Ministry of Infrastructure and the
Environment

Drones in passenger and freight transport

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Summary

In future[1] drones can be deployed in certain passenger and freight transport markets in the Netherlands. Speed is a key advantage of using drones instead of conventional alternatives, such as delivery vans, airplanes or cars. People will pay more to use drones. Although in absolute terms this could involve large numbers of drone flights, it will pertain to niche markets, relative to the total volume of passenger and freight transport.

Technological aspects and social acceptance are key conditions

Society is characterised by scarcity. Consequently, there is a continuous incentive to approach matters more efficiently and effectively, which can result in robotisation. It is against this backdrop that the emergence of professional drone applications is considered, such as in agriculture or the public sector.

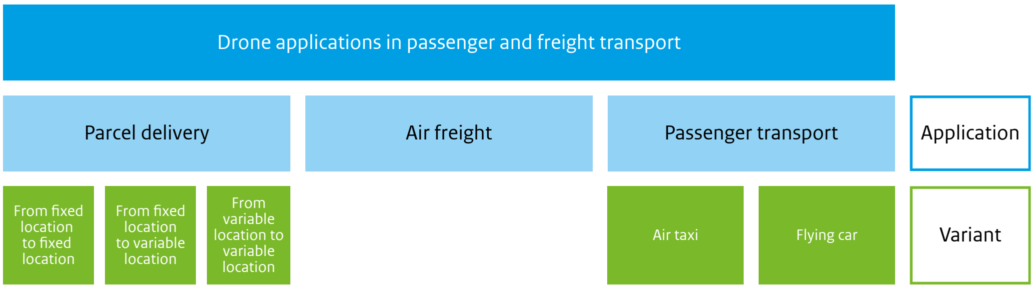
Depending on the type of drone application, certain conditions must be met. For drones to develop, various technological developments and social acceptance are crucial. Moreover, potential conflicts of interest between economic opportunities and societal safety and privacy aspects must be considered. One such example are no-fly zones, which help prevent accidents. However, too many designated no-fly zones can limit the commercial opportunities. For example, in order to deliver goods, drones should ideally fly direct routes covering longer distances. Closed airspaces result in detours and hence higher costs.

Three mobility applications of drones

Drones fly at altitudes rarely used today. In passenger and freight transport, drones can create new, direct connections and moreover avoid congestion. Transport can be faster, and consequenlty this partly explains the consensus that exists pertaining to the entry of unmanned aerial vehicles into this domain.

Three mobility applications of drones are distinguished: parcel delivery, air freight and passenger transport. Further classifications therein are possible – see Figure S1. Such a distinction is pertinent in light of the various market opportunities and spatial effects associated with drone applications.

Figure S1 Schematic overview of drone applications in passenger and freight transport.



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[1] This study looked a few decades ahead, but of course implementing drones in passenger and freight transport occurs step-by-step.

Various promising options for drone applications in parcel delivery

Various promising parcel delivery drone applications exist. Speed of delivery can be a great advantage: some companies expect to be able to deliver within 30 minutes. Moreover, some customers will be willing to pay more for fast deliveries by drones, and this also applies to for example companies needing quick deliveries of spare parts in order to keep production processes running, or to medical applications, such as rapidly delivering defibrillators to certain locations. Nevertheless, most parcels do not require urgent delivery. If speed is not crucial, delivery vans are routinely more efficient from a cost perspective; consequently, they will continue to be widely used in parcel delivery. SESAR, the Single European Sky ATM Research organisation, expects some 70,000 drones to be in Europe’s skies by 2035, delivering 1 to 1.5 percent of all parcels.

Weather has a major impact on the performance of small parcel drones and hence on the reliability of the delivery service. Superior weather resistance is a key technological condition for success in the Netherlands, certainly. Further, the number of drones a single drone operator can operate and a drone’s flight frequency have a major impact on the costs per flight. Other crucial factors in further rolling-out this drone application include the development of autonomous control and the corresponding use of sense-and-avoid technology.

Application of drones in air freight primarily a niche market

Freight drones offer added value to niche markets, in which high value, time-sensitive and/or perishable goods must be transported in smaller quantities than the existing air freight. Market opportunities are bolstered by a lack of competitive alternatives. Compared to parcel delivery, air freight involves longer distances and larger volumes per flight, and air freight drones are also (much) larger. However, given the Netherlands’ extensive transport infrastructure, there are relatively few apparent markets for air freight drones, although there are elsewhere in the world.

Costs and safety crucial for passenger transport by drones

Passenger drones can be deployed as air taxis, thus allowing passengers to avoid road traffic congestion and speedily arrive at their destinations. As with drone parcel delivery, people will pay more compared to the alternative modality, which in this case are cars. Although higher prices will be apparent in the short-term, they will decrease over time if passengers are willing to share their drone flights with others. The longer the distance, the more advantageous the drones become. Safety is more important for passenger drones than for other drone applications. Passengers must have absolute trust in the aircraft before they will be willing to embark. A select target group can and will use passenger drones, also in the Netherlands.

Market opportunities primarily in parcel delivery and passenger transport

Market parties are currently investing relatively heavily in parcel and passenger transport by drones, and relatively little in air freight drones. One possible explanation for this is that more certainty exists about where market opportunities will arise in parcel delivery and passenger transport by drones.

Emergence of drones has consequences for skylines and spatial planning

Drones must be accommodated in the airspace; consequently, the Dutch skyline will change. This will also have consequences for spatial planning; for example, landing sites must be set up, which is challenging, particularly in urban areas, although existing infrastructure potentially offers solutions. To use drones as transport in urban areas, vertical takeoff and landing are a must.

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1

Introduction

1.1 Background and research questions

Unmanned aerial vehicles, or drones in common parlance, are claiming an increasingly prominent role in society. Until recently, drones were primarily used for military objectives, but this is changing due to the widespread sale of drones for recreational use. Moreover, the numbers of professional drone users are steadily increasing. Companies and government agencies see opportunities for drone applications; for example, to reduce risks for their personnel, optimise production processes or offer new services.

Various (Dutch) research studies have examined possible drone applications. Rijkswaterstaat (2015) studied cases in which drones were deployed in the public domain; the Scientific Research and Documentation Centre (WODC, 2015) outlined the various opportunities and threats posed by drones in the public and private sectors, focusing on security and criminality; and Van der Wal et al. (2016) explored drone applications in agriculture and nature.

Observation is a key aspect in many applications; for example, police and fire departments use drones to fight fires, search for missing persons and provide crowd surveillance at large events. Further, Rijkswaterstaat conducted pilot projects in which drones were deployed to help prevent oil leaking into a river, to monitor driving behaviour at traffic intersections, and to inspect water quality and water safety (Rijkswaterstaat, 2015).

A consensus exists about the expectation that drone use in civilian applications will sharply increase in the coming years (Airneth, 2016). SESAR, the organisation that coordinates research and development efforts of EU Member States in the field of air traffic management, estimated the market potential of drones. SESAR (2016) expects that some 7 million drones will be used for recreational purposes in Europe by 2050. Moreover, SESAR expects 100,000 drones to be active in agriculture, that public services (such as police and fire departments) will deploy some 50,000 drones for public safety, and that another 100,000 drones will be used for delivery services.

Despite this expected growth, relatively little information is found in the available literature pertaining to drone applications in passenger and freight transport, which includes delivery services. It is relevant from a policy perspective to learn more about the possibilities that drones offer transport, as well as the extent to which this provides opportunities for Dutch companies, for which regulations must be considered, and what infrastructural and spatial consequences are associated with ‘transport drones’.

In this study the KiM Netherlands Institute for Transport Policy Analysis addresses this question from the policy perspective, examining the present and future opportunities for unmanned aerial vehicles in passenger and freight transport. The future reference year is 2035, as it is for SESAR (2016).

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The research questions are:
1. Which studies explored drone applications in passenger and freight transport and what were their findings?
2. What are the strong points and weak points of deploying drones in:
   a. parcel delivery;
   b. air freight;
   c. passenger transport.
3. Do these three drone applications have viable business cases? Which ones are initially the most realistic?
4. What changes to spatial planning must occur to facilitate drone applications in passenger and freight transport?

To answer these research questions, publically available literature sources were reviewed. Various seminars and congresses were also attended in order to glean a current overview of the rapidly changing drone sector. And finally, various experts were consulted.

1.2 Terminology and classification of drones

In this report, the term 'drones' refers to unmanned aerial vehicles (UAVs), which by definition pertains to aircraft that do not have pilots on board, and includes, for example, unmanned aircraft and helicopters, but not missiles and weather balloons. Similarly, the term 'drones' encompasses related concepts like remotely piloted aircraft system (RPAS), unmanned aerial system (UAS) and unmanned cargo aircraft (UCA). A decision was taken to ascribe this overarching meaning to the term 'drone', as it is now common parlance (SAMR, 2016). This also accords with the WODC, for example (2015).

Drones come in many different shapes and sizes. The Hague Security Delta (HSD, 2015) uses the following classification, as based on the unmanned aerial vehicles weight:
- Class 1: 0 to 150 kg;
- Class 2: 150 tot 600 kg;
- Class 3: above 600 kg.

Most drones fall under Class 1, which primarily pertains to the well-known multicopters that weigh but a few kilograms (see Figure 1.1, left). The Ehang[2] passenger drone is an example of a Class 2 drone. Presently, the largest operational drones are military, like the Global Hawk, an unmanned US Air Force drone weighing 14 tons. The differences within weight classes reveals the great diversity of drones.

Figure 1.1 Examples of drones: DJI Phantom (Class 1, left), Ehang 184 (Class 2, centre), Northrop Grumman Global Hawk (Class 3, right). Source: DJI, Ehang and Northrop Grumman.

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[2] This drone is further described in section 3.3.1.

In addition to weight-based classification, drones can be classified according to technology, with distinctions made between rotor-aircraft and multicopters, and fixed-wing aircraft. Rotor-aircraft can use their rotors for vertical takeoffs and landings (VTOL – vertical takeoff and landing). Fixed-wing aircraft cannot do this, and instead require runways (STOL – short takeoff and landing). Other differences include fuel efficiency and speed: fixed-wing aircraft perform better in this respect than rotor-aircraft during the horizontal flight stage. Consequently, hybrid designs have emerged, combining rotors with wings.
The starting point for a drone is that it takeoffs and lands vertically, yet operates like a fixed-wing aircraft during the horizontal flight stage.

Smolka (2016) illustrated how the number of manufacturers initially rapidly increases when a new industry emerges. Once said product becomes embedded in society however, a dominant design emerges, resulting in standardisation and consolidation. Various manufacturers subsequently take control of the market, as others leave it. Examination of the drone market reveals that it is still in its early stages of development. Although this research study strives to look beyond the present situation, the prevailing uncertainties must nevertheless be kept in mind. The dominant (drone) design has not yet emerged.

1.3 Structure of the report

Chapter 2 focuses on technological developments and social acceptance in the drone sector, thereby establishing the conditions for further implementing drones in society. These conditions apply to all drone applications and hence are also deemed important for deploying drones in passenger and freight transport. Where relevant, regulations are discussed; this primarily pertains to the reliability, safety and privacy issues associated with drones, as well as to their integration in air traffic.

Chapter 3 explores drone applications in parcel, freight and passenger transport; this categorisation is pertinent with respect to the differing business cases and spatial effects associated with each application. Although the present situation is discussed, the chapter's main aim is to offer a glimpse into the future. The emphasis per drone application is on the market opportunities that exist for deploying drones, as compared to the current (alternative) transport modes. Additionally, the various technological characteristics detailed in Chapter 2 are deemed important.

Chapter 4 presents the study's conclusions.

2

Conditions for development and implementation of drones

If drones are to be used for mobility objectives, various general conditions pertaining to drone applications must be met. SESAR (2016) identifies these as technological progression, social acceptance and regulations, and the European Commission (2015) also cited these aspects in the Riga Declaration on Remotely Piloted Aircraft (drones). The European Commission denotes privacy and safety of the citizenry as relevant for social acceptance, but also the noise disturbance potentially caused by drones. On the technological level, this chapter addresses the control, energy consumption, integration into air space, and weather resistance of drones. In terms of social acceptance, at issue are the support that exists in society, safety aspects, and the impact drones have on the personal living environment.

2.1 Technological developments

2.1.1 The control of drones

The following four methods for controlling unmanned aerial vehicles are specified:

- visual line of sight of operator (VLOS);
- beyond visual line of sight of operator (BVLOS);
- preprogramed autonomous;
- fully autonomous.

Operators controlling drones from the ground, while continuously keeping the drones in sight, is the least advanced type of drone control: the aerial vehicle remains in the visual line of sight (VLOS). Using drones in this way is restricted in terms of size, flight distances and speed. In the Netherlands, recreational drone operators are permitted to fly within a sight line of 50 meters high and 100 meters distant. VLOS primarily pertains to small multicopters (Class 1 drones in the HSD classification). VLOS is currently the most common type of control for both recreational and professional use.

BVLOS is characterised by the operators' ability to remotely control drones from greater distances and beyond visual line of sight. Such drones are piloted from a central control centre, for example, and as such operators can pilot multiple drones simultaneously. Of note here is that BVLOS-control offers possible cost advantages compared to VLOS-control. Direct connections between operators and drones

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can be maintained for distances up to 250 kilometres, via 4G networks, while indirect connections, via satellite for example, are used for longer distances. However, a few seconds of delay can occur between the time when an operator issues a command and the drone responds (De Graaff, 2014; De Graaff, personal communication, April 6, 2017). The Dutch Ministry of Defence currently uses BVLOS when conducting reconnaissance drone flights over war zones.

Autonomous flight is the most advanced type of control, occurring when drones are capable of completing flights without operator intervention. Such flights involve all sorts of complex operations, including flying, navigating, avoiding high risk situations and contending with emergencies (De Graaff, 2014). Autonomous flight is the drone designers' ultimate goal. There are generally three main reasons for striving to fly autonomously (Scherer, 2014):

- Efficiency: the other control systems require people to pilot them;
- Safety: many accidents are caused by human error;
- Accessibility: drones can land in places that are unsuited for receiving aircraft[3] (no runways, for example).

Two types of flight are possible with unmanned aerial vehicles: preprogramed flying and fully autonomous flying. The crucial difference between the two types is the presence of sense-and-avoid technology. Fully autonomous flying aircraft can use sense-and-avoid to detect other aircraft, as well as to detect and avoid high risk weather conditions and other hazards. Drones that use sense-and-avoid can fly everywhere, except for in closed air spaces. However, at present, no fully functioning sense-and-avoid systems are available (Airbus, 2016). According to Sebastian Scherer[4] (personal communication, August 14, 2017), sense-and-avoid will become commercially available for small drone types within 1 to 3 years, and 5 to 10 years for larger drone types. Appendix A provides additional information about operating and developing sense-and-avoid systems.

Preprogramed autonomous flight – in which operators enter flight plans that drones subsequently follow – is an intermediate step on the path to fully autonomous flight. Because they lack sense-and-avoid, the implicit assumption is that these drones will not encounter any other air traffic or hazards. Practical examples of this type *do* already exist: the Northrop Grumman RQ-4 Global Hawk (see image in Figure 1.1) is an unmanned US Air Force reconnaissance aircraft. Depending on the situation in the air, operators on the ground can take control (BVLOS) (Northrop Grumman, n.d.). However, the Global Hawk usually flies so high that it does not encounter other air traffic.

2.1.2 Energy sources

Fuel is a major expense in aviation. Defying gravity comes at a cost: per ton kilometre it costs more energy to transport via air than over land. Consequently, it is relevant to examine the various energy sources that are (or will be) used for unmanned aerial aviation, including batteries, fossil fuels, hydrogen, solar energy and lasers.

Batteries are primarily used to power small drone types (Class 1 multicopters, for instance). These are lithium-ion-polymer batteries, or lipos for short. Powered by such batteries, drones can fly for around 30 minutes, and, depending on the model, the batteries are removable.

Fossil fuels (kerosene, diesel) primarily power large drone types (Class 3, the Global Hawk, for example). Lipos are not yet not strong enough for this, which is related to energy density. Kerosene contains 60 times more energy than a battery (Melkert, 2017). A Class 3 drone would therefore require many batteries, thereby adding extra weight and costing more energy. Nevertheless, several initiatives aim to power larger aircraft by electricity, including those by start-ups in the USA, such as Zunum Aero and Wright Electric, as well as those by established firms like Airbus (Melkert, 2017; Dorrestijn, 2017). Developments in the automotive industry could also contribute to achieving electric-powered flight.

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[3] This argument primarily applies to rotor-aircraft, and to a lesser extent to fixed-wing aircraft.

[4] Sebastian Scherer is Systems Scientist at the Robotics Institute of Carnegie Mellon University. He is engaged in developing sense-and-avoid technology.

Hydrogen, which is produced by splitting water into hydrogen and oxygen, contains much energy. Today, various car models are hydrogen-powered, which requires compressing hydrogen into sturdy tanks; however, such tanks are heavy and hence largely unsuitable for aviation. Cooling the hydrogen until it becomes liquid is one alternative, but this technology is still in the developmental stage. Consequently, using hydrogen in aviation is not yet viable (Hermans, 2017).

Solar energy can be used for allowing drones to remain aloft for long periods of time. This energy source is advantageous in that it need not be transported, but rather is generated in the air. However, one disadvantage is that solar cells require much space inside the aircraft, owing to each solar panel's relatively low conversion rate of sunlight to usable energy. Solar-powered drones therefore have a relatively low load capacity. The 6.8 kilogram AtlantikSolar is an example of a solar-powered drone (AtlantikSolar, 2015).

Finally, laser beams can power drones in the air. Laser beams are sent from the ground to the drone, where they are subsequently converted into electricity, thereby allowing the drone to remain in the air indefinitely. The developers of this new technology are focusing on 'low-hanging' satellites (LaserMotive,n.d.), but aerial charging stations for flying drones are also conceivable.

2.1.3 The integration of drones in the airspace

The airspace currently consists of controlled and uncontrolled areas, meaning that air traffic control does or does not coordinate the air traffic. The controlled areas are primarily the higher altitudes and airspaces over airports. Consequently, not all airspace users engage with air traffic control. Recreational aircraft for example make much less use of controlled airspaces.

Small drone types are expected to primarily access the lower altitudes, and hence the uncontrolled airspace. A system that can facilitate large numbers of aircraft is required to ensure that professional drone users have reliable, efficient and safe access to airspace. SESAR (2017) has therefore developed U-space[5], a concept in which airspace coordination (largely) occurs digitally and automatically. Operators submit flight plans, so that their drones are identifiable. The system then coordinates all flights. Areas that are (temporarily) unavailable are also communicated within this system.

Large drone types may however want to fly in both uncontrolled and controlled airspaces. Air traffic control and drone users must jointly develop a method for facilitating this dual airspace use. Clearly, much technological progress is needed before drones can be integrated in the airspace, regardless of their size.

2.1.4 Weather resistance

The weather is the final factor for which technological progress is needed. Weather conditions primarily impact the performance of smaller drone types and multicopters. Of importance are (NVDrones, 2016):

- Temperature: The air is thinner on hot days, so a drone's rotors must rotate faster in order to generate enough lift, whereby the electronics become warmer, forcing drones to remain on the ground longer between flights in order to cool down. A drones' lipo-batteries perform worse on cold days, preventing them producing sufficient power, which means the drone will not work.
- Precipitation and moisture: Drones perform worse in rain, snow and other forms of precipitation, which they currently cannot properly resist. In foggy conditions, drones must contend with moisture, which renders the visual control (VLOS) more difficult. And finally high humidity creates moisture on drones.
- Wind: Higher wind speeds render drone flights more difficult; for example, more energy is needed to manoeuvre and maintain course. Flying is discouraged when the maximum wind speed exceeds that of the drone's top speed. Loss of control can occur in such situations, increasing the risk of crashes.

The previously mentioned weather factors shorten a drone's maximum flight time, or simply make it irresponsible to fly. Moreover, drones must always contend with weather conditions during flights: can

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[5] The U stands for urban or you, in order to indicate that at issue is the airspace over urban areas. Recreational drone users are excluded because they fly at a lower altitude (thus, under U-space).

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the drone fly over a high obstacle, for example? Autonomous flying drones must be equipped with sensors and be 'smart' enough to determine that for themselves (Singh, as cited in Popper, 2016)

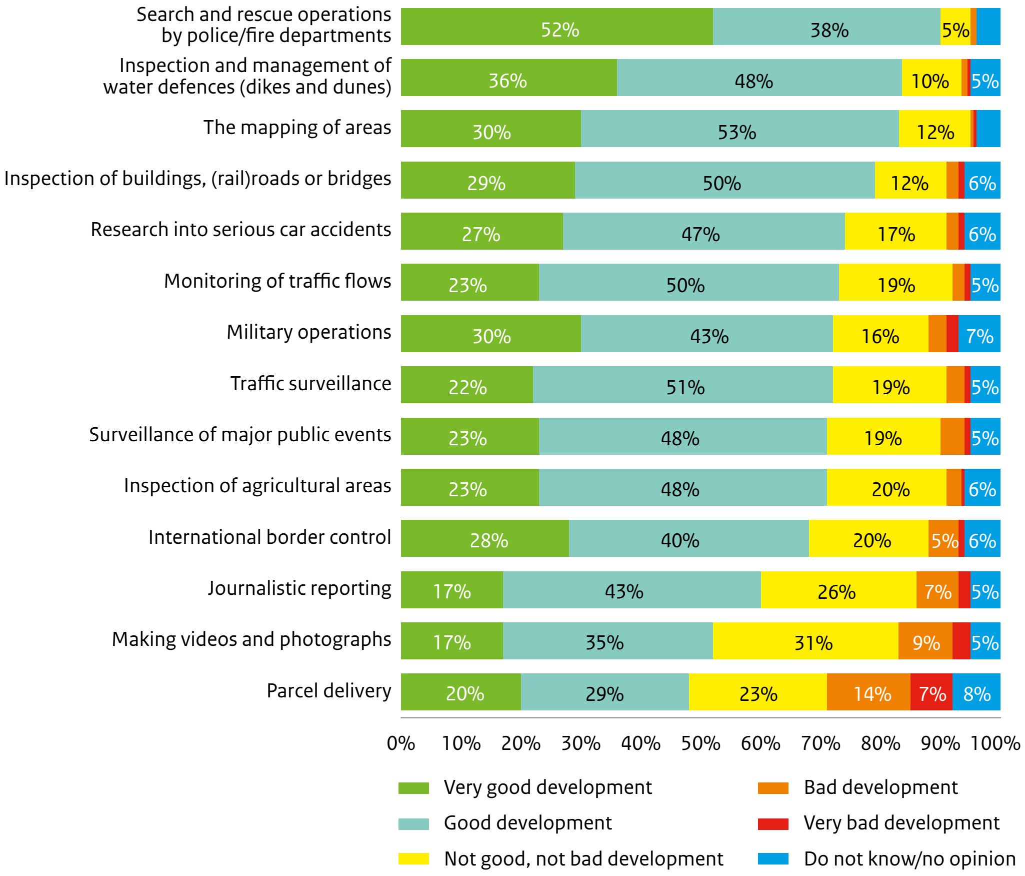
In the Netherlands, precipitation is present approximately 7 percent of the time, which is measured as 1 hour and 40 minutes every 24 hours (Buienalarm.nl, n.d.). In the Dutch town of De Bilt, at least 1 millimetre of precipitation was measured on 134 days in 2016. Multicopters have greater difficulty flying when wind speeds reach 4 Beaufort and higher; wind speeds in De Bilt reached at least 4 Beaufort for an average of 1 hour on 127 days in 2016 (KNMI, 2017).

2.2 Social acceptance

2.2.1 Support

Public support must exist for a wider implementation of drones. In 2016, the Ministry of Infrastructure and the Environment (IenM) commissioned research into the familiarity and use of drones in the Netherlands (SAMR, 2016). The survey (n = 2026) revealed a high degree of support for professional drone applications. Between 50 and 90 percent of Dutch people agreed that the proposed professional applications were a (very) good development (see Figure 2.1). The strongest support was for applications with social utility, such as police and fire operations. For each of the proposed professional applications, a small minority of people found the use of drones to a (very) bad development. The relatively greatest resistance to drones pertained to their use for taking photographs and making videos, and for parcel delivery. These findings largely agreed with those of a similar survey conducted in the United States (Miethe et al., 2014).

Figure 2.1 The attitudes of Dutch people toward professional drone applications. Source: SAMR (2016).



As drone applications become more embedded in society, and consequently their utility more apparent, the level of public support could further increase. However, accidents and other incidents could diminish such support; for example, nearly three-quarters of Dutch people believed there was a high risk that criminals would use drones. Moreover, a majority of people indicated that there was a risk that private or professional drone use would violate their privacy. Ultimately, the key points of concern about drone applications pertained to safety and the impact on the personal living environment (HSD, 2015).

2.2.2 Safety

Safety is in the general public interest and can thus be considered as separate from the social acceptance of drones. Nevertheless, incidents involving drones are expected to negatively impact public support for drone applications. From this perspective, safety can be deemed as a condition for the wider implementation of drones in society. Finally, within ‘safety’, distinctions can be made between inadvertently causing dangerous situations to arise and the occurrence of accidents, and, conversely, criminals or terrorists deliberately misusing drones.

In 2016, the Netherlands Human Environment and Transport Inspectorate (Inspectie Leefomgeving en Transport - ILT) received 64 incident reports concerning recreational[6] drones, as compared to 29 incident reports pertaining to drones that were professionally deployed. The incident reports about recreational drones primarily came from major airline companies, reporting that drones had flown close to an airplane. Whether the drone operators had done so consciously is unknown. These incidents could also have been fly-aways, whereby operators lose control and their drones fly away uncontrollably. Finally, there are few known cases of third-party damage caused by drone crashes; usually only the drone is damaged (ILT, 2017).

Wild et al. (2016) examined 152 case studies of reported drone incidents that occurred from 2005 to 2016, concluding that technical malfunctions occurred in nearly two-thirds of the cases. However, this conclusion does not rule out human error as a factor in drone incidents. Wild et al. (2016) recommend that policymakers devote more attention to the technological aspects of drones, in addition to measures aimed at drone operators.

In addition to the safety incidents associated with each accident, The Hague Security Delta (HSD, 2015) identifies three security areas in which drones could be used maliciously. Firstly, drones can be deployed as deadly weapons or to facilitate the use of deadly weapons. Terrorists can commit attacks. Secondly, criminals can deploy drones; for example, drones have been used to smuggle prohibited goods into prisons. Thirdly, drones can be hacked and subsequently used for malicious ends. To ensure public safety, various countries are striving to develop systems that can detect and potentially deactivate drones.

2.2.3 Drones in the personal living environment

Privacy violations by authorities and individuals are cause for concern (HSD, 2015). Cameras, microphones and sensors can be used to intercept telecommunications, providing information about citizens and companies (espionage). However, even if drones are *not* equipped with such sensors, drones flying overhead can violate people’s privacy, as they often cannot determine if a drone is equipped with a camera, and this can compel people to behave differently due to the overflying drone. This is called the chilling effect: a person behaves less freely than would otherwise be the case (VenJ, 2015).

Privacy is therefore safeguarded by existing legislation. For example, the right to privacy is established in the European Convention on Human Rights and in the EU Constitution. Moreover, the Netherlands’ Personal Data Protection Act (Wet Bescherming Persoonsgegevens) provides further safeguards. Finally, the Dutch Penal Code (Wetboek van Strafrecht) prohibits the deliberate photographing of “a person, present in a home or other location inaccessible to the public”, and prohibits the dissemination of any ‘image’ captured in this manner.

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[6] Incident reports about recreational drones primarily come from third parties, such as pilots. Reports about professional drones largely come from the drone operators themselves. In the Netherlands, this pertains to but a few dozen people and organisations that have ROCs (RPAS Operator Certificates).

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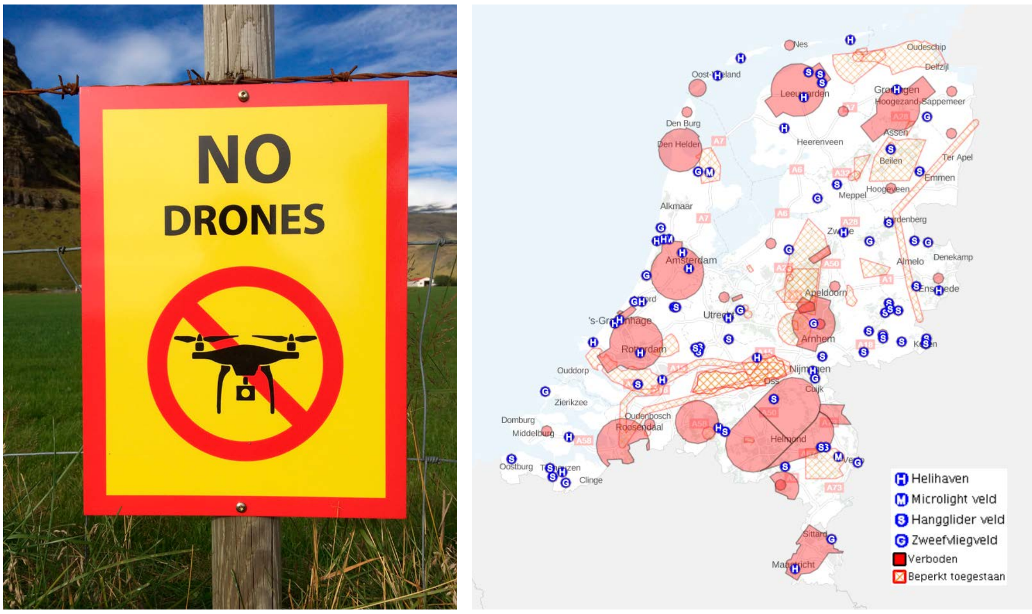
In addition to privacy aspects, other factors can also negatively impact the personal living environment. Drones can make disruptive buzzing sounds[7], for example. Moreover, larger drone models can generate powerful winds during takeoff and landing, which can be a nuisance.[8] The final aspect is horizon pollution: depending on the amount of drones and altitudes at which they fly, environmental degradation can result. Due to drone-generated noise, various Natura 2000 areas in the Netherlands have been designated as no-fly zones, in order to protect their bird habitats (De Jager, 2016). Figure 2.2 shows the Netherlands' no-fly zones for recreational drones (IenM, n.d.). Nonetheless, most no-fly zones were set up to safeguard aviation, and not owing to noise disturbance.

Figure 2.2 Drones are not permitted everywhere; the map on the right shows the Netherlands' no-fly zones for recreational drones. Source: personal photo (left) and IenM (n.d.) (right).



2.3 Conclusion

Drones have diverse professional applications, including in agriculture and the public sector. The numbers of drones deployed for such purposes are expected to significantly rise in the coming years, which offers economic and social opportunities. However, various conditions must be met before the wider implementation of drones in society can occur. SESAR and the European Commission specifically cite technological progress and social acceptance, as detailed in this chapter.

Technology

- In terms of control, autonomously flying drones are the ultimate goal. Although autonomous control is not necessary for all applications, it does offer numerous benefits; for example, human intervention is no longer needed, which saves on costs. However, to achieve autonomous control, sense-and-avoid technology must be developed, and that is still several years away.
- Improvements are still needed in terms of energy, because the drones' payload-range-combination is currently limited. Lipo-batteries are not yet powerful enough for heavier loads and/or longer flights. However, improvements are likely. Apart from the use of fossil fuels, alternative energy sources are not yet sufficiently developed for large-scale applications.

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[7] The term 'drone' comes from the English word for a male be, owing to the buzzing sound it makes.

[8] See the video on YouTube in which a patch of grass is blown away by a small passenger drone!

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- If drones find wide applications, the airspace will become more crowded. At lower altitudes, operators or autonomously flying drones must know where other drones are situated in their area, and they must be able to detect objects on their flight paths. At higher altitudes, drones must be integrated into the air traffic management system for manned aviation.
- At present, small drone types are insufficiently weather-resistant for structural deployment. Professional applications demand a high degree of reliability and deployability.

Social acceptance

- At present there is seemingly sufficient support in society for expanding the number of drone applications. The question is how the general public responds to incidents, such as drones being used by criminals or terrorists, and crashes involving drones.
- Drones must be safe and reliable, in order to prevent accidents. Technological improvements can contribute to this, for example as pertaining to the stability of the connections between drones and operators. Moreover, it is crucial that operators learn how to expertly control their drones.
- Criminals and terrorists could use drones for malicious purposes. Appropriate anti-drone measures must therefore be established in order to neutralise any drones identified as a threat. Public agencies, including the police, are devising such measures.
- Finally, disturbances that drones cause to the personal living environment must be limited. For example, people's privacy must be safeguarded, and in a credible manner, in order to prevent the chilling effect.

Public and private institutions are engaged with above-cited conditions. Technology is rapidly developing: battery energy density is increasing, sensors are becoming lighter, and software improving. As such, the cost/performance ratio improves, rendering more drone applications technologically viable and economically profitable.

All told, the conditions that must be met before drones can be used in large-scale passenger and freight transport are generic by nature. Failure to comply with these conditions thus poses a threat to the market opportunities for these 'mobility drones'. The following chapter addresses these market opportunities.

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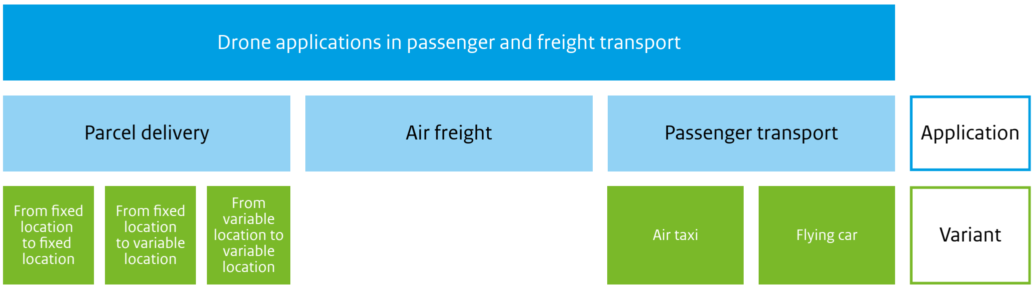
3

Applications and market opportunities for drones in passenger and freight transport

This chapter examines the use of drones in passenger and freight transport. Three drone *applications* are distinguished: parcel delivery, air freight and passenger transport. However, within these applications, *variants* are possible (see Figure 3.1). Such clustering is useful with regard to the differences in business cases and spatial effects associated with the various drone applications. The present situation is addressed, as well as a glimpse into the future.[9] Each variant is examined for its market opportunities. The market potential for commercial drone applications must be large enough for the application to be implemented. The benefits must outweigh the costs, and that positive balance must be greater than the cost-benefit ratio of the existing (alternative) transport modes.

Figure 3.1 Schematic overview of drone applications in passenger and freight transport.



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[9] There are many concepts and prototypes in this framework, but this of course is not a complete overview of this rapidly developing sector.

3.1 Parcel delivery

3.1.1 Variants

Of the three drone applications in traffic and transport, parcel delivery is most advanced in terms of development: various practical examples already exist, often qualified as proof of concept. These developments primarily pertain to Class 1 rotor-aircraft/multicopters, with maximum payloads of a few kilograms and maximum flight times of 30 minutes. This pertains to last mile delivery, for example. Drone manufacturers and parcel delivery companies have invested heavily in this application, often in partnership.

Three variants are roughly distinguished: variant A pertains to parcel delivery from fixed location to fixed location; variant B, parcel delivery from a fixed location to a variable location; and variant C, parcel delivery from a variable location to a variable location. This distinction was made in order to cluster the numerous concepts and initiatives. The underlying business cases, spatial implications and regulations can also differ; for example, for A, aviation authorities must only authorise specific routes, while for B and C permits must be issued for a particular area.

Parcel delivery from a fixed location to a fixed location (variant A) is the simplest: the drone flight is always the same. In 2014, DHL became the first company operate variant A, when it began delivering medicines to Juist, a German Wadden Sea island (DHL, 2014). The drone flies between two prepared landing sites; aDHL courier delivers the parcels to the customers once they arrive on the island. Elsewhere, Swiss Post and Matternet, a drone manufacturer, recently launched a joint initiative in Lugano, Switzerland, where drones will deliver parcels between two hospitals; the hospital personnel load the drones and then launch them via an app (Glaser, 2017a). However, unlike DHL's delivery on a remote Wadden Island, these drones will fly over urban areas. Airbus' Skyways project is a third example: Airbus, in collaboration with SingPost, will deliver parcels on the campus of the National University of Singapore, starting in mid-2017 ("SingPost becomes (...)", 2017). Here, too, the test drones will fly over an urban area. Figure 3.2 shows the Skyways 'campus application' as a system of fixed flight routes (Airbus, 2016).

This variant is advantageous in that autonomous flights are relatively easy to achieve from a technological standpoint. As long as drones do not encounter other objects in the sky, sense-and-avoid technology is not necessarily required, and this can be achieved in industrial zones by designating the area as a no-fly zone for other drones. Autonomous flying saves on labour costs.

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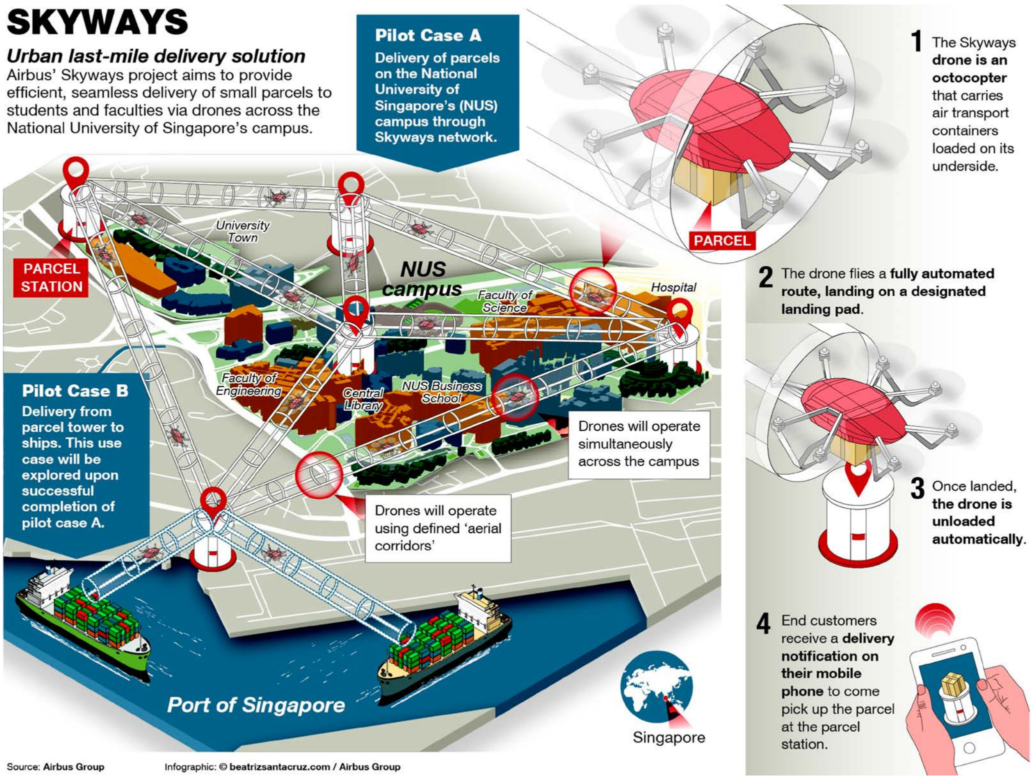
Figure 3.2 Infographic of Airbus' Skyways project. Source: Airbus.



SKYWAYS

Urban last-mile delivery solution

Airbus' Skyways project aims to provide efficient, seamless delivery of small parcels to students and faculties via drones across the National University of Singapore's campus.

Pilot Case A

Delivery of parcels on the National University of Singapore's (NUS) campus through Skyways network.

Pilot Case B

Delivery from parcel tower to ships. This use case will be explored upon successful completion of pilot case A.

Drones will operate simultaneously across the campus

Drones will operate using defined 'aerial corridors'

1 The Skyways **drone is an octocopter** that carries air transport containers loaded on its underside.

2 The drone flies a **fully automated route, landing on a designated landing pad.**

3 Once landed, **the drone is unloaded automatically.**

4 End customers receive a **delivery notification on their mobile phone** to come pick up the parcel at the parcel station.

Source: Airbus Group

Infographic: © beatrizsantacruz.com / Airbus Group

In variant B, parcels are delivered from a fixed location to a variable location; for example, from a distribution centre to a customer's home. Amazon (2016) has developed a service that can deliver parcels within 30 minutes. A pilot project is running in the United Kingdom, where parcels are delivered in the customers' yards. There are also other alternatives for unloading parcels: CleverOn, an Estonian company, built a special column in which drones can unload their parcels, and from which customers can then pick up their parcels.[10]

The 'ambulance drone' is a Dutch example of this variant: the drone, developed by a student at Delft University of Technology in 2014, is equipped with a defibrillator (AED) for resuscitating people in cardiac arrest. The Heart for Oss Foundation (Stichting Hart voor Oss) intends to deploy these drones in the municipality of Oss, starting with a pilot in 2017 ("Hart van Oss (...)", 2016).

Finally, in variant C, drones have variable arrival and departure locations. Amazon for example patented a flying distribution centre from where the drones deliver products. These airships – in the form of a Zeppelin – can fly to an altitude of 14 kilometres (Kharpal, 2016). Elsewhere, UPS is developing a system in which drones takeoff from UPS delivery vans – see Figure 3.3 (UPS, 2017). As such, the drones can deliver parcels while the courier continues to drive. One the parcel is delivered, the drone returns to the delivery van, which is now situated in a new location. Mercedes and Matternet are working on a similar design (Mercedes-Benz, 2016).

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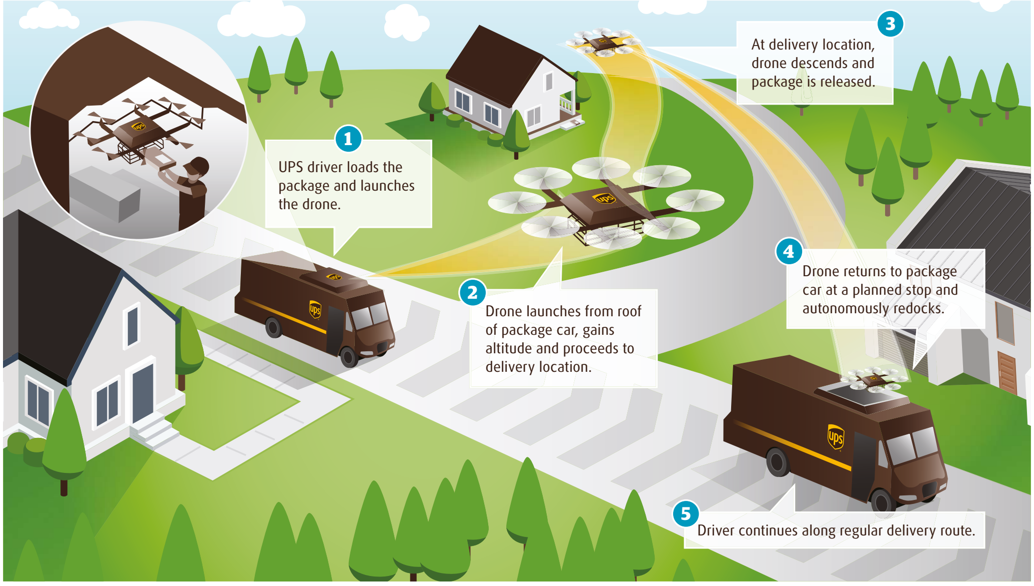
[10] See YouTube for an impression; this concept is also applicable for urban areas.

Figure 3.3 Infographic of the UPS drone application. Source: UPS.



3.1.2 Market opportunities

Various opinions exist about the actual market opportunities for drones in the parcel delivery sector. SESAR (2016) expects that around 70,000 parcel delivery drones will be deployed in Europe by 2035, and some 95,000 drones by 2050. They mainly see opportunities in express deliveries, which customers and companies are willing to pay more for, and which will primarily occur in (densely populated) suburban areas. Beyond this premium segment, SESAR does not foresee any realistic business cases. Gartner (2017) states that the profitability of parcel delivery drones has yet to be proven, and hence expects it to remain a niche market, as compared to other commercial applications of multicopter drones. Gartner does however see opportunities for campus applications within the same company.

Is parcel delivery a promising application for drones? The benefits must outweigh the costs, and that positive balance must be greater than the cost-benefit ratio of the existing (alternative) transport modes, which in this case are primarily delivery vans.

Speed is the main advantage of delivering parcels by drones. The *benefits* of speedily delivering an AED to a person in cardiac arrest are of course profound. However, for someone sitting in a park somewhere who wants to order pizza, fast delivery is less important, yet nevertheless they could be willing to pay more for the service. Fast deliveries can also be extremely beneficial for companies, such as when certain tools and spare parts must be delivered quickly to a large industrial zone. In such cases the benefits are reductions in current costs.

Some rough *cost* estimates of delivering parcels by drones have been made. Keeney (2015) used Amazon Prime Air (variant B) as the model, estimating that one delivery per drone (cargo <2.5 kilograms, distance max. 15 kilometres) would cost around $1.00 USD. Lewis (2014) did the same and arrived at a substantially higher figure, in the range of $10.00 to $17.00. These calculations revealed that much of the costs were variable, and that they varied proportionally depending on the number of drones that must be deployed. In both calculations, the assumptions made about the variable costs are of course crucial.

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In Appendix B, the cost price sensitivity per flight is examined based on various assumptions. The assumptions made about the frequency of drone flights and numbers of drones that a single operator could operate[11] will have a major impact on the costs per flight. Additionally, assumptions about drone purchase prices and capacities of drones and operators matter to the costs per flight. Conversely, energy costs are low. Assumptions about the size of the markets eligible for transport by drone (based on parcel weight and distance to the distribution centre) have little impact on the costs per flight above a minimum scale, whereby an efficient use of drones and operators remains guaranteed. The appendix reveals that as long as drone operators must monitor flights, that the technology continues developing (specifically sense-and-avoid) and that price decreases occur, a realistic cost per flight is more likely to be around $5.00 per flight, rather than $1.00 per flight. An operator's current one-on-one control already costs $25.00 per delivery. Amazon's current delivery costs via delivery van are between $2.00 and $8.00 (Lewis, 2014).

Matternet has provided a practical indication of delivery costs by drones. They delivered medicines in Haiti after many roads became impassable following an earthquake. According to CEO Andreas Raptopoulos (2013), one flight (cargo weighing 2 kilograms, distance of 10 kilometres) cost an average of $0.24 cents – see Table 3.1. Labour costs were not included, because the drone flew autonomously to prepared landing zones. Again, energy costs were low. Matternet intends to set up a network of drones in developing countries that can fly between fixed ground stations (variant A).

Table 3.1 Matternet's variable costs for a drone flight. Source: Raptopoulos (2013).

Vehicle	3 cents
Battery	9 cents
Ground station	10 cents
Energy	2 cents
Total	**24 cents**

Some relevant articles have also appeared in the scientific literature. Haidari et al. (2016), using a model simulation, compared the delivery costs of a truck to that of drones. The case study involved delivering vaccinations in Mozambique. The researchers concluded that drone implementation could lead to lower delivery costs (per vaccination) and greater availability of vaccinations. The key factors behind this cost reduction included the truck's low speed (due to poor quality roads in Mozambique) and population density (drones perform better in sparsely populated areas). Finally, it was deemed important that drones made enough flights to recoup the capital costs of investment in the drone system.

Goodchild and Toy compared a drone's[12] CO_2 emissions to that of a delivery van, with a centrally located distribution centre being assumed. They concluded that a drone is more efficient for the nearby routes and routes with low route density, while a delivery van is efficient for outlying routes and routes with high route density. High route density occurs when many stops are in close proximity and/or many parcels must be delivered at each stop. The explanation for this conclusion is that drones must fly many more kilometres (back and forth to the distribution centre) than delivery vans must drive on outlying routes and routes with high route density.

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[11] Both Keeney and Lewis assume that an operator is required to deliver parcels by drones. There are a range of assumptions about this, however, which explains the large differences in costs per flight. Lewis assumes BVLOS, with one operator serving one drone. Keeney, on the other hand, assumes 10-12 drones per operator, with the drones being used extremely efficiently, with each drone having a structured 30 flights of 30 minutes each per day. Such a high number of drones per operator presupposes that a drone is highly autonomous, and features sense-and-avoid technology.

[12] In addition, a drone does not emit CO_2. Therefore, Goodchild and Toy calculate the CO_2 emissions of electricity generated in a power plant. Moreover, they consider energy loss when transferring the power to the mains and from the mains to the battery of the drone.

3.1.3 Conclusion parcel delivery

Delivery drones have diverse application variants, which various (large) market parties have invested in. The extent to which the application variants differ depends on the various market opportunities. Such opportunities exist in the use of drones as support for deliveries via delivery vans, in the campus applications, and in the premium segment of e-commerce. These market opportunities also exist in the Netherlands.

The literature reveals that, firstly, routing density is crucial when comparing (a network of) drones and delivery via delivery vans, which is the delivery drone's primary competitor. Delivery costs per parcel are relatively low when delivery vans are used on high density routes. Secondly, the distance between the distribution centre and delivery address is important. The further away from the distribution centre a delivery address is, the greater the route density benefits for delivery vans. Thirdly, it is crucial that the investment costs for setting up and maintaining drone networks can be spread over a sufficient number of drone flights. The capacity utilisation rate must therefore be sufficiently high.

The variants devised by the various market parties can be tested against these general principles. UPS, in deploying drones in rural areas, whereby the drones depart from delivery van roofs, is acting in accordance with the route density principle. Route density is relatively low in rural areas and hence drones can operate at lower costs. The delivery van essentially functions as a mobile distribution centre, and the drones therefore fly relatively short distances.

Cost savings can also be achieved in a campus application characterised by fixed routes. The distances to travel on a campus are relatively short. This application benefits from the fact that autonomous flying is technologically relatively easy to achieve, resulting in labour cost savings. Drones can be used on an industrial campus to promptly respond to calls for spare parts that allow production processes to continue running. It is highly conceivable that this variant could be used at universities and industrial zones in the Netherlands. Putting this into practice requires a relatively small step, because the route network location is fixed and permits can be granted.

Amazon, and others, aim to service the e-commerce premium segment, delivering parcels by drones directly to customers from fixed distribution centres. This will not utilise the advantages afforded by route density. Consequently, the costs of parcel delivery by drones are unlikely to be lower (especially in the short and medium term) than the cost level of delivery vans (see Appendix B). Additional income could be generated, however, but a crucial factor is the customer willingness to pay more for fast deliveries by drones (possibly within 30 minutes).

To serve the premium segment, an effective market segmentation strategy is essential: what part of the market is eligible for express delivery by drones? Courier services or webshops would have to use many distribution centres in order to limit the distances between drone and delivery address. Consequently, they will select areas where they could expect to attract many potential customers. Amazon offers 1-hour delivery in the UK, but 'only' around nine major cities. Given the need for a (large) market catchment area in the vicinity of distribution centres, the Netherlands' major cities are highly eligible for such services. According to SESAR (2016), 1 to 1.5 percent of the parcel market in Europe (around 85 million parcels) falls within the premium segment and are of sufficiently close proximity to distribution centres.

In addition to the theoretical possibilities of saving costs or generating extra income, each variant's practical feasibility is crucial. For example, the question is whether it is even possible to deliver to every address with drones. In urban areas, and certainly as it pertains to apartments, consumers cannot directly receive parcels; supplementary services must therefore be offered, such as CleverOn's special columns, where drones unload their parcels and customers pick up their parcels. But this also has spatial implications: such columns must be situated somewhere. In urban areas, public space is scarce; it must be shared with other functionalities (parking, waste collection, and so on). In rural areas, delivering parcels directly to customers (in their yards) is more likely. Landing sites can be prepared for drones in industrial zones and on other campuses.

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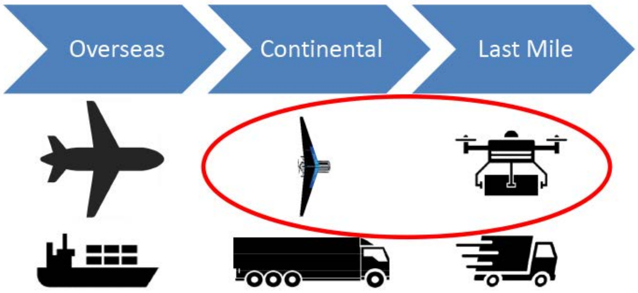
As cited in Chapter 2, weather conditions are a factor that must not be underestimated. Temperature, precipitation and wind all have major impacts on small delivery drones, reducing their deployability. The fewer drone flights made, the higher the costs per flight. For the campus application, or the variant combining drones and delivery vans, reduced deployability means the intended cost benefits cannot be achieved. When servicing the premium segment, a (high) risk exists that drones are insufficiently reliable. The intended target group willing to pay for certainty and speed demands reliable service; weather conditions can therefore prevent this business model from 'getting off the ground'.

3.2 Unmanned air freight

3.2.1 Variants

Unmanned air freight is the second drone application. Unlike the parcel delivery drones, these are larger aircraft. Both rotor-aircraft and fixed-wing aircraft were designed for unmanned air freight transport. Moreover, they have significantly larger loading capacities and range than delivery drones and also offer more conceivable *combinations* of loads and range. This is no longer about last mile transport, but rather continental transport – see Figure 3. 4. Given the diversity within this application, air freight does not readily lend itself to distinctions between identifiable variants.

Figure 3.4 Drones in freight transport (encircled in red) and their counterparts per market segment. Source: Pizarro (2017).



There are few known examples of unmanned air freight systems. The Kaman K-MAX helicopter, the UMS Skeldar V-200 mini-helicopter[13], and the FLYOX amphibious aircraft are already available on the market. Dronamics, Romaeris, and Wings for Aid are examples of organisations that are still developing their unmanned air freight systems.

The K-MAX, a freight helicopter, has a maximum load of 2,700 kilograms and range of 400 kilometres when fully loaded (1,800 kilometres unloaded). The unmanned version is derived from the manned version, which is by far the most commonly used – in construction, for example, but also for rescue and fire-fighting operations. The US Army deployed the unmanned version during the war in Afghanistan; its great advantage is that goods can be delivered in dangerous situations without putting human lives at risk (Kaman, n.d.).

The V-200, a VTOL drone in the shape of a helicopter, has a maximum load of 40 kilograms and range of 90 kilometres. V-200s are used in the cabling of overground electricity networks and for (rapidly) delivering goods (spare parts, for example); moreover, it replaced manned helicopters, rendering this work cheaper, safer and possible in adverse weather conditions. UMS Skeldar conducts practical tests with an autonomous version of the V-200, but the drone is routinely BVLOS operated (Willems, 2017).

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[13] Previously Saab Skeldar.

The FLYOX (see Figure 3.5) is an unmanned aircraft that can takeoff and land on water; it has a maximum load of more than 1,850 kilograms and range of nearly 500 kilometres when fully loaded (5,000 kilometres unloaded). This aircraft is used for fire-fighting, for instance. Rather remarkably, the aircraft can be assembled and disassembled like a do-it-yourself kit (Singular Aircraft, n.d.). The Platform Unmanned Cargo Aircraft (PUCA)[14], in collaboration with the University of Amsterdam, Twente University, DARPAS, and the Ministry of Infrastructure and the Environment, intends to use this aircraft to make the first international flight with an unmanned freight aircraft in the Netherlands. The flight will be between Weeze (Germany) and Enschede (De Boer, 2017).

Dronamics[15], based in Bulgaria, is an example of a start-up in unmanned air freight; they are working on a drone with a maximum load of 350 kilograms and range of 2,500 kilometres. It is a fixed-wing aircraft with a combustion engine and BVLOS control. Dronamics is targeting markets in which they can offer this aircraft as a service, rather than selling their drones to customers (mobility-as-a-service). The company believes the greatest market potential is in developing countries, particularly because of the long distances and smaller cargo loads. Additionally, parcel transport (e-commerce) and fresh products delivery are conceivable, due to their time-sensitivity and perishability (Rangelov, 2015).

Romaeris, a Canadian company, designed a drone with a maximum load of 250 kilograms and range of 1,800 kilometres (see Figure 3.5); it is also a fixed-wing aircraft with a combustion engine and BVLOS control. The drone is initially intended to provide remote communities in Canada with daily necessities, such as food, which is expensive due to high transport costs. The drone must be able to takeoff and land from unpaved landing sites (Pizarro, 2017).

The final example is Wings for Aid, a non-commercial Dutch initiative. Wings for Aid aims to deliver supplies to disaster areas, which will involve delivering supplies from a warehouse situated near the disaster area to the people in need. The existing infrastructure in disaster areas may be unusable and hence air freight is a solution. In the Wings for Aid concept, unmanned freight aircraft can deliver supplies via parachutes (Koperberg, 2016).

Figure 3.5 The FLYOX I amphibious aircraft (left) and the Romaeris air freight drone prototype (right). Source: Singular Aircraft and Pizarro (2017).

3.2.2 Market opportunities

Given the diversity of the variants, it is difficult to identify market opportunities. A drone like the UMS Skeldar V-200 can be used for freight transport, but also as a supplement to cranes on construction sites. Nevertheless, as with parcel delivery, the benefits of unmanned air freight systems must outweigh the costs, and that positive balance must be greater than the cost-benefit ratio of the existing alternatives. The fact that there are only a few examples of unmanned air freight systems could mean that presently these conditions are not often met. SESAR (2016) expects the market for unmanned air freight transport in Europe to be limited to fewer than 1,000 aircraft.

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[14] PUCA is an organisation that stimulates the development of unmanned freight aircraft.

[15] Dronamics won a competition for start-ups (the Pioneers Festival, featuring 1,600 start-ups from 98 countries). One of the founders studied at TU Delft; their pitch is on YouTube.

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Heerkens (2017) concludes that in the development of unmanned freight aircraft, it seems as if "everyone is waiting on everyone else". Moreover, he indicates that transport and airline companies will only decide to exploit unmanned air freight systems if they are developed. Manufacturers, conversely, first want to be certain about the extent of the market demand before committing to develop such systems.

Air freight represents around 1 percent of the annual global freight volume, but 35 percent of the global value of freight. Air freight is usually preferred for high value (machine parts, etc.), time-sensitive (fashion, etc.) and perishable (flowers, etc.) goods. More than half of all air freight is shipped with full freighters, the rest with combi-aircraft or passenger planes (as belly freight) (Boeing, 2016). Consequently, air freight is only possible if the demand on a route is sufficient for operating large passenger or cargo planes. Combining freight with passenger transport ensures that the freight shipped in that space has low marginal costs ("Is there a future (...)", 2016).

Given this background, PUCA (n.d.) identified various (design) aspects that have (cost) benefits for unmanned air freight, as compared to standard air freight:
- No pressurised cabin is needed, so the aircraft no longer needs to be round-shaped. The aerodynamics can be improved, resulting in lower fuel consumption.
- In terms of working hours, flight duration no longer matters. The aircraft's speed can therefore be optimised for fuel efficiency.
- Due to the intended control via BVLOS, labor costs are reduced, because one operator can operate multiple unmanned freight aircraft.
- Smaller (less expensive) airports can be used, because shorter runways are required. Moreover, more destinations become accessible.

In addition to reducing costs, identify promising markets (the benefits) is key. PUCA[16] (n.d.) states that at issue are the routes where the freight value is high, the freight volume low (so-called 'thin' routes), and no alternative direct air connections are available. Moreover, a lack of physical infrastructure, like (rail) roads to an airport, renders unmanned aviation attractive.

At issue in such a context is not so much the competition with or replacement of existing air freight streams, but rather primarily the tapping into of new markets. In a scenario analysis, Van Groningen (2017) shows how unmanned freight aircraft cost less than manned air freight and sea freight on the Ürümqi (inland China) to Stuttgart route, for which no connections currently exist. The same conclusion also applies to the Shenzhen to Stuttgart route, although to a lesser extent, because Shenzhen is situated on China's coast. Additionally, Van Groningen, in her analysis, uses an unmanned freight aircraft with a maximum load of 5,000 kilograms and range of 10,000 kilometres, which is significantly larger than the examples in section 3.2.1, which further highlights the diversity in unmanned air freight.

3.2.3 Conclusion unmanned air freight

Despite the diversity of variants, it is possible to arrive at a general outline of the market contours where drones can be active. These are niche markets for high value, time-sensitive and perishable goods, as with current air freight. Also of interest are goods and routes that are potentially dangerous for humans. However, niche markets lack route density, rendering it difficult to highly utilise drones; consequently, the drones must be flexible and deployed at varying locations. And this is indeed feasible, as no (location-bound) personnel are required. Ultimately, the greatest opportunities for unmanned air freight are in areas that are not properly accessible by other types of infrastructure; this lack of infrastructure results in relatively high transport costs, allowing drones to compete.

As empirically concluded, relatively few (major) parties have invested in the air freight drone application, as compared to the parcel delivery segment. Although some start-ups and operational air freight drones exist, they are comparatively few in number. One possible explanation for this is that investors are reluctant to invest if a combination of niche markets is needed to achieve profitability.

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[16] Based on research from Hoeben, J.S.F. (2014), A value analysis of unmanned aircraft operations for the transport of high time - value cargo and Prent, S. (2013) De markt voor onbemande vrachtvliegtuigen (in Dutch).

When testing the business models of start-ups, Dronamics and Romaeris, against the general contours of the market opportunities for unmanned air freight, they appear to be well aligned. For example, both focus on areas lacking proper infrastructure, and where consequently local transport costs are high; in Canada, from a financial perspective, and in developing countries, from a time perspective. In such areas there is likely to be a small amount of high value freight, in terms of money or time; consequently, their relatively small, long-range freight drones are a good fit.

In Europe, the Dronamics and Romaeris air freight concept could be applied Scandinavia, for example, where the infrastructure is good but labour costs are high. The same principle for delivery vans applies here: as long as there is high volume or stops close to one another, vans offer economies of scale. However, when loads are smaller and distances between stops longer, drones are likely more efficient.

Freight drones could indeed be deployed in the Netherlands for transporting small machine or computer components between ships and drilling platforms in the North Sea, thus competing with the helicopter transport that currently provides this service. Additionally, because the Netherlands is so highly accessible, both domestically and internationally, and by air, land and sea, market opportunities are not apparent. Moreover, if air freight drones use existing infrastructure, such as helipads and airports, the spatial impact remains limited. Alternatively, to reduce access and egress transport, landing sites could be set up near industrial zones. However, in such cases, the spatial impact would be greater. Finally, the use of VTOL has less of an impact on spatial planning than fixed-wing aircraft.

3.3 Unmanned passenger transport

3.3.1 Variants

SESAR (2016) expects commercial applications of drone parcel and freight transport to occur before passenger transport, the third application distinguished here. However, both established and new market parties are investing heavily in passenger drones. According to Matthieu Repellin, investment partner at Airbus Ventures (cited in Airbus, 2016), which also invests in passenger transport drones, such enthusiasm is driven by the fact that the cost/transport performance ratio is rapidly improving. He expects that unmanned (autonomous) passenger transport will become technologically feasible and economically profitable in the foreseeable future. SESAR (2016) however is somewhat more conservative in its assessment; it does not expect the large-scale implementation of these drones to occur before 2035.

The investments currently seem to focus on two variants: the air taxi and the flying car. The major difference between them is that flying cars can drive on public roads and air taxis cannot. Further, in the air taxi concept, passengers pay per ride; they need not own the drone. Flying cars, conversely, are personally owned transport modes. It is however quite conceivable that this distinction will disappear in future, as the technology and methods of use evolve. Why would a drone that can exclusively fly not be privately owned?

With its launch in Dubai in 2017, the Ehang 184 is perhaps the first air taxi drone to have appeared on the market.[17] The Ehang, an electrically powered multicopter suitable for one passenger, can fly for up to 30 minutes. It takes 2 to 4 hours to charge the batteries. The drone operates with BVLOS command and control; its command centre is situated in the Chinese city of Guangzhou (see Figure 3.6). If technical problems occur, the drone itself chooses the nearest safe landing site; however, full autonomy is the ultimate goal (Ehang, n.d.). Dubai is using this drone to help promote itself as a smart city, and by 2030 intends to have driverless vehicles (self-driving cars and autonomous drones) accounting for a quarter of all trips taken in the city (Morlin-Yron, 2017).

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[17] After finalisation of this report, Dubai announced a collaboration with Volocopter instead of Ehang.

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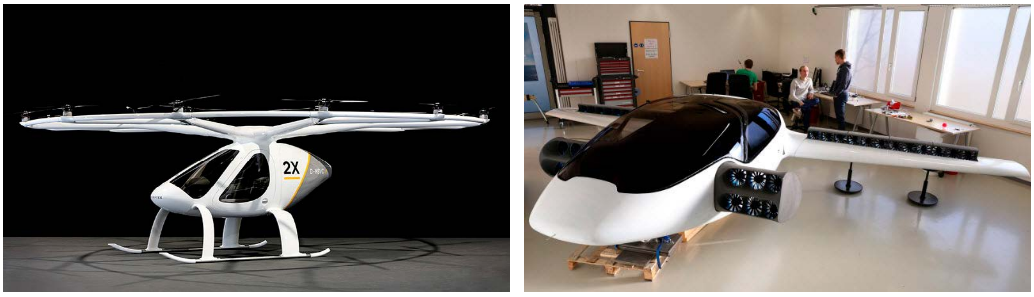
Figure 3.6 De Ehang 184 and the command centre in China, where all Ehang passenger drones are monitored. Source: Ehang.

Germany's Volocopter (see Figure 3.7) built an electric-powered multicopter suitable for two passengers. Featuring replaceable batteries, the drone can fly for 20 minutes and is currently categorised as a sport aircraft, requiring a pilot to steer.[18] In 2018, Volocopter intends to launch a pilot project in which their drone will serve as an air taxi. The ultimate aim is to switch to BVLOS and autonomous control (Volocopter, n.d.).

Lilium Jet is another German initiative (see Figure 3.7). This drone – like the Ehang and Volocopter – can vertically takeoff and land using its rotors; however, once in the air, the rotors rotate and the drone flies like a fixed-wing airplane. The idea behind this concept is that a rotor-aircraft is relatively slow in the horizontal flight phase, inefficiently consuming energy compared to fixed-wing aircraft. The Lilium Jet's hybrid design combines the advantages of a multicopter (VTOL) with that of a fixed-wing aircraft (energy efficiency). The Lilium Jet's range is 300 kilometres. The company recently conducted its first (unmanned) test flight using a two-passenger model[19]; meanwhile, a five-passenger model is in the works (Lilium, n.d.).

Figure 3.7 De Volocopter 2X (links) en de Lilium Jet (rechts). Source: Volocopter en Lilium.



The final example is Uber's Elevate Program (2016), the foundation of which is the development of a network of drones capable of utilising existing infrastructure, such as helipads and parking garage rooftops, and that operates as an on-demand taxi service. Uber will initially devise a *manned* aircraft, but over time the pilot will be replaced by autonomous control. Like Lilium with its Lilium Jet, Uber aims for a hybrid rotor design for vertical takeoff and landing (VTOL), and wings for an energy-efficient horizontal flight stage. Uber, in the Elevate platform, has sought partnerships with various parties engaged in developing unmanned aircraft, charging systems and manufacturing companies (Liberatore, 2017).

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[18] See YouTube for images of a test flight.
[19] See YouTube for images of a test flight.

The second unmanned passenger transport variant is the flying car. Here, too, multiple prototypes exist and some models are coming onto the market. Of note however is that this does not (yet) pertain to drones, but rather to *piloted* aircraft.

In 2018, the Netherlands' PAL-V (which stands for Personal Air and Land Vehicle) will become the first company in the world to launch a flying car on the market. The PAL-V Liberty (see Figure 3.8) is a two-passenger car and gyrocopter[20] in one. To operate this vehicle, the driver must have a driver's license and a pilot's license. The Liberty is not a drone, but the concept is relevant. The Liberty, powered by a combustion engine, can be refuelled at gas stations. The transformation from car to gyrocopter takes about 5 to 10 minutes, and to fly a runaway is required. Due to Dutch regulations, this flying car must takeoff and land at airports. The Liberty can fly 400 kilometres or drive 1,300 kilometres (Witten, 2017).

Figure 3.8 The PAL-V Liberty (left) and the Terrafugia TF-X (right). Source: PAL-V and Terrafugia.

Combining a car with a gyrocopter is unique. Other models of flying cars, such as the AeroMobil and the Terrafugia Transition, use folding wings, and both require that the drivers have pilot licences – neither models are available yet. Terrafugia positions the Transition as a proof of concept and aims to bring an autonomous flying car onto the market with its TF-X concept model (Terrafugia, n.d.; see Figure 3.8). The TF-X is an electric-powered hybrid wing aircraft with VTOL capabilities. Terrafugia eyes a broad customer base, with door-to-door mobility as its target.

3.3.2 Market opportunities

As with the other two drone applications, the benefits of unmanned passenger transport must outweigh the costs, and that positive balance must be greater than the cost-benefit ratio of the existing alternatives. For unmanned passenger transport, the key alternative competitor is the passenger car.

Uber and Lilium (see section 3.3.1) therefore also provide a comparison between a passenger drone and a taxi. To illustrate an on-demand air taxi service, Lilium compares the costs and benefits of a drone flight with that of a taxi trip from Manhattan to JFK Airport. According to Lilium, the trip's duration can be reduced from 55 minutes to 5 minutes, while the fare can also be reduced from $56.00 for the taxi trip to $36.00 when using the air taxi service, and over the longer term the price could even fall to just $6.00 (Lilium, n.d.).

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[20] A gyrocopter is a plane with a motorless rotor. A propeller drives the propulsion, causing the rotor to move and providing for lift. The gyrokopter looks like a helicopter, but the rotor is driven by an engine. Owing to this technological difference, a helicopter can takeoff and land vertically, but a gyrocopter cannot. It takes between 20 and 40 hours of training to get a license, or approximately as long as a driver's license (Autogiro, n.d.).

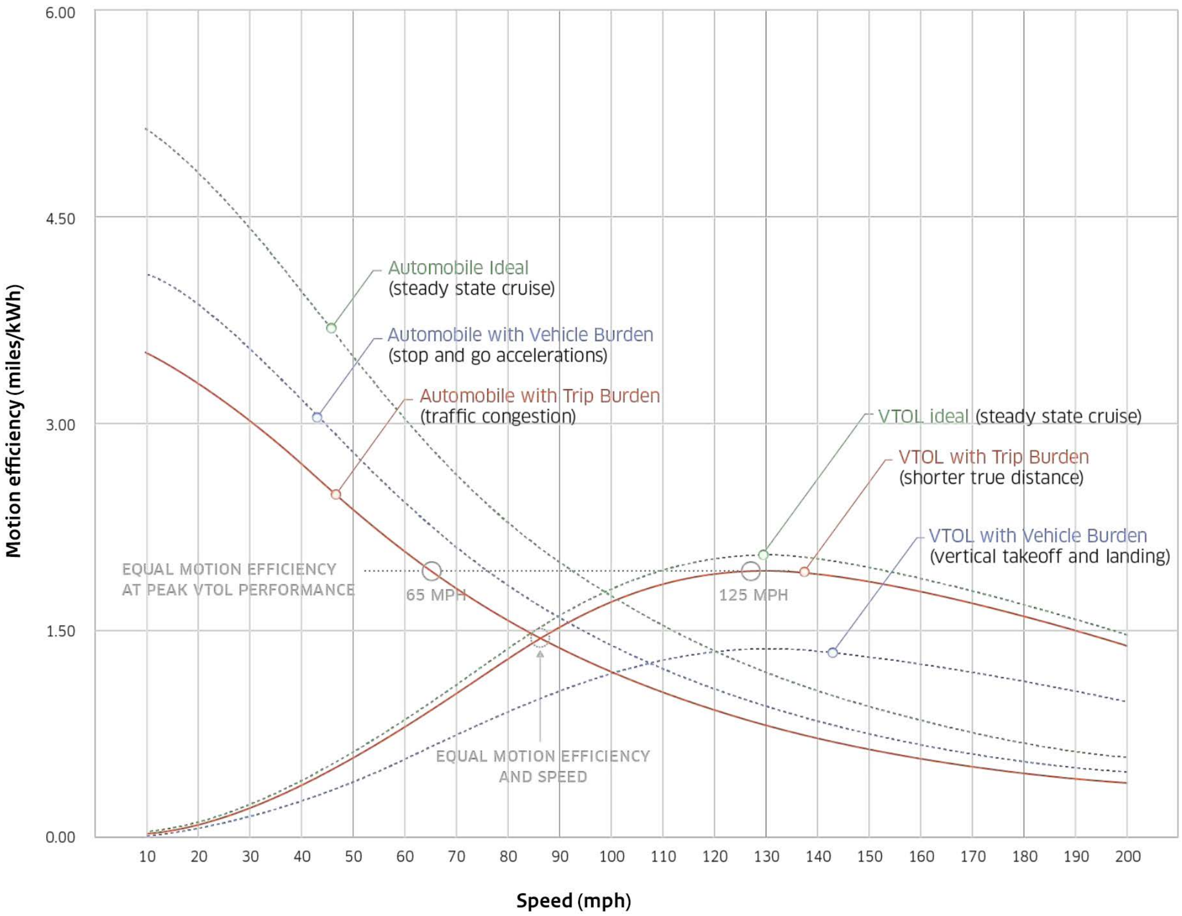
Uber has devised similar case studies for home-to-work commutes between San Francisco and San Jose, for example, whereby the trip duration is reduced from 100 minutes to 15 minutes when commuters switch from an Uber X taxi to an air taxi. The initial price of the flight is $129.00, compared to the Uber-X fare of $111.00, but over the longer term the flight fare will fall to just $20.00 (Uber, 2016).

In the Lilium and Uber examples, the declining costs per trip are explained by the (assumed) rising popularity of the air taxi concept. Consequently, occupancy rates will increase, allowing the fixed costs to be spread over more rides, resulting in lower per trip prices. Moreover, more drones will be needed, which allows for a mass production that lowers the production costs: Uber (2016) estimates that over time the production cost will drop from an initial $1.2 million to $200,000. Finally, pilots will eventually be replaced (see section 3.3.1), which also results in cost reductions.

Energy consumption is an additional factor impacting trip prices (as detailed in Chapter 2). Uber (2016) therefore compares the energy-efficiency of its intended hybrid (4-passenger) drone to the Tesla Model S. For cars, energy-efficiency is determined by a combination of wind resistance and frictional resistance, while for drones it is wind resistance and lifting force. How much energy a drone uses depends on many factors, including its size, the flight distance and altitude, temperature, wind direction and wind speed. Moreover, the weight of the batteries significantly increases a drone's total weight; consequently, its energy performance is less than that of a modern sport aircraft.

Figure 3.9 reveals the results of the comparison between a drone and a Tesla, in which energy-efficiency is denoted as the distance travelled per kilowatt hour (kWh). This analysis shows that drones need large amounts of energy to takeoff, but that at higher speeds they gain in energy-efficiency. The reason for this is that the energy required to generate lift decreases, while the drone's aerodynamics serve to limit the increasing wind resistance. The graph also reveals that if takeoff and landing are excluded, a drone's energy-efficiency is highest at around 200 kilometres per hour (125 miles per hour). When the takeoff and landing energy consumption is included, the drone's optimum speed is 215 kilometres per hour (135 miles per hour), and the drone becomes more efficient than the car when travelling at speeds above 170 kilometres per hour (105 miles per hour). In terms of energy-efficiency, drones are less suitable for short flights, because their takeoffs and landings consume relatively large amounts of energy, and they cannot gain much energy-efficiency (compared to cars) during the short horizontal flight stage.

Figure 3.9 Comparison of the energy-efficiency of an electric car and a VTOL drone. In the 'Trip burden'' scenario, the car's energy performance diminshed greatly due to stop and go accelerations and traffic congestion. In the 'Vehicle burden' scenario, the drone's vertical takeoff and landing significantly increases its energy consumption. Source: Uber (2016, p85).



Uber expects that the initial users of air taxis will be commuters between suburban and urban areas; this is because the amount of saved time increases with the distance travelled. Moreover, a long flight renders the last mile relatively shorter; this pertains to the distance between the location where the drone lands and the passenger's destination. Uber also aims to promote the shared use of flights, creating a shared air taxi system. In its business case, Uber assumes that paying passengers will occupy an average of 67 percent of the seats. That figure is approximately 44 percent for a Dutch street taxi (TNS-NIPO, 2004), while airlines usually have occupancy rates of 80-90 percent. Uber expects a drone to be used for 40 hours per week (Uber, 2016).

The question is whether such an occupancy rate is feasible. Not much is known about people's willingness to travel in unmanned aircraft. The British newspaper, The Telegraph, ran an online poll following the announcement of Uber's plans, asking the question: "Would you travel in a self-flying air taxi?". More than 5,000 people participated in the poll, with 63 percent answering 'yes' (Titcomb, 2016). While this does not necessarily offer a representative overview, it does indicate that there is a social group that would use air taxis.

Sivak and Schoettle, of the University of Michigan (as cited in Glaser, 2017b), examined US public opinion about flying cars. Of all respondents (n = 508), 75 percent said time savings were the main advantage, while 60 percent were deeply concerned about both safety and integration in the airspace, and about the vehicles performance in poor weather conditions. The survey further revealed that 83 percent of respondents preferred VTOL, while 62 percent found 3-4 passengers the optimum capacity. Finally, an

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interesting conclusion from the survey was that people preferred a fully autonomously operating flying car (or air taxi variant) to one that was piloted, regardless of whether this was a trained pilot or the respondents themselves. This revealed great trust in the technology.

The market for flying cars is limited to higher income groups. The PAL-V Liberty's price tag is €300,000 EUR. The AeroMobil costs $1.2 to $1.6 million (Rodriguez, 2017). The Uber business case reveals that even mass production will not lower the price of a personal drone under $200,000.

3.3.3 Conclusion unmanned passenger transport

As based on current prototypes and concepts, a distinction can be made in this drone application between flying cars and air taxis. These are vehicles with differing characteristics. Flying cars can also be driven on public roads.

Notably, large companies, like Airbus and Uber, as well as smaller start-ups with capital-intensive investors[21], have invested heavily in this drone application. Various prototypes exist for both the flying car and air taxi, and how they will be positioned in the market is apparent. Some service providers are ready to go live in a very short period of time. Ehang aims to start offering air taxi services in Dubai this year; Uber aims to have conducted its first passenger flights in Dallas-Fort Worth and (also) Dubai[22] by 2020 (Liberatore, 2017).

The people who will initially be most interested in air taxis and flying cars are those in higher income groups who place a premium on travel time. Uber expects the price for an air taxi flight to fall sharply as usage rates increase, which would mean air taxis had become accessible to a wider public. Such assumptions face some critical challenges, however. First, the question is whether people will be willing to get into a (autonomously flying) drone. Various surveys seemingly indicate that a (ex-ante) group of people exists who will dare to do so. But what happens to such burgeoning enthusiasm if fatal crashes occur? For large-scale applications of flying cars and air taxis, a focus on safety is paramount, in order to gain and maintain passenger confidence.

Secondly, the question is whether air taxi service providers can succeed in bundling demand and creating successful shared air taxi concepts. Passengers can be situated in different locations and may not need to share flights. Essentially, this is no different than current taxi services, and shared taxis claim only a small share of the market. However, solutions can be found, including in fare differentiation, for example. If passengers opt to use a shared air taxi, they will pay a lower price for the flight. Moreover, drones are fast, meaning detours cost relatively little time, as compared to cars.

The possibility of driving on public roads is an added value that flying cars have over air taxis, and as such door-to-door travel becomes possible: the last mile can be travelled without a changeover. Conversely, air taxi passengers must changeover to supplemental ground transport or continue by foot.[23]

Question marks are also affixed to the PAL-V and AeroMobil flying car business cases. On the one hand, luxury brands (like Ferrari in the car industry) do have their markets, although their target group of wealthy consumers is not large. While on the other hand, the crux of their business case is the product's usefulness: will flying car users actually save travel time or will flying cars be a type of leisure activity? If users must use (scarce) runways, as is the case with the PAL-V and AeroMobil, they must also contend with access and egress transport. Moreover, runways are often situated on the outskirts of cities. Ultimately, then, it becomes a question of whether a person saves travel time, as compared to car trips, particularly when their departure points or destinations are in a city. A potential solution could be the VTOL design, like that of the Terrafugia TF-X, because there are more potential landing sites in cities.

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[21] Not all are discussed in this chapter. Examples of other companies working on unmanned passenger transport are: A^3 (Airbus), Joby Aviation, Zee. Aero and Aurora Flight Sciences. See eVTOL for an overview. Larry Page, co-founder of Google, has invested some $100 million in Zee.

[22] The World Exhibition will be held in Dubai in 2020, hence this city was chosen for starting the air taxi service.

[23] A possible exception is the Airbus' Pop.Up-concept, see YouTube.

In that context, Uber proposes to use parking garage roofs and high-rise buildings as landing sites for its air taxis. These are not public spaces and can therefore be commercially exploited. The government could however create boundary conditions, relating to proximity to buildings and the mounting of noise-protection walls, for example. Landing sites must also be established outside of cities, but land is more plentiful there compared to cities and hence more options exist.

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4

Conclusions

Three mobility applications of drones are distinguished: parcel delivery, air freight and passenger transport. Drones can be alternatives to existing modalities when a) speed is a key transport criterion, and b) the quantities are small.[24] Such examples include the delivery of needed spare parts to remote drilling platforms, delivering defibrillators to people in cardiac arrest or a government minister who needs to quickly travel to Brussels for urgent consultations.

4.1 Conditions

Numerous conditions must be met before drones can be used in passenger and freight transport. Firstly, various technological aspects are crucial. Developing sense-and-avoid technology is a key condition for autonomous control. A high degree of autonomy lowers the labour costs associated with drone applications, which is advantageous for achieving various drone applications. Further, weather conditions play a major role, particularly for small drones. If drones are frequently prevented from flying due to inclement weather, this impacts the reliability of the service. Drones must therefore be highly resistant to weather conditions. A system is also required to coordinate drones in the airspace. Given the expected growth in drone numbers, the skies will become increasingly crowded. Coordination improves the system's safety and efficiency.

Secondly, the social acceptance of drone applications must be established. Drones manufacturers face the challenge of enhancing drone safety, both in terms of the technology and the prevention of misuse. Moreover, any possible disturbances that drones cause in residential areas must be minimised; this includes noise disturbances and perceived violations of privacy. Finally, drone applications for humanitarian purposes could enhance their social acceptance, for example.

4.2 Market opportunities

4.2.1 Parcel delivery

A relatively large number of parties have invested in developing parcel delivery by drones, for which clearly identifiable market opportunities exist. The campus application allows companies to deliver faster, on demand. Drones could replace an internal company courier service, for example. Moreover, because the campus application's technological threshold is relatively low, this will seemingly be the first variant to get off the ground.

The e-commerce premium segment also presents market opportunities. The premium segment pertains to that part of the market in which customers are willing to pay more for the quick delivery of their ordered goods. According to SESAR (2016), this pertains to approximately 1 to 1.5 percent of the total

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[24] This can involve loads of several tons, but that is little compared to conventional air freight. The term 'little' is therefore relative, compared to the existing alternative competitors.

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parcel market in Europe. By serving this segment, webshops and couriers can generate additional income. This type of service can also be expected in the Netherlands, especially in (the vicinity of) major cities. Because delivery drones have a limited radius of action (some 15 kilometres), they will deliver in close proximity to distribution centres, and these distribution centres will obviously be situated near major cities, owing to the large numbers of consumers residing there.

If speed is not important, delivery vans are often more efficient from a cost perspective; they will therefore continue to be widely used in parcel delivery. However, a third application combines delivery drones and delivery vans, with the drone departing from the van's roof. Such a combination can lead to cost savings, because drones are used in areas where delivery vans cannot benefit from route density. This technique could also be applied in the Netherlands, with the country's rural areas seemingly the most likely locations.

4.2.2 Unmanned air freight

Drones have a relatively wide variety of market opportunities in air freight, because diverse combinations of payload and range are possible. Consequently, various prototypes were designed. The common thread is that this pertains to niche markets in which high value, time-sensitive and perishable goods must be transported rapidly. The market opportunities are further reinforced by a lack of competitive alternative transport modes. Also of interest are goods and routes that are potentially dangerous to humans. However, niche markets lack route density and this makes it difficult to highly utilise a drone. That relatively little has been invested in this drone application is perhaps owing to the diversity of market opportunities and associated uncertainties.

Freight drones could be used in the Netherlands for transporting small machine or computer components between ships and drilling platforms on the North Sea, where they would compete with helicopter transport. Further, the Netherlands is so highly accessible, both domestically and internationally, and by land, sea and air, that there are seemingly few apparent market opportunites for air freight drones in the Netherlands.

Freight drones could perhaps have a greater impact in countries or areas lacking good infrastructure than in the Netherlands. In developing countries, high transport costs – expressed in both time and money – can prevent farmers from trading their goods, owing to their perishability. The deployment of drones could positively impact such local economies. In the Netherlands it is about *fine-tuning* the transport network, while in developing countries drones could provide an *upgrade*.

4.2.3 Unmanned passenger transport

Passenger drones are perhaps the most appealing to the imagination; they could be someone's personal possession, but also used as air taxis, with passengers able to avoid traffic congestion and arrive quickly at their destinations. The longer the distances, the more advantageous these drones become, because the drone's speed is better utilised, and the energy consumption required for (vertical) takeoffs and landings is relatively lower the further the drone flies. There is also a select target group in the Netherlands who would want to use passenger drones when travelling between suburbs and city centres, for example.

Flying cars are expected to be very expensive to purchase; consequently, only a select group of people will own passenger drones. Using drones as air taxis has a lower threshold. However, as with parcel delivery, this will cost more than alternative modalities, which in this case are cars. As such, people must be willing to pay more to reach their destinations quickly. According to those involved in the development of air taxi transport, trip fares will decrease over time, and also partly because passengers can share an air taxi. Air taxi service providers therefore face the challenge of bundling demand and devising successful shared air taxi concepts.

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4.3 Spatial effects

Because there will be more drone flights, the Dutch skyline will change, and this has consequences for spatial planning. In order to successfully deliver parcels, customers must be capable of receiving their parcels, which is a challenge in urban areas, where space is limited. Columns can be erected to serve as pickup points, for example. The spatial effects are likely to be less significant in rural areas.

Air freight drones have a limited spatial impact when existing infrastructure is used, such as helipads and airports. Alternatively, to reduce access and egress transport, landing sites could be set up near industrial zones. However, in such cases, the spatial impact would be greater.

Landing sites must also be set up to facilitate passenger drone transport. In cities, the roofs of parking garages or high buildings could serve as landing sites: however, vertical takeoff and landing would be necessary. Landing sites need not be in public spaces, and that offers opportunities for commercial exploitation. Landing sites must also be established outside of cities. Using VTOL – regardless of the drone type – ultimately has less of an impact on spatial planning than fixed-wing aircraft.

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Appendices

Appendix A: The development of sense-and-avoid technology

To operate safely, an unmanned autonomous flying aircraft must know its current position, where it is heading and where other aircraft and hazards are situated. To do this, it must be equipped with sensors and computers capable of replicating the aspects of the human eye and brain required for interpreting observations. This is the foundation of sense-and-avoid.

Various measuring devices are used to observe the surroundings from an aircraft (see Figure A1), including infrared cameras, laser altimeters and slow-motion navigation systems. The initial challenge is to observe such a diversity of objects, which can range from high-voltage cables, residential towers, mountainous areas and thunderstorms, as well as other aircraft. Adding more sensors increases an aircrafts' weight and costs. Autonomous rotor-aircraft and autonomous fixed-wing aircraft have similar sensors (Button, 2015).

The next challenge is to interpret the observations, which requires algorithms. Algorithms are decision rules that the computer on board the aircraft bases its decision on; for example, to determine if a landing location is stable and safe or whether flight paths are free of hazards. Scanning the immediate surroundings and possibly altering routes is an iterative process; that is, the drone has defined a flight path and scans to determine if it is safe. The moment the drone detects a (flying) object in its flight path, it selects an alternative route, which it also scans, and should a (flying) object be detected on that flight path, the drone will again select a new alternative route. This process repeats itself (Scherer, 2014).

Figure A1 The sensors that are used for sense-and-avoid (left), and a 3D-impression of a building created by a drone (right). Source: Near Earth Autonomy.[25]

Obstacle detection during takeoff and (primarily) landing is a type of sense-and-avoid. A rotor-aircraft must be able to land on rough terrain, unlike a fixed-wing aircraft; consequently, a rotor-aircraft must make a detailed scan of its surroundings before landing. This occurs at low speed, because observing small objects is more difficult the higher the speed.

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[25] See YouTube for a demonstration of their technology.

A final challenge is the observation of/communication between aircraft. Designing an alternative route based solely on sense-and-avoid technology – that is, without communication between aircraft – is likely to be insufficient. Firstly, the drone is travelling at high rates of speed and the sensors must be capable of observing at great distances. Secondly, a risk exists that the alternative routes both drones have chosen could (also) conflict. To reduce the risks associated with high speed travel, it is beneficial to equip drones with transponders as standard, for example, or allow coordination to occur through a centralised system (such as SESAR's U-space-concept, see section 2.1.3). In order to prevent the drones' avoidance manoeuvres from conflicting, it would be sensible to establish 'traffic rules'.

According to Sebastian Scherer (personal communication, August 14, 2017), sense-and-avoid will become commercially available for small drone types within 1 to 3 years, and 5 to 10 years for larger drone types.

Appendix B: Costs of parcel delivery by drone

Keeney (2015) calculated the cost of delivering parcels by drone in a 16-kilometer radius of action around a distribution centre. Based on that calculations supporting information, it is possible to calculate a number of variants and map the range of costs.[26] The findings are presented in Table B1.

Table B1 Costs per drone flight as based on various assumptions. Source: author's calculations.

	Base	Frequency drones	Utilisation	Price drones	Drones per operator		
Flights per drone per day	30	15	15	15	15	15	15
Use capacity (%)	100	100	75	75	75	75	75
Price per drone (USD)	2.000	2,000	2,000	10,000	10,000	10,000	10,000
Drones per operator	12	12	12	12	6	2	1
Minutes data per flight	2.5	2.5	2.5	2.5	2.5	30.0	30.0
Costs per flight (USD)	0.88	1.71	2.26	2.65	4.68	13.23	25.41
Costs per drone (USD)	9,644	9,377	9,279	10,879	19,212	54,324	104,324

The *Base* column contains calculations according to Keeney's assumptions (2015). Here the cost is established as $0.88 cents per flight, which is lower than Amazon's current delivery costs via delivery van ($2.00 to $8.00) and lower than Lewis's estimation ($10.00 to $17.00) (2014). Keeney assumed that each drone makes 30 flights of 30 minutes per day; each drone is therefore active for 15 hours per day. However, the wind may rise, receivers must accept parcels upon arrival, when returning the drone must be recharged, its battery replaced, and so on. Consequently, SESAR's assumption of 15 flights a day seems more realistic (2016), but this also doubles the cost per flight (see *Frequency drones* column).

SESAR moreover estimates a 125 percent overcapacity and 75 percent occupancy rate for drones. These choices include the varying times at which people can receive orders, variations in orders over the course of a week and a year (more orders in December, for example). Keeney included additional battery capacity in the calculation, and hence only the SESAR occupancy rate is included in the *Utilisation* column. This raises the cost per flight to $2.26.

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[26] These calculations are available on request.

Keeney calculates a price of $2,000 per drone. SESAR (2016, p.72) assumes that the current price of 15,000 to 40,000 euros will fall by a maximum of 2 to 4 percent per year, meaning that a drone that now costs €20,000 will cost €10,000 in 2035. The choice of $10,000 per drone in the *Price drones* column therefore brings Keeney's assumptions closer to SESAR's.

Keeney assumes that each operator operated 12 drones. During the 2.5 minutes it takes the drone to unload its parcel, the drone sends camera images to the operator. Keeney included this data processing cost in the calculation. During a 30-minute flight, 12 blocks of 2.5 minutes transpire, so the operator can theoretically monitor 12 consecutive flights. In practice, however, this is not the case: drones fly varying distances under varying circumstances. The assumption of 6 drones per operator is seemingly closer to what is practically possible. Consequently, the cost is $4.68 per flight.

At six drones per operator, the drone flies without a camera connection to the operator, except during the landing phase. Keeney implicitly assumes that sense-and-avoid technology is available and implemented throughout the entire drone fleet. The table's far righthand column is based on the current situation, namely, that via BVLOS an operator controls a drone and maintains a camera connection to survey the surroundings throughout the flight. The result is a high cost per flight of $25.41. If the operator is capable of controlling two drones in this way, the cost then drops to $13.23 per flight.

All told, this calculation reveals that as long as drone operators must monitor flights, that the technology continues developing (specifically sense-and-avoid) and that price decreases occur, a realistic cost per flight is more likely to be around $5.00 per flight, rather than $1.00 per flight.

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