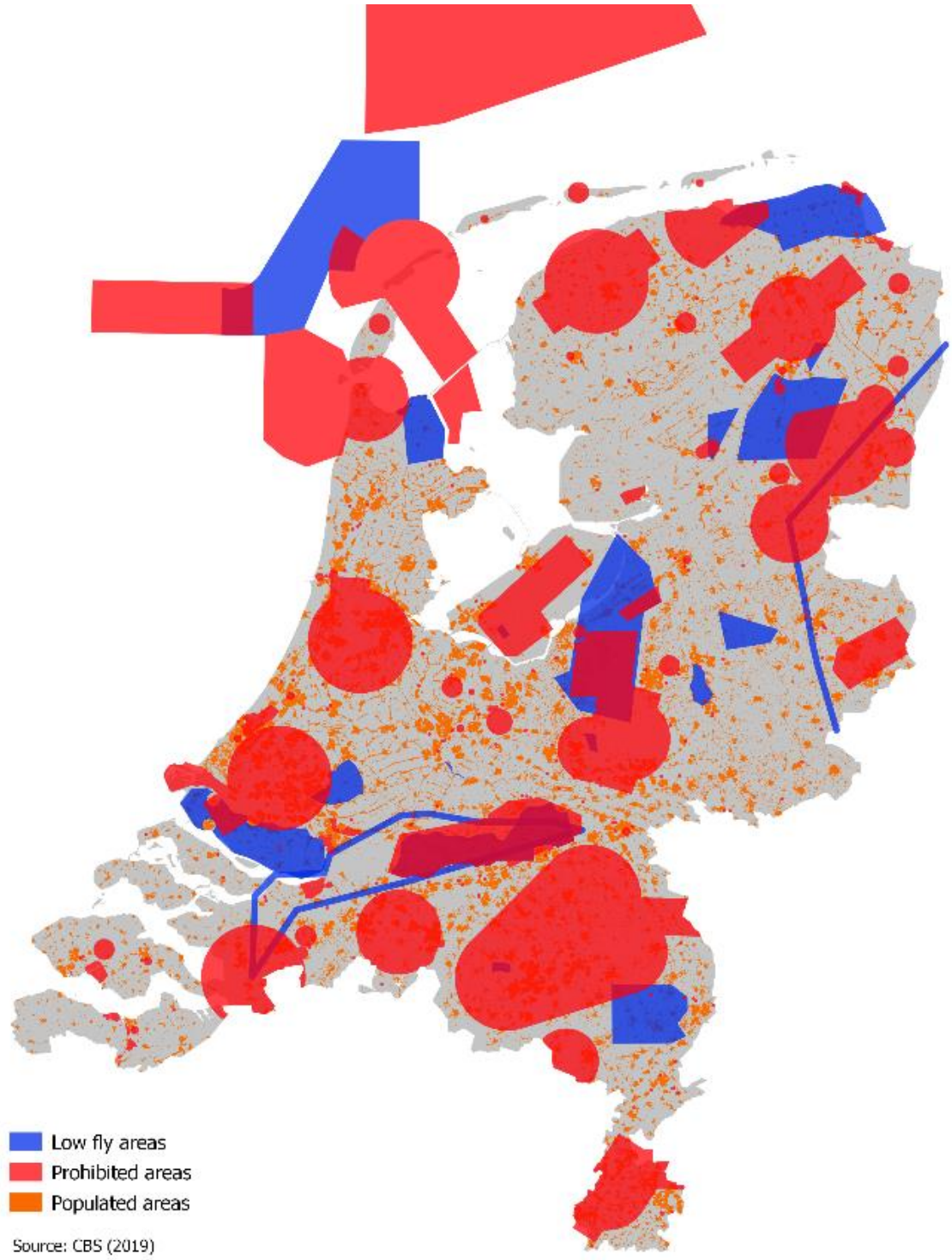
Model 2: Potential of delivery drones based on several aspects.

Each part in the model requires its own method of estimation. For the first two aspects, national parcel volume and weight constraints background data is used. For the national volume this information is gained from the Autoriteit Consument en Markt (2020). The weight constraints are based on the weights that Aurembout et al. (2019) and Doole et al. (2020) provide. These authors have based their weight on numbers provided by Amazon Prime Air.

The efforts of weather conditions of drone implementation

The third aspect is weather conditions. Weather conditions are mainly a limitation for smaller drones (Kennisinstituut voor Mobiliteitsbeleid, 2017). This can be a limit in the first years of implementation, however it is possible that these negative effects will diminish as drones technology improves. Therefore Aurembout et al. (2019) don't even consider weather as a limitation, and assume drones can deliver 365 days in a year, whereas Doole et al (2020) limit the days drones cannot operate because of weather conditions to 20 percent of days. As this analysis studies the potential for drones now, it will take the current limitations into account. Information of the Kennisinstituut voor Mobiliteitsbeleid (2017), as well as from drone sites such as DroneDJ (2019) will be used to describe for which weather conditions drone usage is limited. Weather data from KNMI (2021) will be used. This weather data is focused on three different aspects that limit drone usage; temperature, precipitation and wind. These factors are discussed to find how many days the weather conditions related to that factor would have limited drone usage in 2020. How these factors are defined is described in appendix 7.1. The current weather data will be combined with current drone capabilities as a worst case scenario. The effect of the weather will be in between this scenario and the optimal scenario where weather doesn't have a significant effect on the number of parcels delivered.

There are a few assumptions in this approach. First of all, the weather data is based on information in De Bilt. De Bilt is located in the middle of the Netherlands, and thus provides a reasonable average. However, for instance for the factor wind, the coastal areas will have more days with wind speeds above the margin, whereas inland areas have more days below zero. It should also be noted that weather data for the year 2020 is picked. This is because this estimation is to provide information on current drone potential. Changes as a result of climate change will affect weather in the future, but will not be taken into account here. How the different factors affect the number of possible drone deliveries is described in Appendix 7.1.



Map 1: Areas with extra drones regulations in the Netherlands, with no-fly zones (in red) and low fly areas (in blue). In the rest of the country (grey) recreational drone usage is allowed, as long as the flight rules are taken into account.

Restricted areas for drone operations

In some areas, as shown by map 1, drones in the low risk category are not allowed to fly. This is due to a wide array of reasons, such as military areas, civil airports or industrial areas. In this analysis these no- and low-fly zones will be used to see what the effect of these areas is on the total potential for drones in the Netherlands. It should be noted here that drones in the medium risk category, where most delivery drones would fit in, can operate here after gaining permission to do so. This doesn't mean that delivery drones would be allowed to operate everywhere in the Netherlands however, but as widespread implementation isn't yet realistic no such zones have been identified for drones in this category. Therefore the no-fly zones that are there for drones in the low risk category are expanded to the delivery drones as well. This is a very broad estimation, but since the low air space in the Netherlands hasn't been divided into different volumes yet (Barrado et al. 2020), it is not yet possible to use no-fly areas identified for delivery drones.

With Geographical Information systems, or GIS in short, it is possible to analyse and model spatial data to solve real live problems (Jensen & Jensen, 2012). GIS does this by putting data in a digital map, making it possible to relate the effects of the location of data towards each other. Usage of GIS and its functions has expanded over the years as the capabilities of the software have improved (Batty, 2010). This makes that GIS can not only be used as a visualization method, for which it is also used in this research, but also as a method to relate spatial phenomena. In this research this makes it possible to find how many addresses would fall within no-fly zones for drones. An advantage of this method is that it is also clear which addresses would be included, making it possible to find where addresses are located compared to each other. This will be used to estimate how many addresses can be described as urban, and how many are rural. Using GIS to estimate the capabilities of drones is also used by Goodchild & Toy (2018), who use GIS tools to compare a network of delivery drones with a delivery network of delivery trucks. GIS is quite a popular tool in the field of economic geography to find ideal locations in a hub (Ballas et al. 2018), or to find optimal locations for new stores. GIS might therefore also have the potential to be used to find the best locations for drones hubs.

Although ArcGIS has also been used to convert some data formats, the main analyses for this research have all been conducted in QGIS. The reason why this software was chosen is its relative faster speed compared to ArcGIS for analysis with a large amount of data. This was very relevant in this research, as using all the addresses is the Netherlands, over 9 million features, makes such an analysis a slow process.

Using their location, addresses that would fall within and outside no-fly zones are found. These areas are then defined as either rural, intermediate or urban, based on density of the addresses in this neighbourhood. In the results chapter it is researched which percent of houses in each environment would be within areas where drones can deliver. This can give an answer which spatial environment is most suitable for drones. The data here is from CBS, that defines five categories of urbanity. In this research the categories get brought down to three, using the same levels as Koster et al. (2020), rural, intermediate and urban. The amount of delivery for each customer likely doesn't differ much between urban and rural environments (Beckers et al. 2018), however Doole et al. (2020) expect that a high number of addresses

need to be in proximity of each other, making rural areas less suitable for drone delivery. Koster et al. (2020) do note that a definition of rural and urban for the Netherlands, a very densely populated country, wouldn't necessarily also suit other countries. As Koster et al. (2020) their analysis is based on municipalities they also take population density into account. This is not applicable for this analysis, as this is done on a neighbourhood level. In Appendix 7.2 the definitions of each category are explained.

3.3 Qualitative approach; The future of drone delivery according to companies and experts

Drones aren't yet flying over the Dutch cities. Still there is plenty of information on the technical aspects and possible implementations of these machines in both scientific and non-scientific literature. The way drones will be implemented in delivery traffic will largely determine how drones are going to affect the living environment of people. Although the literature has provided a few scenarios for drone implementation it is currently impossible for any methods to operate in the Netherlands, due to technological and legislative restrictions. Therefore it might seem that drones are unlikely to be implemented in the short term, yet there are quite a few companies that are experimenting with drones as delivery vehicles. Where do these companies see potential, and where do they find limitations? Answers to these questions can play a crucial role to create a view how drones will be implemented in the Netherlands.

From the theoretical framework it has become clear that before implementation of drones is viable first technological progress, societal acceptance and legislative adaptation needs to be achieved. These three themes, identified in the conceptual model as the three factors that determine the potential functions drones can operate in, are central in the first part of the interviews. This provides a new insight in these themes, and gives an answer which of the aspects identified in the theoretical framework are indeed perceived as problematic by the people actually interested in adopting drones. By beginning with open questions other aspects that weren't mentioned by other authors have been discovered as well. With these themes taken into account in the first part, the second part of the interviews focuses on the question how drones would be integrated into a strategy of a company in order to be successful. In the conceptual model it was determined that if a drone will be implemented depends on the potential functions drones can operate, and if there are no other delivery methods that are more economically viable for that specific function. This means only when drones also provide an advantage in terms of cost efficiency, the creation of a viable business model can follow. Via the interviews it has been found where the respondents perceive the potential for functions where drones would meet this criterion. The respondents were also asked about their views on wider implementation of drones in delivery traffic.

Qualitative research through interviews is currently a very popular research method in the human geography field (Hitching & Latham, 2020). In economic geography quantitative methods are still very popular. Steen (2016) notes however that in the field of economic geography qualitative research is more suitable in periods of economic and social change. Qualitative research is in general more explorative in nature then quantitative research. This is the suitable method for a technology not yet implemented like drones. The interviews are semi-structured. This method is used in this research as the respondents were expected to differ quite a lot in their experience with drone usage, as the purposes of their flight and potential for their company was expected to differentiate quite a bit. The semi-structured approach allowed for the freedom to make sure that each of these unique experiences would be explored. Still some structure was required. This is because the different parties have tested drones in different ways, and taking a too free approach would result in answers that couldn't be compared, which would have made an analysis impossible.

According to Steen (2016) an "analysis of innovation and industrial change should be based on a combination of retrospective, contemporary and prospective data" (Steen, 2016, p. 1619). Interviews are a suitable method to collect such data. Nentwich & Horváth (2018) recommend combining the view of both stakeholders and experts in an examination of the first applications scenarios for drones. The two following groups have therefore been approached:

1) Current companies/groups experimenting with drones in the Netherlands.
2) Experts with knowledge about drones and current and future delivery.

The number of companies in the Netherlands that are experimenting with drones as delivery vehicles is quite small. This is most likely the result of the fact that an operating delivery drone network is something that will most likely not happen in the coming years. Only larger companies can afford to invest in experimenting with such costly technology, with possible gains quite far away from now.

The two groups are interviewed in order to answer the second question; Where are the opportunities to implement drones, and where are the limits? The companies have been selected because they all have experience in tests with drones, and therefore have knowledge about the different aspects that need to be taken into account when flying a delivery drone. These currently experimenting groups have a good retrospective view on the successes and limitations so far. For some of the larger companies experiments with drones as delivery vehicles have been conducted in other countries, with different drone regulations.

The interviews have been conducted with five spokespersons from different companies that have done experiments with the usage of drones as delivery vehicles. Which companies the respondents are from is listed in table 2.

Respondent	Company/Organization
1	Dominos
2	ANWB Medical air assistance
3	Port of Rotterdam
4	PostNL
5	DroneQ Aerial Services

Table 2: Respondents of the interviews.

Some of these companies, such as the Port of Rotterdam or ANWB Medical air assistance, are not parcels delivery companies. Yet they all have been using drones to deliver parcels to find out what the potential for this delivery method is, and will therefore be able to provide interesting answers to questions about the current potential for delivery drones in last mile delivery traffic.

Next to the five interviewed companies three experts have been interviewed as well, to learn their thoughts on drone development as part of delivery systems. The interviewed experts are listed in table 3.

Respondent	Function
6	Assistant Professor Sustainable Logistics
7	Lector City Logistics
8	Drone expert Netherlands Aerospace Centre

Table 3: Interviewed experts.

As all interviews were conducted, transcribed and coded by the researcher the richness of the qualitative data is ensured (John & Johnson, 2000). This transcription of the first interviews was done while the other interviews were still being planned and conducted. As a result similarities and differences in the answers that the different respondents gave were already found during this process. This also made it possible to determine when saturation in answers was reached, after which no further interviews were planned.

Companies are approached on their impact on last mile traffic and their knowledge about using drones as delivery vehicles. PostNL is the largest parcel delivery company in the Netherlands, with over half of all parcels delivered. As such their decisions are of major impact on drone delivery in the last mile. Companies such as ANWB medical air assistance are interesting, since their position as a medical emergency services enables them to go further in drone experimentation than other drone operating companies. A company like Dominos provides insight how drones can operate for a more precise delivery, and how different experiments in different countries have succeeded. Port of Rotterdam provides insight about drone operations in an area where chemicals and heavy industry provide unique safety challenges. Meanwhile, DroneQ have great experience in flying drones for different purposes, and have knowledge on the specific challenges that delivery with a drone has to deal with. The scientific experts are specialized in last mile traffic and both follow drone development extensively, while the Netherlands Aerospace Centre has, as one of the institutions that can give permits for drones flights, a very good view on limitations of current drones usage.

The respondents were contacted via email. Some of their email addresses were gained from contacts of UMCG Ambulance Zorg in the drone business or from networks such as the Dutch Drone Delta. Other mail addresses, including the experts, were found online via google search. In this email respondents were already introduced to the topic of the thesis, as well as the goal of the interviews. The interview questions were not sent in advance, as the semi-structured nature would then be lost if the respondents would be prepared for the questions. The interviews were conducted and transcribed in Dutch, as both the interviewer and the respondents were expected to be most comfortable in this language. The quotes in chapter 4.2 and the interview guide in chapter 7 are translated as literally as possible from Dutch to English. Due to the continuing corona outbreak it has not been possible to conduct any of the interviews in person. Instead the interviews were held in online sessions. According to Shapka et al. (2016) the data quality gained from online interviews is similar to face to face interviews. Online interviews do have the tendency to take longer and produce fewer words. Mirick & Wladkowski (2019) conclude that online interviews are a suitable alternative to face to face interviews as well. They do mention that it is important that the person interviewed is comfortable in the use of the technology. Although most people will have gained this experience as a result of the social distancing caused by the Covid-19 pandemic, all respondents were offered to choose an online meeting program they were comfortable in.

The programs used were Skype, Zoom, Microsoft Teams and Google Meet. All the interviews were recorded, to make the transcription more convenient. Generally these recordings were very easy to transcribe, although sometimes some problems with internet connection made one or a view words incomprehensible. These parts were identified in the transcription.

The general structure of the interview is based on the approach of Steen (2016), beginning with a retrospective view on tests that the company has run, followed by contemporary limitations and potential, that takes the three dimensions of technological progress, societal acceptance and legislative adaptation into account. The interview ends with a prospective view on the economic gains that the respondents expect. This prospective view also contains questions about how the company plans to implement drones as part of its business strategy. The interview with the companies can also be found in chapter 7.3. The structure of the interview with the experts differs, as they haven't done any tests themselves. Here the first focus is on current drones potential, followed by expectations for the future, including a discussion of other delivery methods. With the retrospective question in between the three dimensions of technological progress are also taken into account here. The interview with the experts can be found in chapter 7.4.

The interviews were analysed with Computer-Aided Qualitative Data Analysis Software, namely Atlas.ti version 8.4. Van Hoven (2010) describes Atlas.ti as a theory building program, with the capacity to test hunches, ideas and hypotheses. Within Atlas.ti the text was codified to find the connections between the different aspects that were identified in the conceptual model. First the text has been divided into 5 themes, that were identified based on the theoretical framework; the technological needs, legislative limits, societal concerns, economic potential and business strategy. Then within these themes several codes have been identified, that were sometimes based on findings that were also suggested in theory, while other codes were based on similarities between the different interviews. As such it has become possible to find the motivations of each company behind their reasoning to test with drones, and see on which areas opinions differ or whether they consent. This made it also possible to see if hypotheses gained from the literature correspond to the views of the respondents (Van Hoven, 2010). Sometimes quotes are used and discussed in the result analysis to delve further into interesting points of view provided by the companies or experts. Findings about the drones tests and potential that didn't correspond with any of the themes, but were still interesting to this research were noted. These aspects of interest were then added to other interviews to see how other respondents would reflect on this aspect. An example of this was the view of experts that drones might be used for publicity purposes.

Atlas.ti sometimes gets criticized for enticing researchers to focus on volume and breadth instead of depth and meaning (John & Johnson, 2000). To prevent this no auto coding is used (Kellerman et al. 2020). The relative small size of the respondent group also makes this less of a problem, as this especially occurs with large amounts of data (John & Johnson, 2000).

Ethics

Longhurst (2010) identifies two important ethical aspects to take into account while conducting qualitative interviews. First of all this is insurance that data will be dealt with confidentiality, and the other that they are allowed to withdraw from the research at any moment, so during and after the interview. The respondents were told this at the start of each interview. Next to that the respondent have all been told what the goal of this research was, and why they were interviewed for this research. The respondents were asked to give if it would be allowed to connect the name of their company/organization to their answers. They all agreed to this. The experts agreed to connect their title to their answers. As the interviews didn't discuss any cultural or societal sensitive issues it was not necessary to take these aspects into account.

3.4 Combining the analysis and the interviews

This chapter of the methodology is focused on the answer to the question: What is the potential for drones in the areas and functions that, according to the interviews, are likely to see delivery drones implemented in the coming years? In order to answer this question both information gained from the analysis the interviews is used. How this data has been collected is described in 3.2 for the model analysis and 3.3 for the interviews. This chapter focuses on how this information is combined.

From the model analysis a concrete view is created on which factors play an important role in the current potential of delivery drones in the Netherlands. One of the aspects they show is in which spatial environment the most addresses can be reached by drones. This information will be combined with the views of the interviews. In the interviews it has become clear that there are a few functions where delivery drones have the potential to be implemented. This paragraph delves further into these functions and sees how the aspects researched in analysis affect the delivery potential for these functions in different places. By combining the results of both the model and interview analyses this paragraph gives an answer to the final part of the conceptual model, the implementation of drones in a specific place and function. It does this by combining the quantitative results from analysis with the qualitative insights gained from the interviews. By bringing these results together this paragraph is able to give a concrete view on how the first delivery drones will be implemented as part of last mile delivery traffic in the Netherlands, the central topic of this research.

4. Results

4.1 Estimation of drone potential in the Netherlands

Total and national parcel delivery

In 2019 the Dutch delivery market, consisting of all parcels that were delivered by the six largest parcels delivery companies in and from the Netherlands; PostNL, DHL Parcel, DPD, GLS, UPS and TNT (Autoriteit Consument & Markt, 2020), included 576 million goods, and had a total turnover around 2,8 billion euros. Of these 576 million, 399 million, or 69%, were domestic good delivery, while the other 177 million were cross border delivery (Autoriteit Consument & Markt, 2020). This is a large difference from UPS global average of 85% of goods delivered domestically (Doole, 2020). This difference is likely a result from the open borders and large trade relations between the Netherlands and its neighbouring countries. Drones are not suited for cross border delivery as flight permissions, needed for drones in the medium risk category, are all handled on a national level.

Weight

Of delivery drones that are able to operate in urban areas, Doole et al. (2020) estimate the carrying capacity to be around 2,2 kilogram. This is about the weight the drones of Amazon Prime Air are going to carry in the United States (CNBC, 2020). According to Doole et al. (2020) 86 percent of packages are lighter than 2,2 kilogram. If such a weight gets standardized goods might be adjusted to suit this demand. Taken this assumption into account, 343 million (86% of 399 million) parcels would be suitable for drone delivery in terms of weight.

There is a wide array of different drones, with all their own carrying capacity. After all there are also drones that are able to carry persons. Drones that can carry larger weights are often larger however, and therefore less practical for deliveries of small goods. The number 86 percent of parcels therefore only includes the deliveries that can be done by drones that can deliver parcels in inhabited environments.

Weather

Three weather conditions have been identified to have impact on the potential of drone delivery services. The number for these categories have been combined and the results are shown in table 4. There is some overlap in the final number, as there are many days where more of the conditions that prevent drones usage are present. This has resulted in a number of approximately 54 percent of days where drones cannot operate as a result of weather conditions, taken the assumptions in Appendix 7.1 into account.

Factor in 2020	Days	Percentage of year
Temperature < 0	31	8,5%
Precipitation > 1 hour	146	39,9%
Wind speed > 8 m/s	56	15,3%
Days with at least one of the above	197	53,8%

Table 4: Results weather analysis. Source: KNMI (2021).

The number of around 46 percent of days where drones would be able to fly without limitations by weather conditions shows that these are currently a major limitation on the

potential of delivery drones. It should be stressed here that these numbers are a result of a conservative approach, as explained in appendix 7.1. In reality there will be a substantial number of days where it will be possible to fly with drones for at least a few hours without taking major risks. Still, the number is also much higher than the factor of 20 percent that Doole et al. (2020) assume in their calculation. Especially precipitation seems to be a major limiting factor for drones to operate. However also in the fields of dealing with cold temperatures and flying with higher wind speeds drones have still much to gain.

Limitations by no-fly zones

As mentioned in chapter 3.2, the no-fly zones for drone delivery have been defined based on the no-fly zones of low risk delivery. These areas were downloaded from Kadaster (2020) and put into QGIS. There they were compared with the location of all addresses in the Netherlands. In the Netherlands there are about 9,4 million addresses (BAG, 2020). For these addresses it was checked if they were within areas that are currently within the no fly zones depicted in map 1 (page 29). The results are shown in the table 5 below.

Total (9,425 million addresses)

Address	Number of addresses	Percentage
In prohibited areas	4,28 million	45,4%
In low fly areas	377.000	4%
Prohibited and/or low fly	4,53 million	48,1%

Table 5: Results no fly zones analysis. Source: Kadaster (2020).

There is some overlap, as there are houses in areas that are both described as prohibited as well as low fly areas. In the two maps below it is visible where the locations are where drone usage is prohibited. As is visible, these areas are spread throughout the whole country. The resulting number, 48,1% is quite high, with only 51,9% of addresses possible to be reached by drones. No-fly zones are also something that needs to be taken into account when building hubs from where to operate from (Aurembout et al. 2019). For some areas multiple no-fly zones close by could make delivery to places that fall outside of these areas unviable as well.

The location of these no-fly zones is an important aspect. Apart from the total number the difference for delivery potential between rural, intermediate and urban neighbourhoods, as explained in paragraph 3.2 and appendix 7.2, was also studied using GIS. In appendix 7.2 map 2 it is also shown which neighbourhoods have been identified in which category.

Rural (Total 1,376 million addresses)

Address	Number of addresses	Percentage
In prohibited areas	431.000	31,3%
In low fly areas	164.000	11,9%
Prohibited and/or low fly	523.000	38,0%

Table 6: Delivery limitations by no-fly zones in rural areas.

Intermediate (Total 2,999 million addresses)

Address	Number of addresses	Percentage
In prohibited areas	1.028.000	34,3%
In low fly areas	169.000	5,6%
Prohibited and/or low fly	1.156.000	38,5%

Table 7: Delivery limitations by no-fly zones in intermediate areas.

Urban (Total 5,048 million addresses)

Address	Number of addresses	Percentage
In prohibited areas	2.821.000	55,9%
In low fly areas	44.000	0,9%
Prohibited and/or low fly	2.848.000	56,4%

Table 8: Delivery limitations by no-fly zones in urban areas.

As mentioned in the methodology, living in rural, intermediate or urban area has little effect on the average demand per person in terms of deliveries (Beckers et al., 2018). So although these findings are very relevant to provide an answer to the question in which area the most potential for drones is, it doesn't make a difference for the result of the analysis for this specific paragraph. Therefore the results from table 5 are used for the calculation.

As could be expected based on what map 1 already showed, no-fly zones are especially prevalent around urban areas. For intermediate and rural areas roughly similar results are found. The reason for this higher percentage of addresses limited by no-fly zones of urban areas can be found in the fact that the larger no-fly are mainly around civil airports. Civil airports are usually located close to larger cities.

Combined number of possible deliveries

In table 9 the different parts of this analysis are listed, with the percentage of each category that would be suitable for drone delivery. The number of parcels that would remain after adjusting for these aspects is shown below total in millions.

	Percentage suitable for drones	Remaining total in millions
Total parcel volume		576
National parcel volume	69%	399
Parcel volume with a suitable weight for drone deliveries	85%	363
Parcel volume taking weather into account delivery	46,2%	158
Parcel volume taking no-fly zones into account	51,9%	83

Table 9: Parcel volume potential for drones.

So only around 15% (83 million of 576 million) of all parcels in the Netherlands would potentially be suitable to be delivered by drones using this method. This number provides an

interesting estimation at this stage, and shows that especially weather and no-fly zones are very major limitations to drone implementation.

Reflection on the drone potential estimation

The analysis shows that there are currently some major factors that would limit the potential of a widespread drone delivery system. Although this is currently a reasonable estimation, drones are continuously improving, so by the time implementation would become realistic these issues will likely play a much smaller role. Still it is a clear indication that the combination of a maritime climate with a high density of population, and no-fly zones as a result, make widespread drone implementation in an early stage quite hard in the Netherlands. These issues are quite place specific after all. This doesn't mean that the Netherlands would be unsuitable for drones in the future. It should be noted here that in terms of economic and emission reduction potential a high population density is likely to be beneficial for drones (Aurembout et al 2019; Goodchild & Toy, 2018). Therefore this limited current potential is especially relevant for the coming years.

4.2 The future of drone delivery according to companies and experts

This chapter follows the same structure as where the interviews were held in, as described in paragraph 3.3. It starts with a discussion of the three aspects that determine whether drone implementation is possible, as identified by the conceptual model. These are technological developments, public acceptance and legislative limits. The second part then discusses the other aspects identified in the conceptual model, that focuses on the potential that respondents see for delivery drones, implemented in certain functions. This discussion concerns the competition of other delivery methods, as well as possible environments for delivery drones to operate in. As a result all parts of the conceptual model are discussed in this paragraph.

Companies and experts view on technological developments

As discussed in the literature, drones need to improve technically before they can be used widely. The companies mention a lot of different aspects that need to be improved. Some of these issues are quite concrete, such as GPS distortion by objects or buildings. Another problem typical for parcel delivering drones that was mentioned was the fact that a parcel makes it hard to safely land the drone, as the camera on the bottom of the drone its view is blocked by the parcel. Other issues are broader, mentioning a lack of robustness of the technology, or inadequate safety technology. In general the view is shared that these issues will not be as limiting on drone operations in the future as they currently do. By finding smart solutions some respondents are also able to deal with many of the issues themselves.

Respondents that have tested with drones encounter a wide variety of issues. This is likely a result of the fact that only a small number of tests have been done, and some limitations are very test specific. The drones that are used for the tests differ quite in size; some drones carry weights of 750 grams, while others can carry up to 2,7 kilograms. The fact that most flights were test flights means that companies were able to plan these for moments that weather conditions were suitable for drone tests. Some respondents express their surprise about the way drones were able to withstand disturbing weather conditions, such as strong winds and rain, but they also note that they didn't do any test when weather conditions could be too problematic for the drones. This refers back to the lack of robustness as mentioned, but the potential here is clear.

Technological limits are certainly an important limitation on widespread drone implementation. Striking was however when discussing technology with the respondents, the legislative barriers were also often mentioned, as demonstrated by the following quote:

4: Militarily drones are very large, so technology does not stop that. Only practically currently is 1.5 kilos, which we now fly with. But that is again, although we can fly with 15 kilos, it is just not allowed yet.

It should be noted here that this interview was conducted in December 2020, when still the old rules applied, whereas the interviews with the experts were all in January 2021. This could explain why respondent 8 mentioned technological barriers as the main problem currently, as with the new regulations much more is possible, as long as you can prove to the authorities that your drones can do the delivery safely and soundly. According to him however, current

drone technology is not yet reliable enough yet. This view of respondent 8 contrasts quite a bit with the view of respondent 7, according to whom drones have been able to do much more difficult functions, compared to a parcel delivery. He therefore doesn't see technology as a barrier at this stage.

Technology of drones is improving, but in general the results show that large steps need to be made before drones are safe enough to be accepted by authorities in the airspace of the Netherlands. This will be explored further in the next paragraph on legislative limitations.

Legislative limitations

On the question what the respondents perceived as the most important limitation that currently withholds them from implementing drones, all respondents mentioned legislative limits. In three interviews, 1, 4 and 5, they combine this with the technological limits. The combination of these two aspect can also be found in the following quote concerning an accident:

2. *Then who is responsible? Such a pilot can't help it because the system does it. Yeah the programmer isn't there. So technique and legislation go hand in hand, and have to grow accordingly.*

Such questions cannot be answered with a simple adjustment of the law. Integrating autonomy of vehicles into a legislative system is likely to take a lot of time. Autonomy isn't the only legislative issue that is mentioned in the interviews however. Other often mentioned issues are related to not being allowed to drop parcels, and about the BVLOS (Beyond visual line of sight) rules that make useful delivery drones operations very hard. As respondent 8 explains this is likely to remain an important challenge:

8. *"And what I foresee is that a lot of people will shout that we are going to fly BVLOS, out of sight. But the moment you do that, you have to deal with authorities and you have to demonstrate that your device works properly. And I think that will be the biggest challenge."*

Such quotes clearly demonstrate that wider drones implementation is still quite far from a reality, with the current technical capacities and drone regulations.

As none of the companies have yet tried to start an operating network the main legislative issues they have to deal with are related to permission to do tests. Two of the companies feel like it is hard to get legislative permission to test with drones (1 and 3). While two others feel that they have quite a lot of space to test (2 and 4). The reason for this is likely in the fact that respondent 2 and 4, from ANWB and PostNL have been testing for a longer period of time than respondent 1 and 3, from Dominos and Port of Rotterdam. Therefore they have more experience that they can show to the agencies that permit these flights. Both respondents 2 and 4, despite their feeling that they are allowed to do quite a lot, express the desire to be allowed more to test their drones. With the new regulations more space will be created, also for tests. Still, the legislator is likely to remain a limiting force on drone implementation, as illustrated by the quote of respondent 8 above.

Companies and experts view on public acceptance

The researched companies have all put effort into finding out the public responses to drone tests. They do this by informing the public about their tests, and by asking if the public found these tests disturbing. In general the views of the public are perceived to be quite positive, which corresponds to the general findings in the literature such as the research done by the Kennisinstituut voor Mobiliteitsbeleid (2017). The respondents generally support the view of Clothier et al. (2015) that the current views on drones are not very useful for the situation where a fully operational drone service would result in a regular flow of drones over their living environments. Because of the uncertainty of the development of the acceptance towards drones all respondents share the view that a regular drone delivery should therefore start with a product that will be easily accepted. Examples of these are medicine, as mentioned by respondents 1, 3 and 4, or safety goods. The concerns regarding public acceptance mostly revolve around noise, as mentioned by three companies and all experts, and privacy, as mentioned by two companies and one expert. Only one company relates safety to having an effect on public acceptance of drones. While other respondents do discuss safety they do not make the connection to public acceptance, instead addressing technological improvement or legislative rules concerning this topic. The companies are generally doubtful if public acceptance will be equally positive when delivery drones are going to be used regularly for more trivial purposes, and two of the experts express personal annoyance towards recreational drones, and think that commercial drones would also be viewed as disturbing. Disturbance caused by current delivery traffic wouldn't be a reason to accept widespread drones delivery, as illustrated by respondent 6:

6. *"If we are already bothered by a van that drives 36 km per hour through a neighbourhood instead of 30, and that sometimes stands still for ten seconds, so that I cannot pass it. If that already, say, causes social unrest. The vans are about five percent of the transport movements in a city, so that's really a fraction of the total. Yes then it seems to me that drones make things worse and no less bad."*

This view that people are unlikely to tolerate disturbance is shared widely among the respondents, unless there would be a good reason to tolerate the noise, such as an emergency situation.

Another aspect discussed in the literature was the effect that drones might have on public acceptance when they lead to jobs replacement. If autonomous drones do deliveries, then people who drive delivery vans or scooters can be competed out of the market. Both respondents 1 and 4, who are from large delivery companies (Dominos and Post NL), didn't feel that this is something that is likely to occur. Instead drones are more an addition, although respondent 4, from Post NL, mentions that the role of some functions might change when drones would get implemented. These views correspond to Graetz & Michaels (2018) description of the addition of robots to a work chain, where the implementation of new technology leads to jobs changing, and not the decrease in the number of jobs.

Striking is that companies all share similar views concerning public acceptance. This could be a result of the fact that all have put extensive effort in informing and consulting the public on the location where the tests are. The difference between the experts and the companies likely

is a result of a bias caused by the fact that the respondents were asked about public acceptance related to their experiments, and possible functions of their company in the future. As most tests were done in fields that are perceived as acceptable, such as safety and medicine, the perception is likely to be much higher than the views of experts, who mainly considered parcels and food delivery.

Competition of other delivery methods

From the question related to the views of the respondents on the technological developments, public acceptance and legislative limits it has become clear that it will take quite some time before the first operational drones networks have a chance of becoming a reality. In this part the focus will be on where respondents see opportunities for a successful business model with delivery drones.

Although it will probably take at least a view years before a drone network can be operative, the respondents generally see potential for these services. Therefore they have an incentive to invest in drone experiments. The respondents all see potential for drones in many specific areas, including delivery of certain goods. Drones taking over parcel delivery in a manner suggested in papers such as from Doole et al. (2020), where drones deliver millions of different kinds of parcels and become one of the most used delivery methods, is perceived to be unlikely, according to the respondents 4 and 5 (PostNL and DroneQ) and the two experts, 6 and 7. The main reason the respondents give for this is the fact that delivery by vans or bike is already a very efficient system. The costs to operate drones is higher compared to these methods, and as such drone delivery is not likely to be implemented for simple parcel delivery. This is illustrated by the following quote of respondent 6:

6: "*I don't see that gap in the market. Look, I am assuming it will be a business rational choice, a drone. To deploy a drone. That means that a physical profit must be made with that drone. Well, I don't know if you know what a van costs, but that's really nothing. So then it becomes a very complicated story. A van transports 200 packages.*"

A clear technological limit of drones, their limited carrying capacity, comes clearly forth in this quote. With these limitations the number of functions where drones have a competitive advantage is limited. Only high value goods that need to be delivered fast would suit this category. Drones are much cheaper than helicopters to operate, so delivery of goods by helicopter is something drones could replace, which is suggested by respondents 5, 6 and 7. Other purposes that are mentioned where every minute counts, such as in healthcare, or a crucial control part of a computer or a ship. In such cases the higher operational costs of drones are covered by the gains in time.

Although some authors in the literature, such as Doole (2020) see much more potential in drones then in driving robots for urban parcel delivery, both respondent 1 and 4, and respondents 7 and 8, two experts, see more potential for driving delivery robots than drones in urban environments. Reasons mentioned for this are that driving delivery robots are better suited to carry multiple packages in one trip, and that there are viewer legislative barriers related to safety, making an implementation in the short term more likely. As long as technological robustness is lacking a malfunctioning driving robot can easily pull to the side of

a road and stop. For drones this is much harder. The fact that respondent 1 and 4 mention delivery driving robots might be a result of the fact that delivering large quantities in urban areas is especially interesting for their companies. In their situation, driving robots are a good alternative for drones. This combination of high quantities and an urban environment is not as relevant for the other companies.

The three experts all come up with another important factor that can play a role in the eagerness of companies to test with drones, namely a search for publicity. The experts support these statements with giving examples of companies such as Amazon or DHL doing tests that have little economic potential, but do provide cheap publicity. Such news articles can give a company an innovative reputation, an image many companies strive for. As the companies were interviewed after the experts, they haven't been asked what the role of publicity for their tests was. Seeing that some of them are doing experiments over a longer time period, at least for some companies the ambitions with delivery drones appear to be larger than becoming a headline of a news article. Still it is a possibility that this can be a motivation to test with drones for many companies.

A business model for drones

As also discussed in the previous paragraph, current regulation makes drones implementation not yet possible, but the areas where the first implementation possibilities are becoming clear already. In these areas, such a health care, the goal to create an operational drones network is already mentioned by respondent 2 from ANWB medical air assistance:

2: *"The intention is to create a network with drones flying over the Netherlands between the healthcare institutions. It is really a long-term vision, but that is the intention, yes certainly."*

That the creation of such a network is really a long term scenario is a view that is widely shared among the respondents. The aforementioned limitations are the reason for this fact. Within the field of delivery drones two main business models become clear among the views of experts and companies. These are emergency services where a remote controlled delivery drone is used to bring an object to a location that it can reach much faster than other traffic. The other is a network of different hub locations where a drone flies between. An example of this would be the tests that are being done to deliver medicine between hospitals, as shown in the quote of respondent 2. Such places already have infrastructure to allow for medical air services, so an addition of drones is relatively easier here. This will be discussed further in chapter 4.3.

Delivery to houses, as mentioned in the models in the theoretical framework, is perceived to be an unrealistic future scenario for most of the respondents. Also for addresses that might make a route less efficient, a model explained in image 2 in paragraph 2.4, an addition of drones is not seen as a useful addition. The fact that vans then need to carry drones makes the delivery much less efficient, as illustrated by respondent 7:

7*: "Ehm yes if your van is full of drones that are going to deliver a package then you also need a lot of space for all those drones. But as a first thought, yes this is of course inspiring. Ehm but yes, since one hundred percent of the addresses in the Netherlands have the front door downstairs. Then you live in an apartment but you still have to put the doorbell down"*

Next to the space the drones would need on a van, the practical limitations of drones delivery to houses is illustrated in this quote. This is something widely shared among the respondents, front door delivery is simply not possible for delivery drones to many Dutch houses. Using drones to deliver to drop off point than would be technically possible, but if such a drop-off point gets multiple parcels anyway using a single van is likely more efficient than multiple drones, as illustrated by respondent 6:

6: *Ehm, I really don't understand why we don't have a fine-meshed parcel lock network in the Netherlands. That's the right model. So those kinds of innovations. Of course they are fed with vans, again.*

On the question what the respondent perceived as the best areas for drone delivery, rural or urban, the answers differed. Most current attempts are focused on delivery in a rural environment as the risk on the ground is generally much lower here.

Summary

So where do companies perceive opportunities to implement drones, and where are limits?

From the interviews it has become clear that drone development is still in an early stage. In terms of public acceptance, this means it is too early to know what the reception of the general public will be. Technologically, there are still steps to be made, however the potential improvements in this field make this aspect likely not a major limitation on drone development. The most important barriers currently have been put in place by the legislature, that make it impossible to fly a commercial drone delivery service. New legislation has been put in place since January 2021, but even with these new rules legislation will likely continue to be a brake on drone development. These legislation is perceived to be a consequence of limited public acceptance for drones in a wide array of functions. Drones are also more costly to operate compared to other delivery methods, such as vans or bikes, and delivery robots are likely to be more cost efficient for simple delivery as well. Therefore the first drone implementations are perceived to be limited to niche functions, where high priority high value products need to be delivered. Most respondents agree that a wider implementation of delivery drones, into food and parcel delivery, is an unlikely scenario.

4.3 Functions with the greatest potential in the coming years

This paragraph first focuses on the functions where delivery drones might be used for in the short term. The second part then delves further into the question in which locations these drones are likely to operate. As described in paragraph 3.4 the goal is to give a clear view on the last part of the conceptual model; learning about the most likely delivery drone implementation in specific places and functions for the near future.

Functions with the greatest potential; medical drones and high value deliveries

In paragraph 4.1 it has been assumed that drones that operate in urban environments are able to carry up to 2,2 kilograms (Doole et al. 2020). The respondents show however that this weight can be higher when using larger drones, but such drones require more infrastructure to operate. For medical drones operating between two fixed locations, such as suggested by respondent 2 from ANWB medical air assistance, such infrastructure can be created. For medical drones carrying emergency goods to locations where for instance an accident has occurred the weight of the good that needs to be delivered is of more concern. However, as mentioned in the interviews, weight concerns will only become pressing as soon as the current reliability is improved. As long as this isn't the case drones will not be able to operate anyway. The low reliability of drones is partially a result of weather conditions, and lighter drones are more affected by weather than heavy drones. The combination of these factors shows that for medical drones flying between two fixed points is more likely to be successfully implemented in an early stage than flights for emergency situations outside hospitals and other medical centres. Drone delivery is not limited to medical drones, as there is also potential to deliver quite a wide variety of high value high priority goods, such as parts of machinery, control parts and other goods where a small amount of time gained quickly outweighs the extra cost that still comes with a delivery drones operation. For these drones, operating outside the medical field, there is an extra challenge in the field of public acceptance (Kennisinstituut voor Mobiliteitsbeleid, 2017), as they are less likely to be viewed as a positive addition compared to drones that fly with a medical purpose.

Potential in different spatial environments

Public acceptance is a more pressing issue when operating in densely inhabited environments, because then the negative effects of delivery drones, such as noise and safety risks, will affect a larger number of people. In paragraph 4.1 it was discussed that the potential for delivery drones is larger in rural and intermediate areas, and smaller in urban areas. Implementing flight for health emergencies can be quite promising in rural areas. As rural areas are the location where most experiments are done, it can be expected that the first drones will be implemented here as well. Drones with a medical purpose, operating in rural areas can provide many opportunities, as especially areas that are hard to reach are located here. Therefore the first emergency services of delivery drones are likely to be implemented here. This is because the no-fly zones are often located in inhabited environments. That rural areas are more suitable for delivery drones is a conclusion that is not necessarily shared by all respondents, but from the interviews it has become clear that in this stage using drones in rural environments is preferred due to the potential risks of operating in urban environments. In paragraph 4.1 it was found that around 60 percent of all addresses in rural and intermediate areas can potentially be reached by drones. And with rural areas as the main area where

experiments are done, it can be expected that the first non-medical drones will be implemented here as well. From the interviews in paragraph 4.2 it has also become clear that implementing drones in urban environments is, although not unrealistic in the far future, not a likely scenario to be happening in the coming years. This is a major limitation for the number of deliveries, after all paragraph 4.1 showed that over half of the people in the Netherlands live in urban areas. Only around 15 percent of the population of the Netherlands lives in rural areas, so the first drone services aren't likely to affect a very large number of people.

In the interviews another potential environment has been mentioned as a suitable place for drone implementation. These are industrial areas. In these areas drones can be a valuable addition for the transport of crucial parts of machinery between companies, or between different branches of the same company. Operating in industrial areas is less disturbing for inhabitants, but as respondent 3 from the Port of Rotterdam points out in the interviews, provides safety challenges with storage of dangerous materials. These issues will require a protocol in order to ensure safe operations. If such a protocol can be created industrial areas have great potential for delivery drones. This especially concerns the high value high priority deliveries.

5. Conclusion

In this chapter the conclusions to the three sub-questions are given, starting with the first question in 5.1: What is the potential to implement drones in last mile delivery traffic? After this the second sub-question is concluded in 5.2: Where do companies and experts perceive opportunities to implement drones, and where are limits? The third sub-question then is concluded in 5.3: What is the potential for drones in the areas and functions that, according to the interviews, are likely to see delivery drones implemented in the coming years?

After the sub-question the conclusion to the central question of this research is given in 5.4. This is followed by policy recommendations in 5.5 and recommendations for further research in 5.6. This chapter ends with a reflection on the results of this research, and the usefulness of the findings in 5.7.

5.1 Conclusion drone potential analysis

The first sub-question was: What is the potential to implement drones in last mile delivery traffic?

This question is answered by a combination of the results of the calculation that was created with the findings of the analysis and the information from the theory. From the theoretical framework it has become clear that there are three main factors influencing the potential of delivery drones; societal acceptance, technological capabilities and legislative barriers. The literature showed that for societal acceptance, acceptance is really dependent on the purpose of the drone flight (Kennisinstituut voor Mobiliteitsbeleid, 2017). Drones with emergency functions, such as in health care, are more easily accepted than for parcel delivery. Public acceptance is however likely to change when drones become more common (Clothier, 2015). For technological capabilities many improvements are still necessary, and legislative barriers are still partially undefined as a result of very new regulations (Rijksoverheid, 2021). As the concrete effects of legislative barriers and technological potential were still quite vague, these have been explored further in the framework that was created in paragraph 3.2. The findings of this analysis could be found in paragraph 4.1.

The results of this framework showed that several factors related to delivery drones need to change before delivery drones have a chance to become a reality. One of these were cross border deliveries, that are currently not possible with drones. The efforts by the European Union to harmonize drone regulation across its member state can give a major boost to the potential number of parcels that would be suitable for drone delivery. For the Netherlands this would be an extra benefit, as a much larger part of its delivery traffic is cross border, compared to most other countries (Autoriteit Consument & Markt, 2020; Doole et al. 2020). Note here should be that cross border deliveries will likely have a longer travel distance, making drones likely less suitable and therefore not increase the total potential by a very large number. The weight of a single parcel isn't a major limitation on the potential of drones, as the vast majority of parcels would be suitable for drones to be carried. The main growth potential for drones here would be to carry multiple parcels, which could drastically increase efficiency (Doole et al. 2020).

Weather issues appear to be a much larger limitation; over half of the days the weather can be a limitation on the potential of drones for at least a part of those days. Especially precipitation was found as a possible limitation on drone usage. This is especially a problem for the reliability of future drone delivery. An important aspect why weather reliability needs to be taken into account is that one of the main motivators for potential drones delivery companies is the maximum efficiency and predictability delivery companies strive for (Perera et al. 2020). As long as a very large number of days drones wouldn't be able to fulfil this criterion it is unlikely that drones will be widely implemented by these companies. Therefore it is clear that technological improvements on weather resistance would be crucial in order for drones to be implemented as delivery traffic. Fortunately for the drone potential, when drones improve technologically these issues are likely to become smaller. Some authors, such as Doole et al. (2020) expect that the number of days that a drone wouldn't be able to operate due to weather conditions will be limited to almost zero.

Next to that possible regulations that exclude delivery drones from large areas are likely to severely limit the potential of delivery drones, making large parts of the Netherlands unsuitable for drone delivery. Although such areas are likely to fluctuate over the years, technological improvement to the safety of drones are necessary in order to limit the effects these no-fly zones have on drone potential. As was shown in the analysis, especially urban areas are likely to be affected by such no fly areas. This can be an extra problem for the drone potential when a drone network requires a high population density in its environment in order to be efficient. This is something which the authors Aurembout et al. (2019) and Doole et al. (2020) did expect to be a requirement before drone implementation can be economically viable. Taking this into account it is clear that if the current no-fly zones for low-risk drones would be expanded to delivery drones it would make widespread implementation impossible. Although the number of addresses that are not part of these zones is quite large, drone networks would become very fragmented, which would severely limit their efficiency. If the legislation is not adjusted to support such operations the Dutch airspace is not suitable for drone operations. However, as new drone regulations are just in place, these no-fly zones might also change a lot. How this will happen will severely influence the potential for delivery drones in the near future. Despite the limitations caused by the aforementioned aspects, the calculation still showed that currently around 15 percent of all parcels delivered by the six large delivery companies would be suitable to be delivered by drones. This means that 83 million parcels can potentially be delivered by drones, having taken weight, border regulations, weather conditions and no-fly zones into account.

5.2 Conclusion interviews with companies and experts

The second sub-question was: Where do companies and experts perceive opportunities to implement drones, and where are limits? This question was answered via 8 semi-structured interviews, the results of these interviews are discussed in paragraph 4.2.

In terms of technical capabilities, the companies and experts felt that the current drone technology isn't adequate for delivery in inhabited environments. Many of the issues mentioned by Murray & Chu (2015) were mentioned by the companies as well. These are

issues related to safety, GPS and battery capacity. Apart from these issues the respondents generally felt that drones technology was not yet reliable enough, and that improvements here are necessary to ensure wider implementation. In general the view of the respondents was that the improvements would be happening in the future, but that these limitations make wider drone implementation unlikely for the coming 5 to 10 years.

The fact that this implementation isn't yet happening makes that the respondents are often not sure if wider drone usage will receive public approval. This is in line with the views of Clothier et al. (2015) that this attitude is likely to change when drones get used. Clothier et al. (2015) expect that the attitude will become more positive when the purpose of the drones is clear and perceived as useful by local residents. Although the respondents support this view, they do note that people are unlikely to accept delivery of parcels with the disturbance it causes. Some of the respondents already expressed annoyance towards recreational drones, which was also found in the literature (Nentwich & Horváth, 2018). This could be an indication that drones that fly for delivery purposes will also receive a negative reaction from a lot of people.

Legislation is seen by most companies as the first limiting factor on drones implementation. Legislation for drones is regulated by aerial authorities who have strict safety regulations, and drones are generally not reliable enough to meet these demands. Since the new U-space regulation this legislation is no longer necessarily a barrier on wide drone implementation, but as the current safety is not yet of a high enough level yet to gain permission to do flights. As the U-space is still getting formed (Rijksoverheid, 2021) clear standards in the future will make it more clear for companies what the possibilities are, and many of the current barriers are then likely to disappear. The interviews showed that regulation and technology have to grow together, in order to make drone delivery possible in the future.

With these limitations taken in account it has become clear that widespread delivery drone implementation is unlikely in the coming years. This is largely caused by the fact that a drone delivery system would have to compete with an already very efficient delivery system that uses vans or bikes, that is able to deliver at such low prices that there isn't a market gap for drones. This is for a major part the result of a much larger carrying capacity that traditional delivery methods have compared to drones. Although models such as Marinelli et al. (2018) or Aurembout et al. (2019) find potential for drones in these fields their analysis do not take many of the practical limitations into account that the respondents recognize would occur when delivering goods in a relatively densely populated country such as the Netherlands. Delivery by other new delivery methods, such as driving robot vehicles and bikes is perceived to be more likely by many of the respondents in the future. The advantages of drones compared to these methods are expected to be minimal, as infrastructure is already quite good in the Netherlands, and therefore these methods are expected to be more cost effective. Although technological changes do provide a certain level of uncertainty it is still safe to say it is unlikely that drones are going to be implemented widely for parcel delivery.

5.3 Conclusion on the functions and location with the greatest potential for delivery drones

This third sub-question was: What is the potential for drones in the areas and functions that, according to the interviews, are likely to see delivery drones implemented in the coming years?

The respondents from the interviews already see the first areas where the potential is largest. These are in emergency services and other high value, high priority deliveries. Examples of emergency could be blood or medicine to a specific location. High value, high priority services also include services that are currently conducted by helicopters, for instance off-shore deliveries, or crucial parts of machinery. A major role in parcel delivery is unlikely as there are many practical barriers, as described in paragraph 5.2.

In terms of spatial environment it seems likely that the first drones will be implemented in rural areas. This differs with the view of Aurembout et al. (2019) who perceive cities to be the best places for delivery drones to operate due to the fact that drones need a large number of people close to a hub in order to be economically viable. With the lack of robustness that the respondents have found in their test with drones operations it seems however very unlikely that drones will be accepted to fly in busy inner cities. Industrial areas are another area where delivery drones have the potential to be implemented, but safety concerns make this still a large challenge.

5.4 Conclusion to the central question

The central question of this research was: To what extent will delivery drones be implemented as part of last mile delivery traffic in the Netherlands in the coming decade?

In the theoretical framework several authors have found economic potential in last mile delivery using drones (Aurembout et al., 2019; Doole et al., 2020; Marinelli et al., 2018). Both when operating from a hub network, or in cooperation with delivery trucks the authors assumed that drones would lead to a reduction in time and costs. Although there are clearly many technological barriers that limit the potential at this moment, these would diminish over time and drones wouldn't longer be limited by aspects such as the weather conditions. Other descriptions were much more conservative (Kennisinstituut voor Mobiliteitsbeleid, 2017) foreseeing still many barriers, and expecting a smaller role for drones in delivery in the future.

From both the model and the interviews it has become clear that although drone deliveries have been studied and tested for a few years already, wide implementation is a far future scenario at best. Currently there aren't any functions yet where drones are being implemented, because progress is necessary in terms of technical development, public acceptance and a legislative base in the Netherlands. As was found in the analysis of the framework in paragraph 5.1, current drone technology and legislation are still a very large limit on the number of places where drones can operate, and for how many flights drones would be a suitable option. Although these factors don't prevent all delivery drone operations, they still prevent widespread implementation for now. However it is likely that when technology and legislation develop further, the role of these limiting factors will diminish. This fact doesn't mean that drones will be used for a wide array of functions, as has become clear

from the interviews. As mentioned in the previous paragraph 5.3, the first functions where drones are likely going to be implemented are niche roles in high value functions such as health care or high priority delivery. Such niche functions could function as a blueprint for delivery operations for drones in other fields as well, but again implementation here depends on if drones are more competitive than other delivery methods.

In general the results of this research show less potential for delivery drones than the literature described in the theoretical framework. One clear reason for this is that many researchers assume certain technological improvements on drones. This is quite a debatable thing to do, as it is uncertain if these developments will indeed happen. Even if such developments occur, extra protection on drones could substantially drive up the costs to operate drones, making it much harder to implement them. Another aspect that might cause the more conservative result in this research is the densely populated environment that is the Netherlands. Many of the respondents from the interviews mentioned that Dutch inner cities are very unsuitable for drones operations, as these vehicles won't have any space to drop parcels here. Such aspects are often not accounted for in literature, such as in the approach of Marnelli et al. (2018). The outcome of this research is especially suitable for countries with advanced infrastructure such as the Netherlands. In countries with poorer infrastructure the competition of other delivery methods is likely to be a less important factor, and the potential for drones might be larger at this moment in time.

5.5 Policy recommendation

The findings of this research can provide an interesting view for policy makers regarding the implementation of delivery drones in the Netherlands. From both the analysis and the interviews it has become clear that legislative barriers still prevent wider implementation of drones. In the analysis no-fly zones limit the total number of feasible addresses for drones to deliver by almost 50 percent. Other regulations that need to be made clear before drones can operate are related to responsibility in case an accident occurs. This is especially important for autonomous flying drones. These barriers will need to be removed to make drone delivery possible. When these barriers are removed, drones really have the potential to be a valuable addition to various fields of delivery. But although in the long term a loosening of regulation would be necessary to make wider drone implementation realistic, in the short term, it is probably better for the potential of delivery drones that regulations remain strict. In terms of regulations for recreational drones it would be beneficial to apply even stricter regulations then that are currently applied. Both from the interviews and the literature it has become clear that people perceive such drones as annoying. Such a sentiment is bad for the acceptance of drones in general. Also, when a drone, flying either recreational or commercial, causes an accident with serious consequences, public opinion is likely to turn against drones. This would make commercial delivery drone implementation impossible. The public view towards drones is likely to, in the end, determine the extent to which drones will be implemented. It is therefore crucial for the future of delivery drones, that strict regulation will continue to be applied for all drones usages, to make sure that drones obtain a reputation as a safe vehicle.

5.6 Recommendations for further research

This research has identified several aspects that could drive and limit drone implementation. One aspect that didn't receive that much attention, but might be an important driver of drone development is the environmental impact of different delivery methods. Although there is already attention for the CO_2 impact of drones compared to vans on fossil fuels (Goodchild & Toy, 2018), a more complete comparison should also take new delivery methods such as driving robots, bikes and electrical vehicles into account. Many delivery companies are already using electric vehicles or bikes for deliveries, and therefore a CO_2 impact analysis with a comparison with diesel fuelled vehicles is outdated for the Netherlands. Also impact on fauna is something that needs to be included. Especially remote areas are often close to nature reserves. If drones want to operate here a thorough analysis of the disturbance of drones is necessary. The inclusion of other potential delivery methods should also be included in an economic analysis of future delivery.

During this period this research has been written, new drone regulation concerning the U-space has been implemented, no-fly zones have changed and Amazon has gained permission to start delivering parcels in the USA. These developments show that drone delivery is still developing rapidly. As soon as more drones delivery systems begin operating worldwide research can be done about if such systems also have the potential to become implemented in other environments. As has become clear, implementing drones in the Netherlands is likely to be relatively hard compared to a lot of other locations.

5.7 Reflection

Drones are a new technology, and a disadvantage of researching a new technology is that reality sometimes catches up with your research. This also happened in this research, as from 1 January 2021 the U-space rules were implemented, and all that was written about drone regulations in this paper became outdated instantly. As the no-fly zones were also updated the analysis also needed to be run again. Although changes were not that much extra work to incorporate, it does show that some of the assumptions made, and data used in this research can become outdated rather quickly. This fact doesn't make the current results less interesting, but it is certain that if this research would be done again in five years these results would differ quite substantially.

The analysis of the framework has shown what the effects of some of the identified limitations was on the total number of delivery drones. Although the individual aspects are interesting to look at and compare, the usefulness of the final value is limited, as many other limitations were not taken into account. At this stage it is too early to make strong estimations, because by the time drones might be capable of operating in an autonomous delivery system, the extra technology required will make the costs of such delivery likely quite different from what it would currently cost. Such a framework can give more interesting results as developments make drone implementation possible at that moment in time. It is now quite early for such an estimation.

Concerning the interviews; The general enthusiasm of the respondents about talking about this topic made this a very pleasant experience. The widely varying angles of approaches of the respondents to the potential for delivery drones in their fields of expertise gave a wide

array of different perspectives. In general the respondents came to similar conclusions; great potential for some purposes, limited potential in last mile parcel delivery traffic. The fact that the respondents generally agreed on most issues make that the predictions of the future of drones are quite reliable, despite the exploratory nature of this research, and the contrasting potential found by some of the authors in the theoretical framework.

In general this research can provide interesting insights in several aspects drones delivery needs to take into account, as well as the potential of several functions drones can operate in. However, the long term future of delivery drones is still hard to predict, even with the information gained in this research.

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7. Appendix

7.1 Weather constraints on drones usage

Weather

In this analysis weather data from the KNMI station at De Bilt, in the centre of the Netherlands is used. There are a few assumptions in this approach. First of all, the weather data is based on information in de Bilt. De Bilt is located in the middle of the Netherlands, and thus provides a reasonable average. However, for instance for the factor wind, the coastal areas will have more days with wind speeds above the margin, whereas inland areas have more days below zero. A second assumption is that weather data for the year 2020 is picked. This is because this estimation is to provide information on current drone potential. Changes as a result of climate change will affect weather in the future, but will not be taken into account here.

Three weather related aspects are of impact on the functioning of drones:

Temperature: Most drones can operate in a temperature range between 0 to 40 degrees Celsius, according to DroneDJ (2019). Higher or lower temperature affect the functioning of the battery, with higher temperature providing a risk of overheating, and lower temperature affect the functioning of the accu, even to the extent that the drone doesn't function at all (Kennisinstituut voor Mobiliteitsbeleid, 2017). In the Netherlands the temperature has only been above 40 degrees Celsius once since 1900, and in the central temperature station at de Bilt this has even never happened. Temperatures below zero degrees are more common however. In leap year 2020 there were 31 days where the minimum temperature was below zero degrees Celsius (KNMI, 2021). There were no days where the maximum temperature was below zero however. However, to allow for a safety margin, the minimum temperature will be used here. This accounts for 31 of 366 days that drones are not able to fly due to too cold temperature, or around 8,5%.

Precipitation: Most drones are not water resistant or waterproof, but an increasing number of drones are developed that can withstand precipitation. Therefore with very small and short precipitation drones can still operate. In the Netherlands, precipitation comes mainly in the form of rain. In 2020, there were 146 days where there was at least one hour precipitation (KNMI, 2021). Of course drones would be able to fly in the moments that there is no rain on such days, however the moment of precipitation is to an extent unpredictable, making it hard to operate drones on such days. As the days where fewer than one hour precipitation is measured, the assumption is made that drones cannot fly on a day with at least one hour precipitation. 146 of 366 is 39,9% of the days.

Wind: Generally, the heavier a drone, the better is resistance against wind. Drones get less efficient with stronger winds, as they require more energy to remain on route (Kennisinstituut voor Mobiliteitsbeleid, 2017). When the wind speed is faster than the maximum speed of a drone its operations become unsafe. According to Dronewatch (2019), most drones are able to fly in wind speeds up to 10 m/s. In 2020 there were 15 days where the maximum windspeed was equal or higher than this (KNMI, 2021). It should be noted here that drones that carry an object are more affected by wind. Lowering the margin to 8 m/s, the margin assumed by Doole (2020) there are 56 days in De Bilt where this is reached (KNMI, 2021). Differences are of

course quite large within the Netherlands, especially in coastal areas the wind speed is higher on average, making drone operations harder. 15 of 366 is 4,1% of days. 56 of 366 is 15,3% of days. For the final calculation the conservative approach is taken, so a margin of 8 m/s.

7.2 GIS analysis no- and low fly zones

Input layers

The layers used in the GIS analysis are listed in table 10.

Layer:	Source	Type
Neighbourhoods	CBS (2020)	Polygon
BAG Addresses	BAG (2020)	Point
No-fly zones	Kadaster (2021)	Polygon
Low-fly zones	Kadaster (2021)	Polygon

Table 10: input layers analyses.

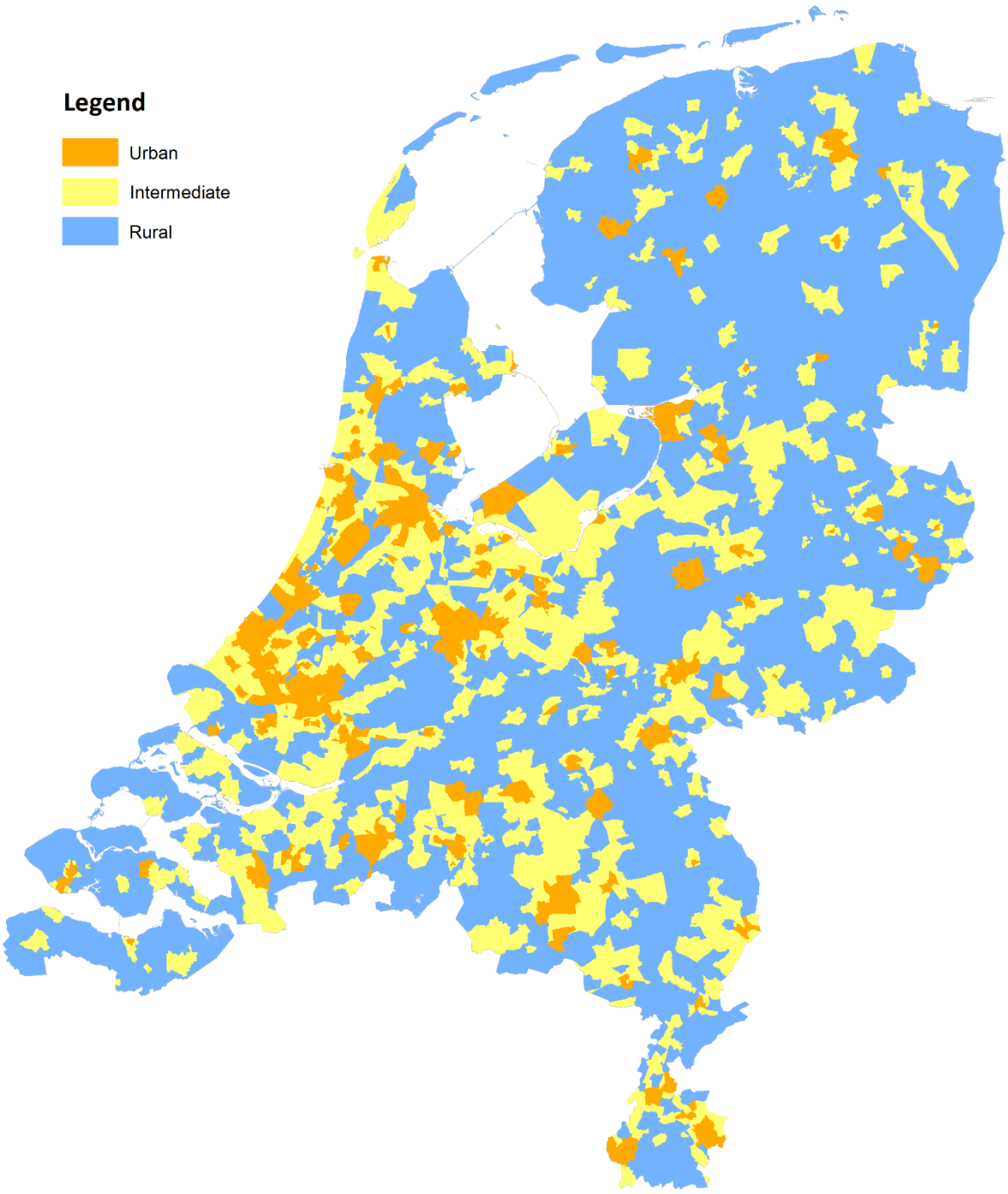
Classification of neighbourhoods

The neighbourhoods have been classified into three categories based on the classification the CBS uses. These are listed in table 11:

	Addresses per km²	Number in NL (in millions)
Rural	< 500	1,4
Intermediate	500 - 1499	3,0
Urban	≥ 1500	5,0

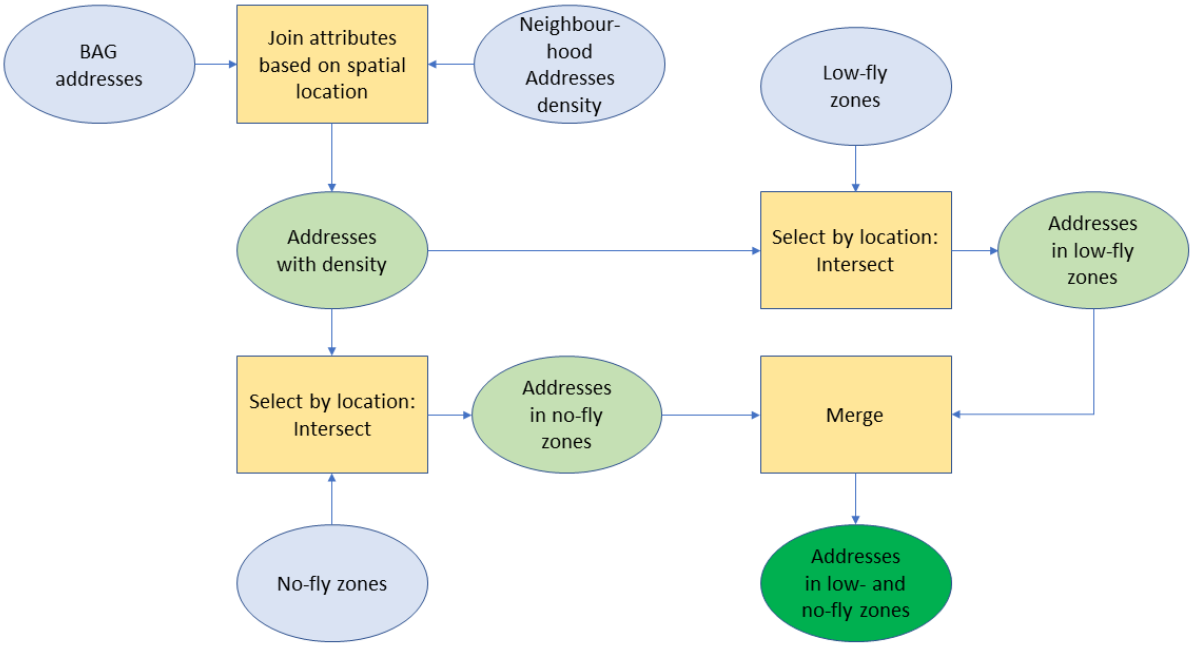
Table 11: Number of addresses in each category.

In Map 2 the classification of different neighbourhoods is visualized over the Netherlands.



Map 2: Classifications of areas on a neighbourhood scale (Source: CBS, 2020)

Method



The Addresses in low- and no-fly zones is listed here, and this is the number that is used for the analysis of 3.2.

Next to the no-fly zone areas there are also areas where flying with drones is only possible to a certain height, often 40 meters (Kadaster, 2021). Since delivery drones would have to fly higher these areas are also excluded. Apart from no- and low fly areas Kadaster (2021) also includes Natura 2000 areas in their maps. Often these areas have extra regulations, but this is something not nationally collected. There is a possibility that Natura 2000 areas could turn in no-fly zones, but not enough environmental impact analyses have been conducted to know what the effect of drones on different animal species is. Since this is still unclear, Natura 2000 areas still can be used as drone delivery areas in this analysis, but this might change in the future.

7.3 Interviews with drone companies

The interviews are semi-structured. The questions are a guideline to follow while the interview is happening. Quite often questions were already answered by the respondent as part of another question. When this happened the question would later be skipped, or some clarification would be asked if necessary. When a topic within the same theme was already visited in a previous question, the order of question was adjusted to give the conversation a more logical flow, and prevent the respondent from having to tell the same thing multiple times.

Interview guide

First of all, the respondent is informed about what this research is about and for what purpose I want to use the interview for. Next, the respondent is asked if the interview can be recorded (audio only) and what happens with these recordings. I will also ask if they agree to associate their company / group name with their answers (adding this information may be of interest to the survey). Subsequently, the respondent is informed that he / she may stop the interview at any time, and that he / she can also decide afterwards that this interview should not be used.

Introductory questions

• What is your position at (company name)?

• How is your position within (company name) related to drones?

• Which experiments / tests has (company name) done with drones and what is the result of these experiments?

About opportunities and limits

• What are the main limitations that can limit the potential of drones as a delivery vehicle?

• Technological: In which weather conditions is the use of drones limited?

• Technological: Up to what weight can drones deliver well?

• Technological / social: How can safety be improved?

• Social: How has the public responded to your test with the drone so far?

• Legislative: Do you perceive to have enough opportunities to test with drones?

• What do you expect from drones for the future, regardless of your own company?

About a potential business model

• What is the incentive to test with drones?

• How will the drones work (network with hubs or other delivery method)?

• Will the company operate the drones itself?

• What kind of packages are drones expected to be suitable for?

• In which spatial environment would drones be suitable (rural, urban, semi-urban)?

• When does the company expect drone delivery to be profitable (or not at all)?

• Would drones replace existing delivery jobs?

• Are other delivery methods, such as robots or bicycles, and vans / trucks / scooters, more likely to be used as delivery vehicles in the future?

7.4 Interviews with experts

The interviews with the experts differed from the companies, as the experts didn't do any experiments themselves where they could be interviewed about. Instead to focus was on the broader development of drones as delivery traffic. Just as with the companies, the questions were loose guidelines. The first and second introductory questions differed between the scientific experts and the expert from the Netherlands Aerospace Centre. The questions to the expert of the Netherlands Aerospace Centre are in italics.

Interview guide

The interviews are semi-structured. The questions are a guideline to follow while the interview is happening. Quite often questions were already answered by the respondent as part of another question. When this happened the question would later be skipped, or some clarification would be asked if necessary. When a topic within the same theme was already visited in a previous question, the order of question was adjusted to give the conversation a more logical flow, and prevent the respondent from having to tell the same thing multiple times.

Introductory question

• Have you already conducted research into the use of drones as a delivery vehicle?
What is your position at the Netherlands Aerospace Centre?

• If not, have you supervised studies of students who have conducted studies of drones in this field?
How is your job related to the use of drones as delivery vehicles?

• Do you actively follow the developments regarding delivery drones?

About opportunities and limits

• What are the main limitations that can limit the potential of drones as a delivery vehicle?

• What developments do you see internationally in the field of delivery drones?

• Technological / social: How can safety be improved?

• Social: How do you expect the acceptance of local residents to develop if a regular drone service were introduced?

• What do you expect for the future of drones as delivery vehicles?

Economic potential

• Is development going faster or slower than you expected five years ago?

• In which spatial environment would drones be suitable (rural, urban, semi-urban)?

• In what kind of functions do you expect the first delivery networks of drones?

• When do you expect delivery by drones to be profitable / operational (or not at all)?

• Under current legislation, setting up a drone delivery service is not possible. Do you expect there will be more space to use drones in the future?

Other delivery methods

• Does growth in the delivery market require new delivery methods, or is this development mainly driven by other factors?

• Do you expect more from delivery robots that drive than delivery drones?

Then I would like to thank you very much! Do you have any questions for me?