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Risk-based approach to developing unmanned aviation in Finland

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Tiivistelmä

Työssä käytiin läpi miehittämättömien ilma-aluksien erilaisia tyyppejä ja niiden käyttämää tekniikkaa mukaan lukien uusimmat turvallisuutta parantavat järjestelmät. Katselmus uusimmista tutkimuksia miehittämättömän ilmailun turvallisuudesta sisälsi uusimpien törmäys testien tulokset, jotka pohjustivat tämän työn luotaavaa kyselytutkimusta Suomessa vuonna 2016 toimineista miehittämättömän ilmailun operaattoreista ja heidän toiminnastaan. Tavoite oli saada selville uutta tietoa miehittämättömän ilmailun toiminnasta ja siihen liittyvistä riskeistä Suomessa, koska kyseistä tietoa ei ole ollut saatavilla riittävästi tai tarpeeksi luotettavassa muodossa aikaisemmin. Ilmailun turvallisuuden mittaamisessa käytetään vakiintuneita arvoja, jotka on muodostettu vuosittaisista toiminnan tilastotiedoista. Tässä työssä kerättiin miehittämättömän ilmailun turvallisuuden mittaamiseen tarvittavia yleisen toiminnan tilastoja.

Kyselytutkimuksen avulla kerätyistä tilastoista selvitettiin arviot onnettomuus ja törmäys todennäköisyyksistä miehittämättömille ilma-aluksille Suomessa, joita voidaan vertailla jatkossa vuosittain turvallisuustilanteen kehittymisen seuraamiseksi. Kerätyistä tilastoista selvitettiin myös miehittämättömien ilma-aluksien teknisten vikojen todennäköisyydet ja yleisimmät vikojen tyypit. Teknisten vikojen sekä törmäysten todennäköisyyksien arviota voidaan käyttää Suomessa miehittämättömien ilma-aluksien operaatioiden riskiarvioiden tekemiseen. Työssä tehtiin myös analyysi erilaisista miehittämättömän ilmailun toimintamuodoista kaikista riskialteimman toiminnan tunnistamiseksi.

Tämän työn tuloksia voidaan käyttää Suomalaisen miehittämättömän ilmailun kokonaisturvallisuuden arvioinnissa ja miehittämättömän ilmailun lainsäädännön kehittämisessä. Nykyinen miehittämättömän ilmailun ilmailumääräys on luotu tilanteessa, jossa tämän työn keräämää turvallisuus tilastoa ei ollut saatavilla. Tällä työllä pyritään aloittamaan miehittämättömän ilmailun turvallisuustilanteen sekä yleisen toiminnan seuranta ja tilastointi Suomessa.

Avainsanat Miehittämätön ilmailu, Miehittämätön ilma-alus, Riski, Turvallisuus, UAS, RPAS, Tutkimus, Kysely, Suomi

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Abstract

This work explored different unmanned aircraft types and the technology they use including the latest safety systems. A review of research on unmanned aircraft safety was conducted and the latest collision test results were summarized. The results of the latest research were a base from where a survey for all unmanned aircraft operators who flew in Finland during 2016 was conducted. The goal of the survey was to find out new information of unmanned aircraft operations in Finland and the risks associated with those operations, because this information was not available before in reliable enough form. Aviation safety is measured using statistics of past yearly activity and this study aimed at gathering the necessary statistics of unmanned aviation in Finland to calculate these safety metrics.

The gathered statistics of general unmanned aviation activity were used to find out accident and crash probabilities in Finland. Technical fault probability was also surveyed and the most common technical fault types. All of these probabilities can be used when conducting risk assessment of unmanned aircraft operations. This work also assessed different aerial work types to measure which one is the riskiest.

Results from this work can be used in assessing the total risk level of unmanned aviation in Finland and the development of regulations. the current aviation act regulating unmanned aviation in Finland was drafted in a situation where there was no safety statistics of unmanned aviation. This work aims to start the gathering of general and safety statistics of unmanned aviation in Finland.

Keywords Unmanned Aviation, Unmanned Aircraft, Risk, Safety, UAS, RPAS, Survey, Questionnaire, Finland

Foreword

The idea for the subject of this thesis came naturally from work with UAS safety at Finnish Transport Safety Agency Trafi. The real levels of risk associated with unmanned aircraft operations have been unknown and this thesis sought to clarify the situation in order to base future Finnish regulatory work on a more concrete foundation. There was no direct funding for this work, but Trafi allowed the use of some of their time. This survey was intended to be an exploratory study, but it can be replicated with small effort if Trafi wishes to have a longitudinal survey of UAS activity in Finland.

I am grateful to many who have guided, informed, and supported me throughout the course of this thesis. To all of you, I extend my sincere appreciation.

I owe foremost gratitude to my professor Pentti Kujala for providing valuable advice for the completion of this thesis. I would also like to thank my advisor Jorma Kivinen and other personnel at Trafi, through which this work was partially supported. Trafi personnel gave valuable advice that allowed me to focus the research questions onto existing information gaps. All involved parties' insights and guidance is greatly appreciated. Several other individuals provided additional guidance and insight into the UAS community. Thanks to Jukka Hannola, who has kept me abreast of his work on UAS safety. Thanks to Kirsi Lähteenmäki-Riistama at Trafi for supporting my work by providing the needed time to complete this thesis.

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Abbreviations and list of symbols

AIS	Abbreviated Injury Scale
ARMS	Airline Risk Management Solutions
BVLOS	Beyond Visual Line of Sight
DAA	Detect and Avoid
EASA	European Aviation Safety Agency
FAA	Federal Aviation Authority
ICAO	International Civil Aviation Organisation
ICE	Internal Combustion Engine
MTOW	Maximum Take-Off Weight
RPA	Remotely Piloted Aircraft
RPAS	Remotely Piloted Aircraft System
Trafi	Finnish Transport Safety Agency Trafi
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UTM	Unmanned Traffic Management
VLOS	Visual Line Of Sight
VTOL	Vertical Take-Off and Landing
N	Population
n	Sample

1 Introduction

Unmanned aviation has been around for a long time. The very first unmanned aircraft were not similar to the unmanned aircraft that people would identify these days. The V1 flying bomb for example was an early unmanned aircraft, but it was controlled by a mechanical set of gyroscopes, altimeters and pendulums and had no remote controls. First unmanned aircraft that we would recognise as a remotely piloted aircraft system started to be used around the Vietnam War, but these were large and expensive aircraft operated by US military. Later in the 1980's radio technology had advanced enough to make designs of much smaller unmanned aircraft possible. Around this time Israel started to be the nation leading development of small unmanned aircraft, but all of these were still being designed for military use. With the growth of processing power and after the invention of first smartphones the necessary technology and miniaturized components had become orders of magnitude less expensive than before enabling the commercial unmanned aircraft market. The early development of unmanned aircraft closely mimicked the history of manned aircraft. Unmanned aircraft have transformed from recognisance platforms to strike platforms and now finally to the civilian market after some decades of development in military use.

During the last couple of years unmanned aircraft have become very popular around the world due to their ease of use and rapid decrease in their cost. Civilian unmanned aircraft are mostly used for taking videos or photos, but the possible applications are almost endless. Unmanned aircraft have several advantages that make them superior in many operations to manned aircraft. Simply the cost benefit of being able to perform missions with significantly smaller aircraft and no crew is the major driver of demand for the market. Also operations that are dull, dirty or dangerous are better to be performed with an unmanned system. These advantages are driving the demand for unmanned aircraft and both the civilian and military market is growing very rapidly. The worldwide unmanned aircraft market was valued at approximately 1 billion US dollars in 2016 and it is projected to grow at a steady 17,5% annual growth rate until 2024 (ESTICAST Research & consulting, 2017) when it will have more than tripled in size. This rapid growth is causing a lot of pressure for aviation authorities to find ways to safely integrate unmanned aircraft into the common airspace.

The growth in the numbers of unmanned aircraft systems has led to safety concerns regarding unmanned aircraft colliding with other aircraft or falling on people. This concern is raised mostly by pilots and air traffic controllers who have witnessed close encounters of manned aircraft and small unmanned aircraft around aerodromes. The number of occurrence reports from these encounters is rising rapidly around the world and has alarmed all the aviation authorities. Most countries have created strict legislations limiting the legal use of unmanned aircraft significantly with the idea that until the true associated risks are known it is better to be conservative. Finland is one of the outlier countries that sees more potential than threat in unmanned aircraft and has created very liberal rules for unmanned aviation when compared to most other countries. A good argument against the fear of unmanned aircraft is the actual accident record. There are only a handful of cases worldwide where unmanned or model aircraft have collided with manned aircraft. This fact shows that even though the risk is rising it is still low when compared for example to bird strikes that happen just in USA, Canada and UK together around 1700 times a year (EASA, 2008).

Finnish legislation regarding unmanned aviation was introduced for the first time in September of 2015 to address this growing concern regarding unmanned aircraft. While the new aviation act OPS M1-32 (Finnish Transport Safety Agency, 2016) on “use of remotely piloted aircraft and model aircraft” was being drafted, there was very little knowledge or statistics available of actual UAS activity and the associated risks. During the preparations of OPS M1-32 Trafi conducted a safety assessment (Finnish Transport Safety Agency, 2015) according to the Airline Risk Management Solutions (ARMS) model which relies heavily on expert judgements of risk. This was the only possible method since there was no statistics available at that time. Aviation authorities around the world have a great need for more statistics of unmanned aviation to aid their decision making and this is also true in Finland. To allow more demanding and risky unmanned operations it is necessary to gather statistical data on the risk levels of operations.

The possibility to start gathering data of unmanned aviation in Finland opened up only after the aviation act OPS M1-32 (Finnish Transport Safety Agency, 2016) was implemented, since the legislation required RPAS operators who perform aerial work to make a notification to Finnish aviation authority before starting operations and to keep a log of all flights. From this register of operators it is impossible to find detailed enough information of any actual flights, but the possibility to conduct a survey opened up. Therefore, in this thesis a survey was conducted by sending a questionnaire to all the unmanned aircraft operators in the Finnish register asking about their flight activities in Finland during the year 2016. A literature search was also performed to find out the latest studies of risks related to unmanned aircraft systems. Additional knowledge gained from this thesis is aimed to help Finnish aviation authority to focus its resources on the most relevant UAS activities and to get evidence to back up further decisions when designing integration of unmanned aircraft into the air space.

In the design of this survey the aim was to find answers to the following research questions.

1. How many UAS flights are flown annually in Finland?
2. Where are these flights flown?
3. What are the most typical UAS flight operations?
4. How many incident, occurrences or accidents happen annually with UAS?
5. What are the leading types of incident, occurrences or accidents?
6. How reliable different UAS types are?
7. What factors correlate most with incidents, occurrences or accidents?
8. What type of UAS activity has the greatest associated risks?

2 Unmanned Aircraft Systems

Unmanned aircraft system (UAS) is the currently most appropriate term being used to describe aircraft that have no pilots on board. Previously Unmanned Aerial Vehicle (UAV) was the more commonly used term, but UAS has the benefit of also including all the required subsystems such as the control station. In Finland the current aviation act (Finnish Transport Safety Agency, 2015) uses terms Remotely Piloted Aircraft System (RPAS) to make it clear that autonomous UAS are not included. Also the term model aircraft in the Finnish aviation act describes RPAS that are being used only for hobby or sporting purposes. The media commonly uses drone as a term even though this encompasses much more than just UAS. The world of unmanned aircraft is still so young that normal citizens who are not well versed in the details of the industry have difficulties understanding and finding the right words to describe UAS.

2.1 Basic types of UAS designs

There are almost endless numbers of different designs of UAS as the remotely piloted nature allows far faster development of new designs and there is no risk to test pilots lives. Military UAS are often larger in size than civilian UAS and also fixed wing aircraft are more common than multi-copters. However, this thesis focuses only on risks from the civilian UAS operations and the civilian market is dominated by small battery electric multi-copters manufactured largely by a few leading companies. There are also endless numbers of small civilian UAS manufacturers, but their market share of sold products is small. The large leading manufacturers focus on the small scale UAS and the heavier end of the market has more even competition between manufacturers (Glaser, 2017).

2.1.1 Multi-copter and helicopter UAS

Typical multi-copters sold to hobby users or photographers are small quadcopters weighing somewhere around 1kg to 3kg (Finnish Tranport Safety Agency, 2017). These UAS are at the cheapest end of the market not including toys weighing below 250g. Multi-copters used for professional filming, mapping or inspections usually are designed to have more redundant systems to increase their reliability and fault tolerance. Therefore, many of the larger multi-copters aimed at professionals have six or eight electric motors and weigh anywhere from around 5kg up to the commonly regulated maximum mass threshold of 25kg. The heavier weight is a byproduct of enabling more diverse payloads on the higher end professional multi-copters. Some multi-copters weigh even more than 25kg, but these systems start to diverge from the common battery electric systems to more varied designs in their technical solutions such as fuel cell power sources and all sorts of hybrid electric systems.

Due to higher cost of larger helicopter type UAS designs they are more likely to be of a traditional large single rotor or counter rotating design. The higher cost of a larger UAS allows using designs that would not be economical in the cheapest categories, but using these solutions also offers better payload and endurance. When a design is optimized for high payload capacity and endurance the power source changes from the simple battery electric systems to more power dense solutions. Currently many of the largest commercial helicopter type UAS are designed to have a maximum take of weight (MTOW) of less than 150kg to avoid the EASA certification requirement from EU regulation (European Parliament and Council, 2008).

2.1.2 Fixed-wing UAS

Fixed-wing UAS are less common in the civilian market because current rules do not allow Beyond Visual Line of Sight (BVLOS) flights that could be planned quickly and the typical operator usually has no need for longer flight times. Also the lack of Vertical Take-Off and landing (VTOL) capability limits use of fixed-wing UAS in urban areas where there isn't enough space to launch. However in the special cases where longer loitering time is needed or BVLOS flights are conducted a fixed-wing UAS has clear advantage in speed and endurance over helicopters just like their manned counter parts. For example BVLOS inspections of oil and gas pipes are usually conducted with fixed-wing UAS and border guards also prefer the longer range and better endurance of fixed wing designs when conducting surveillance missions. Smaller fixed-wing UAS can be launched simply by throwing, but some larger systems need a runway or a catapult for launches. The larger fixed-wing UAS use more often internal combustion engines to extend their range and endurance. However, the longest endurance is achieved by solar powered fixed-wing UAS representing a new type of aircraft at the largest end of civilian UAS market. The current world record holder aircraft for flight endurance is Airbus Zephyr S with a flight lasting two weeks. These new solar powered long endurance UAS are designed to be used as replacements of communications satellites or as surveillance aircraft that can stay over an area for weeks or months.

2.1.3 Hybrid VTOL UAS

Unmanned aircraft have made experimentation of novel concepts easier due to the low cost of building demonstrators when compared to manned aircraft. Many of these new concepts try to combine the benefits of helicopters and fixed-wing aircraft to offer platforms that are more versatile than either (Tyan, 2017). There are many ways of achieving a VTOL capability, but common to most is the use of multiple electric motors to achieve a vertical take-off and then easy shut down of these take-off motors during forward flight with only one active pusher propeller. This type of concept has been showcased by Amazon for package delivery. Other way to design a hybrid fixed-wing VTOL aircraft is to design some form of a tiltwing or tiltrotor aircraft where the same engines or motors can be used for both vertical take-off and forward flight. One example of a tiltwing UAS is DHL's Parcelcopter 3.

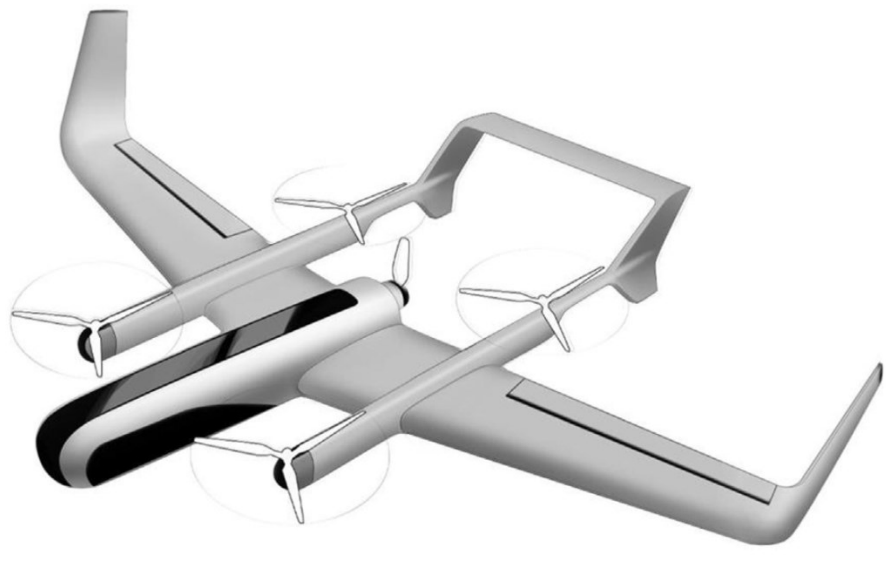

Figure 1 Example of a hybrid VTOL UAS (Tyan, 2017)

2.1.4 Other types of designs

A said before there are almost endless amounts of different UAS concepts, but the three different types above encompass a large amount of the market. Some rarer types are airships, balloons and rockets. Although an argument could be made that weather balloons have for a long time been a very common type of UAS, but they are not controllable and are not regulated by the Finnish aviation act regarding RPAS. There are some UAS operators in Finland using airships and some hobby rocket builders. Airships are very useful for long duration loitering for advertising or surveillance. Amazon has patented a design for an airship that acts as a floating warehouse dispatching smaller UAS to deliver packages. Whether this patent actually will become a reality or not, existing airship UAS have their place in the market. Likely the most expensive unmanned aircraft in the world is the Boeing X-37 spaceplane a mysterious vehicle that is launched to earth orbit with a rocket and then lands at an airport like the space shuttle. There are also many more different types of UAS such as the bird mimicking flapping wing Nano Hummingbird by AeroVironment.

2.2 Problems of categorization

There are all sizes and shapes of unmanned aircraft and categorizing them is very difficult to do in a way that is meaningful from many perspectives. Militaries often use terms such as Medium Altitude Long Endurance (MALE), High Altitude Long Endurance (HALE), strategic UAS and tactical UAS (Kimon P. Valavanis, 2015) (Gupta, 2013). All of these categories are not useful for describing civilian unmanned aircraft. Some have categorized UAS according to their weight (Kimon P. Valavanis, 2015). This has the benefit of being simple and easy to understand, but it does not capture the purpose or flight dynamics of a UAS. From a safety perspective there is a big difference between a 3kg UAS that is hovering at 10m height and a 3kg UAS flying at 100km/h at 10m height. Some have suggested creating categories according to impact energy levels to take into account the speeds of a UAS. The problem that arises from this approach is defining how you calculate the impact energy and the fact that different UAS don’t transfer their kinetic energy in the same way. For example an airship has very different impact dynamics to a metal construction fixed wing UAS.

Many nations are dividing civilian UAS into categories by weight and whether the UA is flown in Visual Line of Sight (VLOS) or Beyond Visual Line of Sigh (BVLOS) (Ren, 2017). This categorization has the benefit of being easily understandable by regular citizen, but capturing only some of the complexity of the different UAS types. Some nations also divide UAS according to their use either for aerial work or for a hobby as a model aircraft (Finnish Transport Safety Agency, 2015). This division tries to acknowledge the history of safe flying with traditional model aircraft, but making a clear definition that would separate traditional model aircraft from the new UAS types has proven to be difficult (EASA, 2017). The coming EU regulation will likely change the definitions of UAS used in Finland when the new legislation comes active.

2.3 Power sources

Unmanned aircraft use many different types of power sources, but most of the popular small UAS designs are battery electric. Batteries and electric motors provide great flexibility to designers when defining what a UAS could look like. The ease of transferring power with electricity allows placing the batteries and motors almost anywhere in an aircraft. However, batteries have low power densities and can usually provide a maximum endurance of around one hour. Even though batteries can only provide a short endurance multiple companies have started to produce prototypes of battery electric flying taxis capable of flying a few hundred kilometers during that approximate one hour endurance. The economics of this type of electric UAS taxi are forecasted to be favorable due to the efficiency of electric motors combined with autonomy eliminating the cost of employing a pilot.

Extending the endurance of a battery electric UAS can be done by converting it to a hybrid electric power source. Just like in cars the hybrids can be either series where the combustion engine acts simply as a generator or parallel systems where the engine drives the propeller or rotors in parallel with the motor-generator (Karpiński, 2017) (Kimon P. Valavanis, 2015). These systems have higher energy densities, but also add complexity and cost to the aircraft using them. One type of a hybrid electric power source is a fuel cell most of which use hydrogen as a fuel, but other types of fuel can be used such as methanol. A good example of the difference in energy densities between batteries and fuel cells is Lockheed Martin’s battery powered Stalker UAS and its fuel cell powered XE variant (Lockheed Martin, 2017). The Stalker XE has four times longer endurance to the battery powered version as claimed by Lockheed Martin.

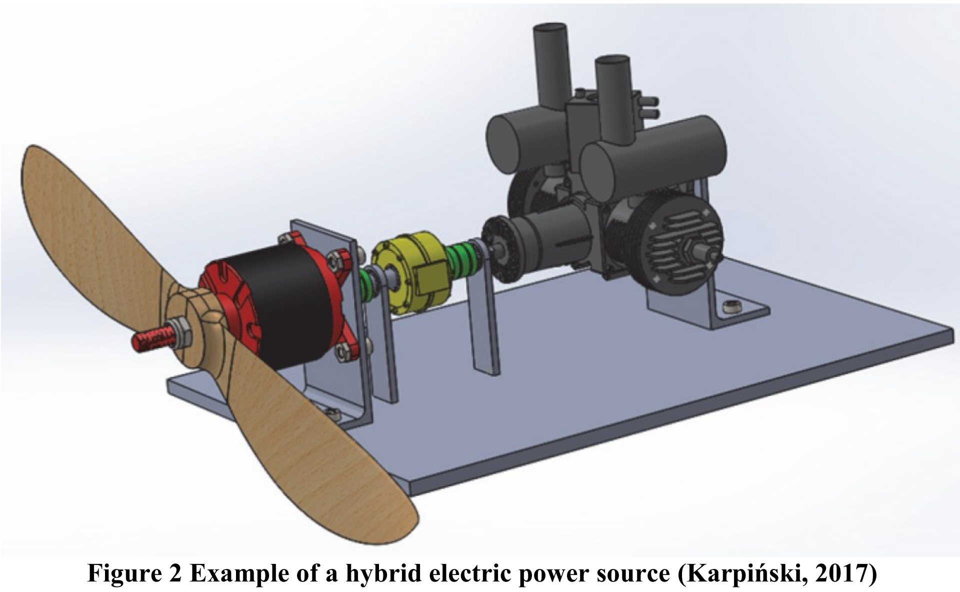

Figure 2 Example of a hybrid electric power source (Karpiński, 2017)

Internal combustion engines are common in many fixed-wing UAS as they provide an energy dense power source that is relatively simple and cheap. However, at the very smallest UAS categories internal combustion engines are not viable due to their minimum functional size being around a typical model aircraft single piston two stroke engine. Four stroke internal combustion engines have better fuel efficiency, but they also weigh more and add complexity and cost. Direct injection is also a technology that helps fuel efficiency and also reliability as the fuel mixture is easier to adjust according to altitude. In general internal combustion engines gain efficiency with size and additional aiding devices like turbos and fuel injection. This has made internal combustion engines more common in the larger fixed-wing UAS types where the additional weight can be tolerated for the increase in fuel efficiency. Even in smaller UAS a two stroke internal combustion engine has far better energy density than a battery electric system.

2.4 Command and Control link

UAS can be controlled directly with a radio controller such as model aircraft have without any autopilot or they can have an autopilot that is commanded to fly somewhere. The common commercial multi-copter UAS have an autopilot and a radio controller that connects directly to the unmanned aircrafts radio to provide directional commands. Usually if the UAS has a camera it will use a different radio link to send the video image back to the ground. A direct radio link requires as its name suggests a direct line of sight between the UAS and the controllers antenna (Gupta, 2013). This connection is usually limited by the signals power or the aircrafts maximum flying altitude as it has to fly higher the further it is from the ground antenna to counter earth's curvature. Some command and control links circumvent this problem by using nodes that pass the message to the aircraft (Schalk, 2017). These nodes can be mobile network towers, satellites or even other aircraft. The General Atomics MQ-1 Predator UAS use satellite communications so that a remote pilot can control a UAS on the other side of the globe. Using this sort of communications network for control allows extending the reach of the control link, but latency can become a problem if the nodes are not able to pass the message instantaneously. A common problem with all wireless communications is the availability of frequency spectrum. Currently there are very few open frequencies available for commercial UAS control links (Kimon P. Valavanis, 2015).

2.5 Payloads & Sensors

UAS can have almost any type of sensors that a manned aircraft can carry (Kimon P. Valavanis, 2015), but the typical cheap multi-copter usually carries a video camera of varying quality. Some of even the cheaper end UAS can have fairly good electro optical cameras that are stabilized and provide 360 degree views if mounted on a gimbal. Having any type of thermal camera on a UAS will increase the price significantly and that price range is very wide starting with low resolution uncooled thermal cameras and ending at the large actively cooled thermal cameras. Hyper spectral imaging sensors are cameras that capture electromagnetic radiation from a very wide frequency bandwidth. These sensors can be used to detect materials and this is useful when trying to find locations for mines or new oil fields. LIDAR means a range sensing laser radar and these sensors function in a very similar way to a normal radar, but use a laser instead of radio waves. LIDAR's have become a common tool in mapping and UAS are simply a cheaper platform to use for this sensor than manned aircraft. The cost reduction of airborne imaging with a LIDAR has given rise to new uses such as fast and accurate volume measuring of piles of coal or earth at mines and power plants. This would have been uneconomical if manned helicopters had to be used instead of small UAS. Some UAS have radars as sensors and these can be very useful in maritime surveillance or if the radar has good resolution it can be used as a good all weather sensor for any surface targets. The miniaturization of radars has made it possible to fit a relatively small UAS such as Insitu ScanEagle with a small synthetic aperture radar.

2.6 Safety systems

There are many different types of systems developed for UAS with the purpose of increasing safety. Some of the simple safety systems can be found on many of the cheapest UAS. Geofencing means a set of predefined area coordinates inside a UAS where the aircraft will not fly even if the remote pilot tries to do so (Luxhoj, 2016). This system can also be only advisory giving a warning of flying into a protected area. The areas usually protected by geofencing systems are airports, but any area can be protected. Current systems are static where the coordinates have been uploaded to the UAS in the previous software update. In future concepts geofencing could be done dynamically with the UAS receiving a message through mobile network with coordinates of a temporary new protected area (Kopardekar, 2016). This type of active communication between UAS on surrounding dynamic airspace is the foundation of Unmanned Traffic Management (UTM) systems (Kopardekar, 2016) (SESAR Joint undertaking, 2017).

Figure 3 U-Space (SESAR Joint undertaking, 2017)

UTM or as its European version is called U-Space (SESAR Joint undertaking, 2017) is a concept of automated air traffic control managing multiple UAS using mobile network connections to deliver messages between UAS and the system. These UTM systems are intended to provide safe routing of unmanned aircraft in very low level airspace where most manned aircraft are forbidden to fly. UTM systems are vital if totally automated unmanned aircraft flights are to be allowed and many new business ideas are relying on totally automated UAS such as Amazon Prime Air package delivery service or all of the planned UAS taxis. Currently there are some limited UTM services available, but these systems are not yet ready to fully automate the very low level airspace management.

Flying above the very low level airspace in non-segregated airspace with manned aircraft requires UAS to be able to fly and communicate as a normal aircraft would. A difficult requirement of seeing and avoiding any air traffic without the help of a UTM system is called a Detect and Avoid (DAA) system (Molloy, 2017) (Kimon P. Valavanis, 2015). These systems could use many different sensing methods like electro optical sensors, radar, thermal cameras or active beacons from aircraft such as ADS-B. There have been tests trying to validate the functioning of a DAA system of some type, but no system has yet been approved to be capable of flying in non-segregated airspace with other aircraft.

One of the simplest but most effective safety systems is a parachute. There are many parachutes on the market that have been designed specifically for UAS, but these have many different launch methods such as springs, compressed air canisters and small explosives (Prisacariu, 2016). Some manned aircraft also have parachutes proving that they are a very effective recovery system even for larger aircraft. Parachutes must be integrated into UAS autopilot to be able to receive the necessary signals for when to launch and to stop spinning of the rotors and propellers before launch.

Figure 4 UAS landed with a parachute (Prisacariu, 2016)

3 Previous knowledge and research of UAS risks

Empirical research papers on UAS safety and reliability have been uncommon for the past years, but now new studies which try to empirically quantify the risks are starting to be published. Most of the older empirical studies were focused on military systems as armies have been early adopters of unmanned aircraft technology. The data gathered for these earlier studies is mostly of older types of military UAS reliability (Dermentzoudis, 2004) (Dalamagkidis, 2008) as these systems have been widely fielded in various armies around the world. However, military UAS reliability data cannot be applied straight to the civilian world because of multiple technical differences between military and civilian UAS. Military UAS can be much larger, fly at higher altitudes, often use much more expensive components and also be propelled by internal combustion engines, whereas the typical civilian UAS rely on commercial of the shelf electric motors, lithium batteries and electronic components. Therefore, empirical studies of military UAS reliability and extrapolation of this to the civilian world's ground risk (Dalamagkidis, 2008) cannot be taken as a reliable estimate of the current civilian UAS aviation. Thus a completely new set of studies is needed to quantify commercial UAS reliability and risks associated with operations.

3.1 Theoretical studies of UAS risk

Most of the older studies of risks related to UAS tried to find theoretical frameworks to estimate related risks. These theoretical studies on UAS safety and ground risk offer tools for estimating probabilities and risk levels, but the lack of statistical data makes these models only a thought experiment without confirmation. Many studies have tried to estimate UAS impact severity with theoretical methods such as blunt criterion calculations from impact energy (Radi, 2013) (La Cour-Harbo, 2015) (Magister, 2010). These early theoretical studies have influenced current regulations around the world by establishing mass thresholds for UAS categories. Commonly accepted mass limit for "harmless" UAS is under 250 g which was established from blunt criterion calculations trying to match the resulting risk to current manned aviation (La Cour-Harbo, 2015). The current risk level for manned aviation is one death per 10^8 flight hours.

Another influential study calculated the impact energy limit for UAS able to penetrate a shelter with corrugated iron roof (Clothier, 2010). This limit results in an estimate of UAS weighing less than 7 kg being safe for people inside buildings. It is important to note that these estimates are drawn from simplistic assumptions and result in conservative estimates of risk. Two of these conservative assumptions were that the UAS won't deform on impact and that the UAS kinetic energy is transferred completely to the target. Because of these assumptions a cricket ball thrown at a human is evaluated to be lethal using the same model, but the empirical evidence shows that this estimate is clearly not true and too conservative (Radi, 2013). This example shows the need to have empirical studies verifying real world results that offer more accurate models for estimating risk.

The more reliable theoretical studies conducted are simulations of UAS behaviour in an accident. Computer simulations are a powerful tool in aviation industry and the models used for simulations are getting better with time. Netherlands Aerospace Centre made simulations of small UAS impact location distributions and found them to be approximately of elliptical shape and varying according to UAS speed and type (Y. Haartsen, 2016). Curiously for multi-copter UAS flying at a height of 150m or 300m the impact distribution covering 80% of impacts were the same from both heights. For this probability the impact areas were 60x60 square meters for drops from both altitudes. This is a useful estimate when designing an operation and the needed safety boundaries.

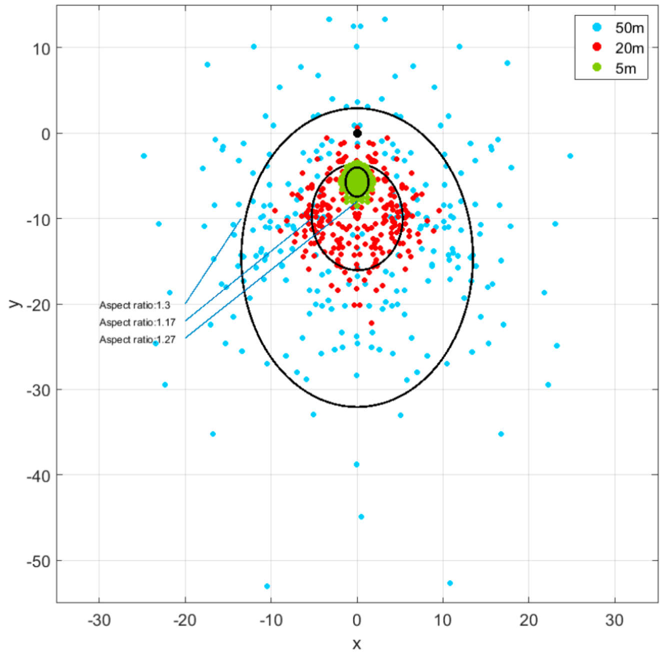

Figure 5 Simulated UAS impact probability pattern (Y. Haartsen, 2016)

Simulation from Virginia Tech modelled outcomes of UAS impacting jet engines (Song, 2016). This study was motivated by the fact that 76% of recorded bird strikes impacted with passenger aircraft's engines (Radi, 2013). Knowing what a jet engines resilience is to UAS impacts is very important if bird strike data is a reliable estimate of mid-air impact locations. The study (Song, 2016) modelled a 5.6 kg UAS being ingested by a high bypass ratio jet engine with the intention of finding out is UAS ingestion more dangerous than an equivalent sized bird ingestion. Results showed that a UAS weighing the same as a Canadian goose will cause a catastrophic failure to a jet engine if ingested. This result can be considered to be reliable since structure modelling techniques nowadays are very accurate. However, the weight of the modelled UAS was much larger than the average commercial UAS, leaving open the question would a 1 kg or 2 kg UAS cause as much damage to a jet engine? Looking at the market leader DJI's development of cheap UAS, the trend in these types seems to be reduction of size. First DJI Phantom had a mass of 1.2kg, the newer Mavic model weighs around 800g and after Mavic DJI launched the Spark UAS which has a mass of 300g.

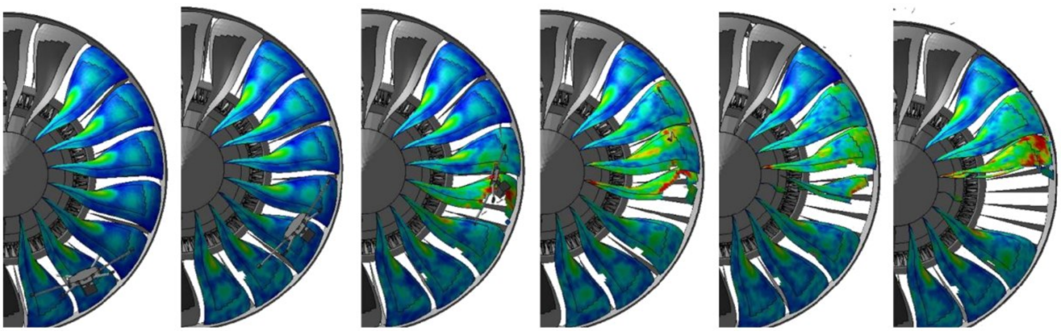

Figure 6 Simulated UAS impact to a turbofan (Song, 2016)

3.2 Empirical knowledge of UAS risks

The normal aviation occurrence reporting structures have produced a record of pilot reports of close encounters between manned and unmanned aircraft. The accuracy of this record is a big problem because it is formed from pilot visual sightings that in many cases are uncertain whether the flying object was a bird, balloon or UAS. The record is also likely missing many close encounters where the pilot didn't notice the UAS and the drone pilot didn't know about the reporting culture because he or she didn't have a pilot licence training or otherwise sufficient knowledge of aviation reporting. Still this record has shown that close encounters between manned and unmanned aircraft have been rising fast (EASA, 2016) as expected with fast growth of the commercial UAS industry.

Australian study found a correlation between Google searches of UAS online shops and numbers of occurrence report numbers (ATSB, 2017). This is a valuable finding as the technique can be used to estimate numbers of consumer UAS operating any one country. Also the European Aviation Safety Agency (EASA) has noted the trend of rising occurrence reports in its study (EASA, 2016), even though the report mostly identifies knowledge gaps and recommends funding research in these areas. The EASA report highlighted as one of the knowledge gaps not knowing how much damage an impact to a jet engine would cause. This is raised as concern due to the expected probability of 76% of all impacts hitting the engines (Radi, 2013), drawn from bird collision statistics.

A statistical study very much like this thesis (Graham Wild, 2017) analysed 152 occurrence reports of UAS accidents collected from various sources between 2006 and 2015, which is a small sample spanning a very long time in perspective of the fast developing UAS world. The time and location span of the data, combined with a small sample arguably make results from this study (Graham Wild, 2017) unreliable. Study analysed the information included in the standard ICAO occurrence categories and found that 63% of the reported accidents were caused by technical failures while 14% were caused by loss of control. These values can be used for comparison to the results gained from this thesis, but the data used in the study is of a world that is not representative of current civilian UAS market, so the expectation is that these numbers will be somewhat different. Also it should be noted that ICAO occurrence report is designed for manned aviation and does not include some of the technical fault categories or unique occurrences which UAS experience. In this thesis questions were designed to include these missing categories that are unique for UAS operations such as lost link faults, crashes where no people were involved or different control methods.

Most notable resent study (ASSURE, 2017) of civilian UAS risks was conducted by Alliance for System Safety of UAS through Research Excellence (ASSURE) program that was tasked by FAA to do research needed to integrate UAS safely into airspace. ASSURE groups study is one of the first empirical assesment of third party ground collision risk. The research used common types of UAS in its tests, so it is a very good benchmark to estimate risk from. The report included a large literature research of different casualty models and injury models and compared them. The study identified three injury types that represented the most significant threats to humans from UAS collisions, these types were lacerations, blunt force trauma and penetration injuries.

The ground breaking part of the research was a set of 24 collision tests of UAS against a 50th percentile male crash test dummy to find out how much energy is transferred during an impact. The results of these initial tests estimated the transfer being 44-67% of the UA's kinetic energy. Dummy was set up in a seated position for the test impacts which were targeted to the head from angles of 90°, 65° and 0°. The UA used was DJI Phantom 3 and the speeds tested varied from 5 to 15 m/s. Resulting evaluation of impact severity from a 1.2 kg UA at these velocities was a 12,5% probability of an Abbreviated Injury Scale (AIS) level 3 injury or greater (ASSURE, 2017). The most likely injury type predicted was a neck injury and skull fractures were estimated to have only a 1.5% probability. These tests are a good first basis for evaluating the potential severity of a common UAS impacting with a human. However, the speed range of these tests does not go high enough to cover a hit from a drone travelling at a typical maximum speed or a drop from maximum allowed height. These tests provided extremely valuable new information, but there are still many unknown scenarios that need to be tested in the future.

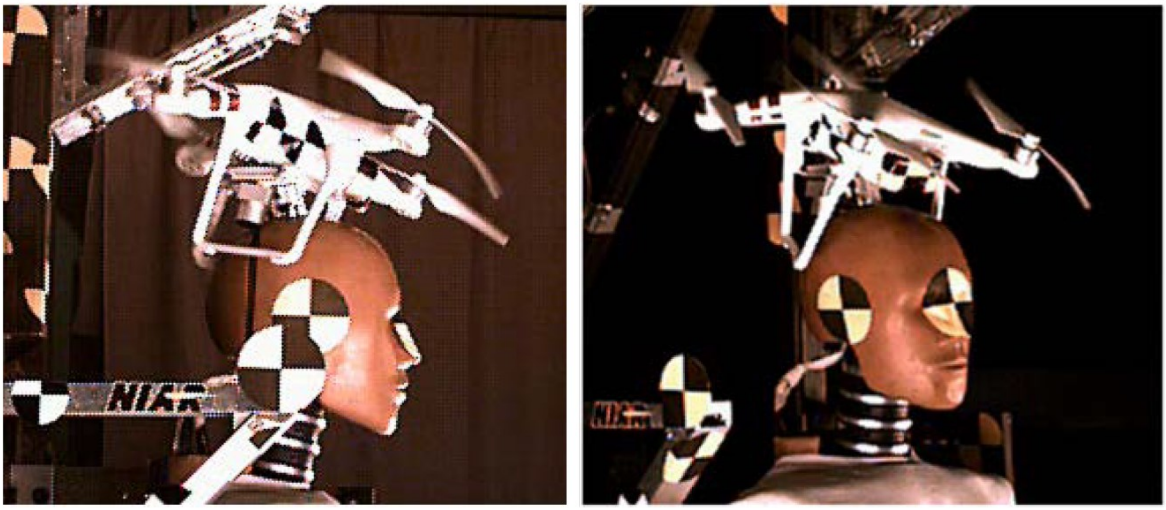

Figure 7 UAS collision test (ASSURE, 2017)

One of the key findings in the study (ASSURE, 2017) is that in a collision with a human the UAS transfers approximately 44-67% of it's kinetic energy into the target. This is a very important result when compared to the earlier theoretical studies that used assumptions of perfect kinetic energy transfer to target. Re-evaluating the mass thressholds established in the earlier theoretical studies (La Cour-Harbo, 2015) (Clothier, 2010) would result in higher estimates of safe mass. It should be remembered that mass is not the only factor that affects impact severity and thus it is a conservative decision to use a smaller safe mass threshold. Arrow and a tennis ball that weigh the same have very different impact dynamics and this problem means that more tests with varying types and sizes of UAS should be conducted to draw more generalizable conclusions.

Final assessment from the reports full content is that UA kinetic energy, energy density and rotor diameter are the most critical measures that affect the severity of a collision. Kinetic energy seems to be the most determining factor so long as the UA doesn't have a large single rotor with rotational energy reaching lethal levels. Even smaller rotors can cause laceration injuries and thus rotor guards are recommended. ASSURE programs UAS Ground Collision Severity Evaluation Final Report is a very thorough vanguard study into the actual effects of a ground collision between humans and UAS.

Probably the latest crash test study of small UAS was conducted by Virginia Tech (Campolettano, 2017). This study had a less controlled test set up than the ASSURE report. Researcher used a 50^{th} percentile male test dummy that was seated in a garden chair in the middle of a large indoor space and then three different types of commercially available UAS were flown at the dummy or dropped on to it. This set up couldn't produce exactly similar impacts repeatedly but instead a distribution of fairly similar ones. The flight impacts were set up so that the UAS started accelerating from 40m away from the dummy to reach top speed and then was steered to impact the dummy's head. With this set up multiple attempts to hit the dummy's head failed and no flight impacts of the 3,1kg mass drone were successful. Drop impacts were set up so that the UAS was dropped from a platform with height of 5.5m directly above the dummy so the final impact velocity was 10m/s. The three different types of UAS used for the tests had masses of 1.2kg (DJI Phantom 3), 3.1kg (DJI Inspire 1) and 11kg (DJI S1000+).

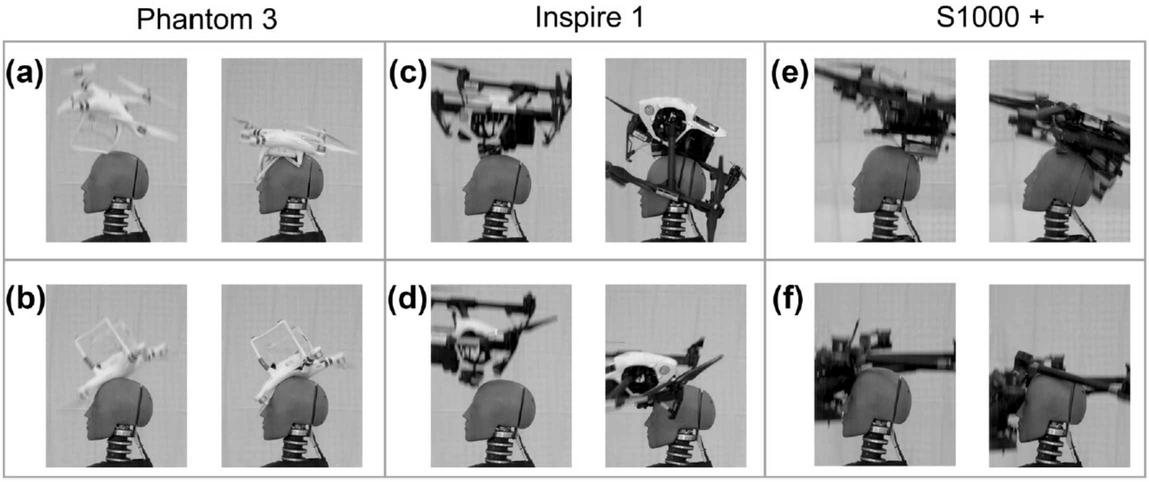

Figure 8 Virginia Tech UAS collision tests (Campolettano, 2017)

Results from this study estimated head injuries of level AIS 3 severity for the 1.2 kg and 3.1 kg UAS to have probabilities close to 0%, while the 11kg UAS had a probability of around 40% for similar injury (Campolettano, 2017). As estimated in the ASSURE report (ASSURE, 2017) neck injuries were predicted to be more likely than head injuries. The 1.2 kg UAS was estimated to have probabilities of 3.9% up to 11.6% for causing a neck injury of AIS 3 severity from an impact. The 3.1kg UAS had probabilities ranging around 10% to 20% for similar neck injuries and the 11 kg UAS had probabilities ranging from around 20% to 70%. The wide range of injury probabilities for the same type of UAS shows that the test set up was not very controlled, but also shows that in real life small changes in the impact location or UAS orientation can cause big differences in injuries. It is noticeable that the largest UAS model had very high injury probabilities even when dropped from a height of just 5.5m. This would suggest that filming over a crowd of people with such a heavy UAS is very dangerous if the impact risk is not mitigated in any way.

4 Questionnaire

The survey of unmanned aviation in Finland during year 2016 was done with a voluntary anonymous online questionnaire. This period was chosen because it would give the first full years' worth of data and possible further yearly surveys could be compared to this study. Method of an online survey was chosen because of the large sample size and ease of data analysis from a digital system. Participants were guaranteed anonymity in hope that this would yield honest answers even of negative events. These negative events such as crashes or near miss incidents are the main interest from a risk management viewpoint and knowing the main risks is essential for defining the appropriate level of regulation for UAS operations. Manned aviation has an established occurrence reporting system, which is used to gather similar information, but since UAS pilots have no training requirements this system is unknown to most operators. The normal occurrence reporting system is not generating enough reports from unmanned aviation activities and thus this survey provides much needed clarity into the current situation. The existing system is also partially unsuitable to unmanned aviation as occurrences such as lost link or loss of visual contact are absent from the reporting form. Questionnaire was formulated so that it would cover common occurrences to unmanned aviation as best as possible and also survey basic statistics of operations.

The population for the survey was all unmanned operators that had made a notification to Finnish civil aviation authority's online register before 31.12.2016. There were no hobbyists included in the sample due to the impossibility of contacting them efficiently. Out of the 1059 email addresses gathered from the unmanned operator register, 28 emails were found not functional anymore after the questionnaire was sent. The total response rate to the survey was 22% of the population (N) of 1031 functional registry members. Out of these 227 respondents 15 had no activity during 2016 and were counted out from the scope of the survey and also 3 participants were disqualified due to erroneous answers. This gives the sample (n) of 209 participants a confidence interval of 6% at a 95% confidence level.

Margin of error for a finite population at 95% confidence level

$$\frac{0{,}98}{\sqrt{n}} * \sqrt{\frac{N-n}{N-1}} = \pm 6\% \qquad (1)$$

4.1 Goal of questionnaire

Goal of the questionnaire was to gather previously unknown data of unmanned aviation in Finland. The data should be of sufficient quality and type to be able to calculate statistical probabilities of different risk factors and be able to compare these factors to each other. Expected levels of occurrences and reliability statistics of UAS are of particular value to the aviation authority when trying to determine an acceptable level of risk mitigation measures for operations near people or important infrastructure. Another problem when trying to determine risk to people on the ground is understanding population density in accurate and dynamic manner. A particular road for example can be very crowded during morning and evening traffic hours, but almost completely empty during night. Population density was surveyed in a vague manner due to limitations set by the survey format and thus only parts of the equation of ground risk can be estimated from this survey.

Through this study Finnish Transport Safety Agency should gain a window into the realities and risks of unmanned aviation. Ideally the information gathered can be used to focus efforts into most pressing problems and to proportionately scale the regulatory demands and other actions to the risks. For the operators themselves the information on aircraft reliability can be useful in trying to determine what types of operations are economically feasible or safe enough for third parties. If this survey will remain as a single study it will have offered a quick glimpse into the commercial unmanned aviation operations around Finland, but the greatest use from these statistics would be figuring out trends in the nation if the survey is used to perform a continuous longitudinal study.

4.2 Design of research questions

The survey was designed to gather statistics of unmanned operations in a form that can be analysed to find the most influential variables to risk. Also general statistics of UAS operations can be used to estimate the total flight numbers and their distribution around Finland. Common risk statistics in manned aviation are accidents or deaths per flight hour and also the total number of flight hours. Similar basic safety statistics gathered form UAS operators activity can be used to scale authority resources accordingly to the level of UAS risks and levels of activity. The intent of the overall questionnaire is to provide enough data to narrow down the uncertainty in estimates of risk to the general public. This estimate can then be used when assessing whether the current regulation is adequate, too prohibitive or not stringent enough.

The questionnaire was produced using Webropol company's online survey systems third edition. Unfortunately the system was still partially under development while the questionnaire was designed and lacked some useful features that would have made the questions easier to answer for the respondents. Some participants gave feedback to improve the questionnaire and hopefully if this survey is to become longitudinal the corrections will be possible in the Webropol system. Finished questionnaire had 32 questions about UAS activity and it was translated into Finnish and English. One difficulty in designing this survey was the attempt to keep it short so that the response rate would be high enough to provide reliable results, but not too short that the questions provide no real value due to being too vague. Some of the questions were too detailed and other could have had some more details, but the overall resulting balance was quite good. The questions are listed on the next page in English and the full questionnaire with all the answering options and visualisations can be found in Appendix 2. Introductory letter that was sent with the questionnaire can be found in Appendix 1.

Research questions:

1. Did you have any flights with unmanned aircraft during 2016?
2. What types of unmanned aircraft you operated during 2016?
3. Estimate how many flights you performed in Finland during 2016?
4. Estimate how many minutes one flight lasted on average?
5. Estimate the division of all flights during 2016 by province in percentages.
6. Estimate the percentages of all flights during 2016 according to operation type.
7. Estimate how many flights you did over a crowd of people during 2016.
8. How did you ensure the safety of these flights in the case of an aircraft falling to the ground?
9. Estimate how many flights you did over densely populated areas during 2016.
10. Estimate how many flights you did beyond visual line of sight during 2016.
11. Did you have a need to fly closer than 5km from an airport or fly higher than 50m inside the airport control zone during 2016?
12. How many times did you contact air traffic control to ask a permission to deviate from normal rules inside an airport control zone?
13. During 2016 were you involves in any occurrences, incidents or accidents?
14. Estimate the numbers of occurrences, incidents and accidents you were involved in during 2016.
15. Estimate the division of occurrences, incidents and accidents according to visibility conditions during flight.
16. Estimate the division of occurrences, incidents and accidents according to flight area.
17. Estimate the division of occurrences, incidents and accidents according to control method.
18. Did you make occurrence reports from the events?
19. Did you know about the requirement for making occurrence reports?
20. Do you feel that making the report is too difficult?
21. Have you taken insurance against third party damages according to EU-requirements?
22. Did your aircraft experience any technical faults during 2016?
23. Estimate the numbers of faults to the most suitable categories.
24. What types of unmanned aircraft were the faults in?
25. Did any of your aircraft fall down during 2016?
26. How many times your aircraft fell during 2016?
27. Estimate how many of the falls were controlled?
28. Estimate what reasons led to the aircraft falling.
29. Do you think Finnish aviation regulation on use of remotely piloted aircraft and model aircraft is easy to understand?
30. What makes you feel this way?
31. How do you see the future of unmanned aviation from your perspective?
32. What makes you feel this way about the future?

4.3 Sample

Questionnaire was sent to 1059 unmanned aircraft operators that had registered to Trafi between 2015 and 31.12.2016. 42 of the operators were from outside of Finland and the rest were Finnish. Foreigners were given an English version of the introductory email and the rest received a Finnish language version, but all had the option to choose in which language they wanted to see the questionnaire. The survey was closed on 31.8.2017 and gathered 227 answers out of which 209 held valid information of operations during 2016. 227 answers to the survey were submitted out of which 15 answered to the first question that they did not have any flight activity during 2016. On top of this, 3 participants made so erroneous and illogical answers that they were removed from the analysis altogether. The 209 answers that held valid information of activity during 2016 constitute around 92% of the total responses. The sample is not representative of the entire unmanned aircraft sector as the survey is missing all recreational UAS pilots. Therefore, the sample should be viewed as a small but active portion of the unmanned operators. Out of the 1031 operators with functional registry information we estimated 92% were active during 2016. With these numbers the total estimated number of flying UAS operators during 2016 was 949.

Survey's sample of 209 active operators with flight activity during 2016 is not representative of the entire UAS community because it excludes all hobbyists. Hobbyists are presumed to be a much larger group and therefore the results of this study can only be used as a meaningful estimation of the professional unmanned operators. However, the reliability data of UAS can be used as a good estimation of hobbyist drones since professionals often use the most popular drone models on the market that are also available for hobbyists. In future if UAS activity will be surveyed there should be effort put into including hobbyist in the sample.

4.4 Data corrections

Estimating submitted data's integrity was a huge dilemma during this study. What to do with incomplete, erroneous or just suspicious answers? To resolve this problem a choice had to be made whether to abandon such answers altogether or try to edit the more obviously false data points. The selected choice was a middle ground of removing the completely false answerers and editing the remaining few typing errors with a conservative touch. Three participant's answers were removed completely due to the fact that their answers were contradicting themselves from one question to the next. The remaining erroneous data points were one skipped flight distribution estimate, one impossible answer to average flight time estimate, two extreme outlier values in flight numbers and in crash estimates plus 9 suspicious values in Question 23. The two extreme outlier values seemed like typing errors with extra zeros in the number, so they were corrected by removing the assumed extra zeros from the numbers. The unbelievable flight time estimate and the missing answer were simply ignored in the analysis as this would have the smallest effect on the overall estimates. The large number of suspicious or erroneous answers to question 23 is explainable by bad wording of the question. After several percentages scale questions faults were asked to be estimated in numbers of instances. All these answers totalled 100 as requested in the few previous questions. Correcting this error was big dilemma as it would affect the average estimate of UAS faults. A choice was made to edit the answers to be the minimum numbers of faults that would keep the answers to the following questions still logical. This does mean that there is a larger error probability in the analysis of numbers of faults to the direction of fewer faults. This was due to the fact that there was certain knowledge that the answerers had experienced faults but it was impossible to know as to how many. The only certain knowledge from the erroneous answers was the types of faults experienced.

5 Results

The major goal of this questionnaire is to find out the average levels of safety associated with UAS flights in Finland. The survey questions were designed so that the basic metrics of aviation safety could be formulated for UAS operations. The basic metrics are numbers of occurrences, crashes and technical faults against total flight hours or numbers of flights. Estimating UAS risks has some unique elements and metrics due to the fact that crashes and accidents won't necessarily cause any injuries or casualties. If UAS flights are conducted in areas where there is low risk of collision with third parties the activity can be totally safe even though the UA would crash very often. However, the safety aspects of this survey can only be generalized to professional UAS operators because of the sampled population, but technical fault propensity can be expected to be approximately equal to all UAS and model aircraft in Finland. The survey also aimed at providing an overall picture of the activities that professional UAS operators conducted in Finland during 2016. The general statistics of activity around Finland can be used for focusing resources to the most active regions.

5.1 Basic statistics of UAS aviation in Finland

5.1.1 Numbers of UAS operated in Finland

The UAS operators who had activity during 2016 and answered the survey operated in total 452 unmanned aircraft. The most aircraft for a single operator was 35 while the average was 2.16 UA for every operator. However, looking closer at the numbers of UAS the median shows that the typical operator only has one UAS in use. The aircraft were divided into different types according to Table 1. Helicopter/Multicopter type UA were the most common type representing 85.18% of all UA. The proportion of helicopter/multicopter UA from all UA is likely even higher for hobbyists, but this cannot be verified from this study. These numbers were already somewhat known from the registry data, but a verification of the statistics will improve the registers reliability as a source of up to date information.

Table 1 Aircraft operated

Helicopter / Multicopter	Aeroplane	Helicopter-Aeroplane Hybrid	Airship	Other
385	45	9	0	13
85.18%	9.96%	1.99%	0.00%	2.88%

5.1.2 UA flights in Finland during 2016

Operators answered that they flew in total 15569 flights during 2016 with the most flights for a single operator being 1000 in a year, while median was 30 flights per year and the average for all operators was 74.49 flights. The results of numbers of UAS operated and flight numbers show that there are many small operators that are not very active and a few that are operating on a much larger scale. The estimate for a single flights time was on average 15.1 minutes for all operators with the longest average flight time an operator reported being 90 minutes. This estimate of average flight time is believable and expected as the maximum operating time of common types of multicopters are around 20 to 30 minutes.

Calculated from numbers of flights and the estimates of average flight time the annual total flight hours for these 209 active operators is 3559.17 hours. The first questions answers give a number of 92% operators are active in the register. Using this percentage the estimated total number of active operators in Finland during 2016 is 949. Out of the total number of active operators during 2016, we can approximate the total flight hours for all operators would be 16161 flight hours. This is still a small number when compared to the 300000 flight hours (Finnish Transport Safety Agency, 2017) that manned aviation performed in Finland during 2016. It should be remembered that the UAS flight hours is only a valid estimate of the professional UAS operators excluding all hobbyists. The number of commercial UAS operators has been increasing fast in Finland ever since the register was opened. It will be interesting to see to what direction unmanned aviation operations will develop. Perhaps BVLOS operations will become more common place or maybe photographing will become even more dominating with ever cheaper models of UAS entering the market.

Table 2 UAS flights in Finland

Total number of flights surveyed (n)	15569
Average time of flight (min)	15.10
Total number of flight hours surveyed (h)	3559.17
Estimated total flight hours for all registered operators during 2016 (h)	16161

5.1.3 Distribution of flights around Finland

The participants were asked where their flights took place in Finland in percentages by county and from the answers a distribution of the total flight hours around the nation could be calculated. The results are shown in Table 3 and illustrated in Figure 9 with color-coded counties where darker colour means more flights. Comparing the distribution of flight hours with the population distribution of Finland from February 2017 (Statistics Finland, 2017) we can see a very close relation. Only significant outlier counties are Lappi with higher than expected flight hours and Pohjois-Savo with lower than expected flight hours. This close relation of population distribution and flight hours is intriguing and useful information for aviation authorities. It will be interesting to see if the distributions of flight hours and population will start to diverge more in the future, but for now population distribution can be used as a fairly accurate estimation of where UAS flights are taking place. Even though there is no data of hobbyist included in this survey, the fact that even the commercial operators follow closely the population structure would suggest that this is true also of hobbyists.

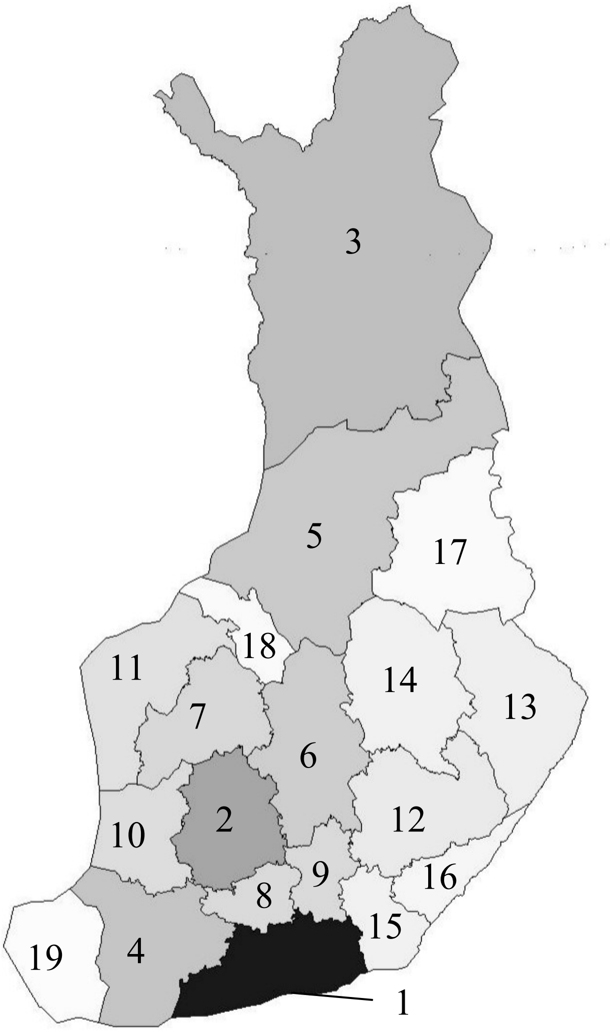

Figure 9 Distribution of UAS flights in Finland

Table 3 UAS flight hours by county

County	Flight hours	Percentage of all flight hours	County's percentage of Finland's population
1 Uusimaa	1012.5	28.57	29.81
2 Pirkanmaa	390.6	11.02	9.26
3 Lappi	282.2	7.96	3.27
4 Varsinais-Suomi	252.6	7.13	8.64
5 Pohjois-Pohjanmaa	229.7	6.48	7.47
6 Keski-Suomi	213.3	6.02	5.01
7 Etelä-Pohjanmaa	171.83	4.85	3.48
8 Kanta-Häme	162.1	4.57	3.15
9 Päijät-Häme	160.87	4.54	3.66
10 Satakunta	150.1	4.23	4.02
11 Pohjanmaa	135.6	3.83	3.30
12 Etelä-Savo	96.2	2.71	2.70
13 Pohjois-Karjala	71.3	2.01	2.98
14 Pohjois-Savo	64.7	1.83	4.50
15 Kymenlaakso	56.7	1.6	3.22
16 Etelä-Karjala	42.66	1.2	2.37
17 Kainuu	21.9	0.62	1.36
18 Keski-Pohjanmaa	15.5	0.44	1.26
19 Ahvenanmaa	13.68	0.39	0.53

5.1.4 Types of aerial work done in Finland during 2016

Participants were asked what different types of aerial work their operations were in percentages of all flights. Using this distribution the most common types of aerial work done with UAS was calculated. The distribution is shown in Table 4. Photographing and videotaping makes up 69.75% of all aerial work activity in Finland with the next most common aerial work being mapping or charting at 8.37%. This shows that the commercial UAS industry is very much driven by a single aerial work type. However, it is likely that if aerial work types were compared in euros earned during 2016 Photographing and videotaping would not be the major market. Most exemption permits for more complex operations are granted for LIDAR measuring, charting or infrastructure inspections. One clear current trend is increased use of UAS for inspections of the electrical grid. This is evident from the numbers of airspace reservations for BVLOS use of UAS.

Table 4 UAS aerial work flight hours

Type of Aerial Work	Flight hours	Pecentage of all Flight hours
Photographing, videotaping	2482.47	69.75
Mapping or charting	297.79	8.37
Test flights for development of new devices or functions	139.31	3.91
Press, media	135.04	3.79
Search and rescue services	77.17	2.17
RPAS flight training	49.68	1.40
Agricultural work	41.75	1.17
Forestry work	39.99	1.12
Inspection of buildings or roofs	39.09	1.10
Scientific research	37.65	1.06
Measurement of mobile phone networks or other telecommunication networks	34.07	0.96
Providing an overall situation picture for an entity in command of other operations	29.80	0.84
Logistics	25.21	0.71
Surveillance	20.70	0.58
Tasks using a thermographic camera	15.41	0.43
Inspection of masts or wind power plants	7.48	0.21
Inspection of other constructions, e.g. bridges	5.18	0.15
LIDAR or other sensor	3.33	0.09
Powerline inspection	3.17	0.09
Gas pipe inspection	0.06	0.00
Aircraft external inspections	0.06	0.00
Ship emission measurements	0.00	0.00
Measurement of radiation or other emissions	0.00	0.00
Ore prospecting or other soil survey	0.00	0.00
Other	74.75	2.10

5.1.5 Flights above crowds of people, densely populated areas and beyond visual line of sight

Operators were asked how many flights they conducted above crowds of people, Beyond Visual Line of Sight and above densely populated areas. The results are listed in Table 5. Flights above densely populated areas were almost exactly one third of all flights during 2016. This is not a very surprising fact when taking into account that flight numbers closely follow population density across Finland, if anything the percentage could be expected to be even higher. Flights above crowds of people and densely populated areas are subjective measures since there is no clear definition of a crowd and densely populated areas are similarly difficult to measure objectively during an operation. This lack of clarity shows its effects on the free text answer to the question "How did you ensure the safety of these flights in the case of an aircraft falling to the ground?" Large numbers of operators answered that they conducted operations above crowds of people, but then added that they actually flew close to a crowd and never directly on top of one.

The only objective measure in Table 5 is numbers of BVLOS flights which make up 7.9% of all flights. This is a large number when considering that these flights require reserving a temporary danger area for the operations, but in one operation there can be multiple flights. It will be interesting to see what types of operators will grow in numbers as the market evolves. BVLOS flights would seem to have the greatest economic potential and thus could grow faster in future, but if multicopters keep getting less expensive even more photographers could purchase one.

Table 5 Special UAS flight statistics

	Above crowds of people	Above densely populated areas	BVLOS flights
Flights	191	5096	1225
Percentage out of all flights	1.2%	32.7%	7.9%

Operators who had flown above crowds of people during 2016 were asked to clarify how they had ensured the safety of uninvolved persons during these flights. The free text answers to this question were categorised, grouped and shown in proportion of their frequency in Figure 10. Some of the operators had used multiple methods of risk reduction while a small portion answered that they had done nothing, but trusted the reliability of their UAS. Only 6% of operators flying above crowds had installed a parachute in their UAS. However, this is understandable as 41% answered that they did not even fly directly above a crowd which technically means these operators did not in fact fly above crowds. Removing this 41% from the sample and calculating again with the operators actually flying above crowds 10% use a parachute in their UAS.

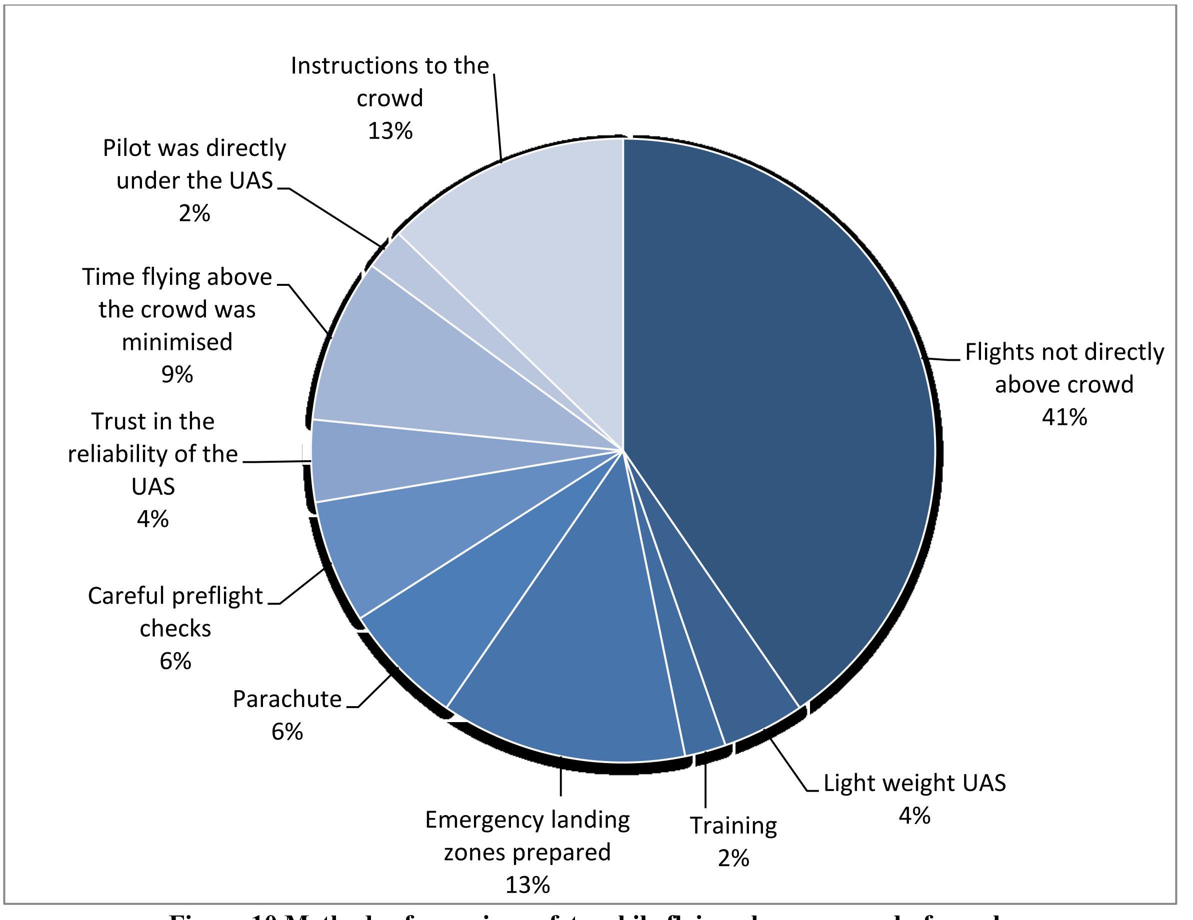

Figure 10 Methods of ensuring safety while flying above a crowd of people

5.1.6 Flights close to airports

A frequently highlighted risk from UAS operations is a collision between passenger aircraft and UA. The risk of a mid-air collision is greatest around airports where passenger aircraft are flying low enough to encounter UA. However this also means that the passenger aircraft are travelling at slower speeds. The current Finnish regulation on unmanned aircraft prohibits flying closer than 5km of an airport runway with a UA or higher than 50m when outside the 5km border but below the airport control zone. These rules are illustrated in Figure 11. No UAS operator has ever been caught violating this rule, but multiple hobbyists have. Arguably no close encounter situation between a UA and a passenger jet has happened so that the UA was flown according to these rules. The conclusion from this is that lack of regulation is not the real problem, but rather general knowledge of the rules amongst hobbyists or people are ignoring the rules.

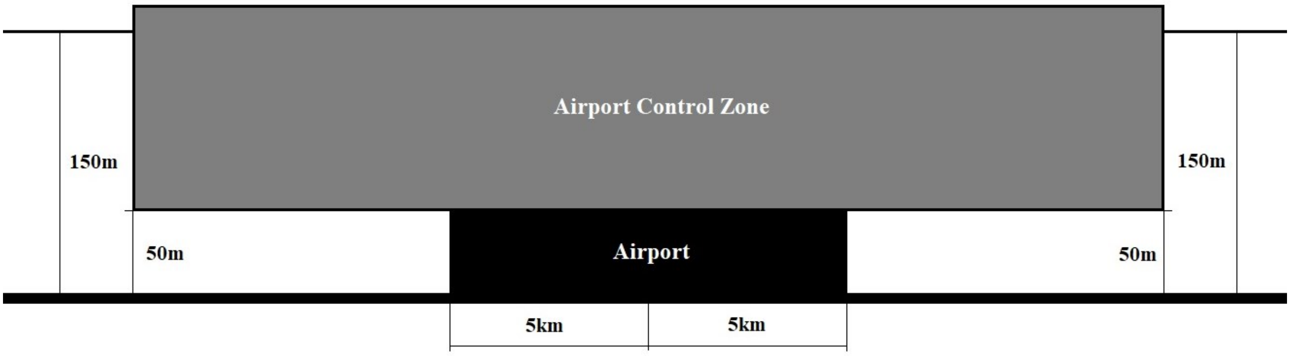

Figure 11 Airspace rules for UAS around airports

Questionnaire asked if operators needed to fly closer than the allowed distance from airports or higher under the airport control zone. To estimate the work load this need poses to air traffic controllers the next question asked how many requests operators had made to ATC to deviate from these rules. The results are shown in Tables 6 and 7. Little over one quarter of operators answered that they needed to deviate from airspace rules around airports. This is expectable as many airports are close to population centres and the 5km protective zones cover large areas of cities, but still many operators need to fly in these areas. If estimating from all of the active UAS operators 259 needed to deviate from airport airspace rules during 2016, but only an estimated 204 operators asked for deviation permits from the ATC.

Table 6 Did you need to deviate from airport airspace rules?

Answer	n	Percentage of all
Yes	57	27.3
No	148	70.8
Don't know	4	1.9

The number of operators requesting deviation from airport airspace rules was less than the number of operators needing to deviate from the rules. This leaves two possible options, either some of the operators simply did not do those operations needing a permit or some operators simply did those operations without the permit from ATC. Either way this fact means that the process for asking a permit should be made easier and probably some operators feel that the risk is not correctly analysed and the protective airspace areas have been made too large. The 45 operators who made requests to ATC asked for a permit to deviate 502 times. Estimating this to all of the active operators the total estimated number of requests to ATC is over 2200 during 2016.

Permits are requested either by email or phone call depending on which airport is in question. This survey cannot specify to which airports the requests were made, but logically the distribution should be close to the distribution of flight hours. However some airports are located closer to the city centre than others and airports of Utti and Jyväskylä have extremely large protective airspace areas that can raise the number of requests locally.

Table 7 Request for exemption from airports

Number of operators requesting	45
Requests to deviate	502
Percentage of all operators	21.5%

5.2 Number of incidents, accidents and occurrences

Respondents to the survey were asked if they had accidents, incidents or occurrences that they were involved in during 2016. There were 60 respondents who answered yes which is 28.7% of the entire sample. This is the percentage of operators that experienced either accidents, incidents, occurrences or some combination of these. The participants were asked to specify what types of accidents, incidents or occurrences had they been involved in and how many times. Total number of events was 459 for the 60 operators. Measuring the major three categories accidents constituted 8%, incidents made up 7% and occurrences 85% of all events. Only in one of the accidents reported in this survey a person was injured, but to what extent was not asked in the survey. Extrapolating from these numbers for all of the 949 active operators' an estimate of 160 accidents, 140 incidents and1700 occurrences can be given for the year 2016. Estimating total numbers of accidents leading to people being hurt is not meaningful from this small of a sample.

Table 8 Total numbers of accidents, incidents and occurrences with UAS

Accidents	**Incidents**	**Occurrences**	**Total**
37	32	390	459
8.0%	7.0%	85.0%	

Question 14 asked the operators to place the events in predefined categories of which some were estimated before the survey to be most likely types of events. As expected before the survey, control link losses were the dominating type making up 73.4% of all occurrences. The fact that only 28.7% of the operators answered experiencing lost link occurrences is not believable and probably this is attributable to most operators not considering this condition as an "occurrence" in the traditional aviation meaning. This is speculation, but examining the fact that the 60 operators who answered experiencing lost link occurrences had 337 events in total between them, leads to suspect the fact that the other 889 operators would have had no lost link occurrences. The other presumed category of occurrence was technical faults which made up 9.2% of all occurrences, this percentage conflicts with answers to a later question regarding technical faults. A reasonable explanation to this conflict is that some operators do not consider technical faults as occurrences in the traditional aviation meaning. All the results are listed in Tables 8 and 9.

Table 9 Numbers of different accidents, incidents and occurrences

Type of occurrence	n	Percentage of all
Loss of control link (Occurrence)	337	73.4
Technical fault (Occurrence)	42	9.2
Incident	32	7.0
Other occurrence	11	2.4
Accident no person injured	36	7.8
Other accident	1	0.2

Questions about the type of flights during which occurrences happened reveal that the majority of the flights were within visual line of sight while only 4.5% were BVLOS flights. This is a close relation to the numbers of flights that the surveyed operators had done in VLOS and BVLOS, making both types of operations seemingly as likely to experience occurrences as show by Table 10. These answers would give VLOS flights approximately a 3% chance for an occurrence per flight while estimate for BVLOS flights is 1.7% of flights experiencing an occurrence.

Table 10 Occurrences in VLOS and BVLOS

Occurrences in VLOS	Occurrences in BVLOS	Total flights in VLOS	Total flights in BVLOS
438.5	20.5	14344	1225
95.5%	4.5%	92.1%	7.9%

Question 16 asked if the events happen in densely populated areas and only 13.3% of the occurrences happened while flying in densely populated areas as shown by Table 11. This is a significant difference from the percentage of flights conducted in densely populated areas. A possible explanation for this difference could be that operators are willing to take more risks in rural areas than in densely populated areas, but the true reasons behind this difference cannot be deducted from the questionnaire results.

Table 11 Occurrences in densely populated and rural areas

Occurrences in densely populated areas	Occurrences in rural areas	Total flights in densely populated areas	Total flights in rural areas
60.9	398.1	5096	10473
13.3%	86.7%	32.7%	67.3%

Question 17 asked how the UA was controlled during the occurrences and the results are shown in Table 12. Direct control flights have a slightly smaller representation in the results than VLOS flights have in the total number of occurrences. This can be explained by a small number of waypoint controlled flights taking place in VLOS.

Table 12 Occurrences by different control methods

Occurrences in direct pilot control	Occurrences during pre-planned waypoint routing	Occurrences during dynamic waypoint routing
401.42	44.19	13.39
87.5%	9.6%	2.9%

Out of the 60 operators that had occurrences only 6 told that they had made a report of the events. This means that only 10% of the events were notified to the Civil Aviation Authority in Finland. When asked did these operators with occurrences, but who didn't report them know about the requirement, 33.3% answered yes. Out of all 209 participants 65.1% knew about the legal requirement of making an occurrence report. These numbers tell that making a report is seen as either not necessary or not worth making by the 65.1% of operators that know of the requirement.

Table 13 Did you report your occurrences?

	Yes	No
n	6	54
Percent of all occurrences	10%	90%

Table 14 Did you know about the requirement of reporting occurrences?

	Yes	No
n	136	73
Percent of all operators	65.07%	34.93%

A large portion of operators didn't know of the reporting system or the requirement to use it in case of an occurrence. This is a clear indication that most operators have not read the regulation with enough care. There is no requirement for any kind of UAS pilot training in Finland and this is one area where that fact shows itself.

Table 15 Operators who didn't report events knowledge of occurrence reporting

	Yes	No
n	18	36
Percent of operators who didn't report their occurrences	33.33%	66.67%

From the beginning of this survey when forming the questionnaire there was a suspicion that the occurrence reporting system is poorly suited to UAS operators, their level of training and types of occurrences that UA encounter. The operators were asked if the occurrence reporting was difficult for them and their answers are shown in Table 16. We can see that 39.7% of the operators had no idea of whether the reporting system is easy to use and approximately one third of the operators who had an opinion thought the system is too difficult.

Table 16 Do you feel that making the report is too difficult?

	Yes	No	I don't know
n	44	82	83
Percent of all operators	21.1%	39.2%	39.7%

Analysing the operators that encountered occurrences during 2016 separately gives us a different view than the average of all operators. The 6 operators who reported their occurrences are split 50-50 by their conclusion of the reporting being difficult. However, this is a very small sample and should not be considered to be representative in any way. On the other side the operators with occurrences, but who didn't report answered according to the results in Table 17. This also shows the near 50-50 split between operators who had an opinion on the matter.

Table 17 Operators who didn't report events: Do you feel that making the report is too difficult?

Yes	No	I don't know
15	13	26
27.8%	24.1%	48.1%

A problem that had been identified before making the survey was that not all operators had taken the required insurance against third party damages. Finding out the proportion of operators that have taken the legally required insurance is interesting from the aviation authority's point of view. Out of the 209 operators surveyed 133 had taken the insurance, while 76 admitted that they had not. This result was expected when taking into account the relative novelty of Finnish unmanned aircraft regulation and difficulties in acquiring these insurances. For a given period no Finnish insurance company was offering this type of insurance and this was causing problems for the operators. Today there is more offering from the insurance industry and Finnish companies have also started insuring UAS operations.

Table 18 Have you taken insurance for your operations?

Yes	No
133	76
63.6%	36.4%

5.3 Technical faults in UAS

One interesting question that has not been answered is what is the likelihood for a UAS to experience a technical fault? This question has been asked from the major manufacturers of small civilian UA by aviation authorities, but no answer's been given. There are occasional reports from UAS pilots where technical faults are reported, but these are not frequent enough to give a complete picture. In the questionnaire the participants were asked "Did your UAS experience any technical faults during 2016?" to which 56 operators answered yes. The results of this question are shown in Table 19. To further clarify this matter the respondents who had experienced technical faults were asked what types of faults and how many faults they had experienced. Nine operator's answers to this question were erroneous and edited. Therefore the total number of faults could be larger than the numbers represented here. The large number of erroneous answers was likely due to the rhythm of the questionnaire with multiple percentage answers before asking again numbers of incident.

The 56 operators who had experienced technical faults in their UAS reported in total 187 separate faults. The number of faults has a larger error due to the fact that 9 operators answers had to be modified and the answers were modified to a minimum number of faults experienced that still retained internal logic with the following questions. This means that the numbers of faults likely have some error to the more reliable direction. On average UAS experience one fault during every 83.3 flights, but taking a closer look at the types of technical faults in Table 20, we can see that this statistic is greatly affected by radio link failures. Radio link failures can be caused by external disturbances and vary between different locations and thus the failure rate is not necessarily an intrinsic property of a given UAS.

Table 19 Did your aircraft experience any technical faults during 2016?

	Yes	No	I don't know
n	56	153	0
%	26.8	73.2	0

Of all technical problems radio link related faults make up 50.8%. A radio link failure would not result in a crash if the UA is equipped with return to home function, unless the UAS happens to hit something on its way back. Return to home function will fly the UAS back to its starting position in the event of loss of control link and this function is a common feature in many UAS. One typical pilot mistake is forgetting to set the home location before a flight and this can result in the UAS flying away from the pilot. Radio link problems can be expected to occur around once per 164 flights. The presumption before formulating the survey was that radio link failures would be the most common technical fault.

Reports of battery and propeller/rotor failures made these fault types known before designing the survey, but how common failure types these are was not known. The results show that batteries fail at around once every 1112 flights and propellers fail once every 915 flights. This makes these failure types fairly uncommon when compared to the numbers of problems with radio links. The "other" fault category has a significant number or faults in it, but unfortunately there was no free text answer possible to explain further what types of faults fit under this heading. This was because of an attempt to try and keep the questionnaire short enough that operators would be willing to finish it.

Table 20 Numbers of technical faults by type

Fault type	n	Percent of all faults	Percent of all faults not including radio link failures	1 fault / number of flights
Fault in radio link	95	50.8		163.9
Fault in electric motor	6	3.2	6.5	2594.8
Fault in combustion engine	0	0	0	
Fault in servo	5	2.7	5.4	3113.8
Fault in propeller/rotor	17	9.1	18.5	915.8
Fault in airframe	1	0.5	1.1	15569
Fault in batteries	14	7.5	15.2	1112.1
Fault in fuel supply	0	0	0	
Other	49	26.2	53.3	317.7
TOTAL	187			

When looking at if the UA type affects the likelihood of technical failures we see that 94.1% of technical faults are in helicopter type UA, while these types of aircraft represent 85.2% out of all aircraft. This difference between failure rate and aircraft numbers is small and could easily be explained by the sample size. The numbers of aeroplane type UAS in this statistic is so small that no estimate of differing failure rates can be drawn from the survey. However, in further studies with more data there will likely at least be different types of typical faults for the UAS types. Fixed wing UAS are more suitable for long range BVLOS flights and this could affect the numbers of radio link faults or other faults that could differ because of the typical operations.

Table 21 Faults by aircraft type

Aircraft type	n	Percentage of all faults
Helicopter/Multicopter	175.9	94.1%
Aeroplane	11.1	5.9%
Helicopter-Aeroplane Hybrid	0	0
Airship	0	0
Other	0	0

5.4 UAS crashes during 2016

A fundamental question regarding unmanned aircraft safety is how often they crash. From all of the surveyed operators 50 answered that they had crashed their drones 69 times in total during 2016. This means that 23.9% of operators had crashes and on average UA are crashing once every 225.6 flights. This is a very meaningful number as it is one of the necessary parts in a risk assessment and the other part is the severity of a UA colliding with a human. Severity has already been studied by multiple different groups (ASSURE, 2017) (Campolettano, 2017) and combining these results it is possible to calculate some rough estimates of risk when local population density and impact area are known. From this survey we can estimate that typical operators UAS will have around 3 years of average life span when calculated from average flights per year.

Table 22 Did any of your aircraft crash during 2016?

Yes	No
50	159
23.9%	76.1%

Operators who had crashes were also asked what caused the crashes and were the crashes controlled. The results are shown in Figure 12 and Table 23. Only a tiny minority answered that the crashes were controlled. This was expected as most operators are using helicopter type UA and thus cannot glide back to a landing.

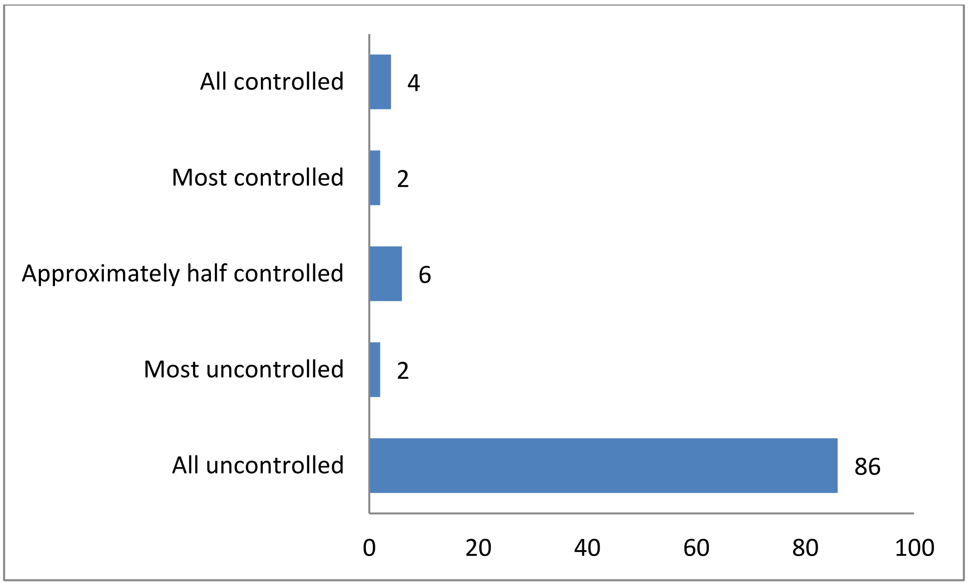

Figure 12 Were the crashes controlled?

Operators who had crashed their UA during 2016 answered that 52.8% of the crashes were caused by equipment malfunctions and 41.2% were caused by human error. Similar study (Graham Wild, 2017) estimated that 63% of UAS accidents are caused by technical faults, which is fairly close to the estimate from this questionnaire. These figures tell that increasing pilot skills could reduce crashes significantly. When compared to manned aviation where approximately 90% of all crashes are caused by human error technical faults play a much larger role in UAS crashes. This could be expected as most UAS are not manufactured to any standards and price competition is not encouraging manufacturers to invest in reliability in the cheapest and most popular UA models. Third parties practically didn't cause any crashes for the surveyed operators.

Table 23 Causes of the crashes

Human error	Equipment malfunction	Third party	Other
28.4	36.4	0.15	4.05
41.2%	52.8%	0.2%	5.9%

5.5 Operator viewpoints on regulations and future

Operators were asked if they thought the regulation was easy to understand in a 3 point scale with the results shown in Figure 13. According to this survey most operators find the regulation easy to understand. Operators were able to clarify their choice with a free text answer and those answers were summarised and grouped. The most common complaints about the regulation were lack of or unclear definitions for crowd of people, densely populated area and aerial work. Also some complaints were not towards the clarity of the regulation but the contents, with some wishing tougher regulation on hobbyists others wanting more lax insurance requirements. Multiple operators found the language of the regulation difficult to understand for persons that had no previous background in aviation. Operators expressed that they felt the regulation was unfairly lax for hobby pilots with more stringent requirements applied only for operators doing aerial work. Some also feared that a hobby pilot could cause an accident that would adversely affect the whole UAS market in Finland. However, the unsatisfied viewpoints were in the minority with most of the operators feeling the current regulation was easy to understand.

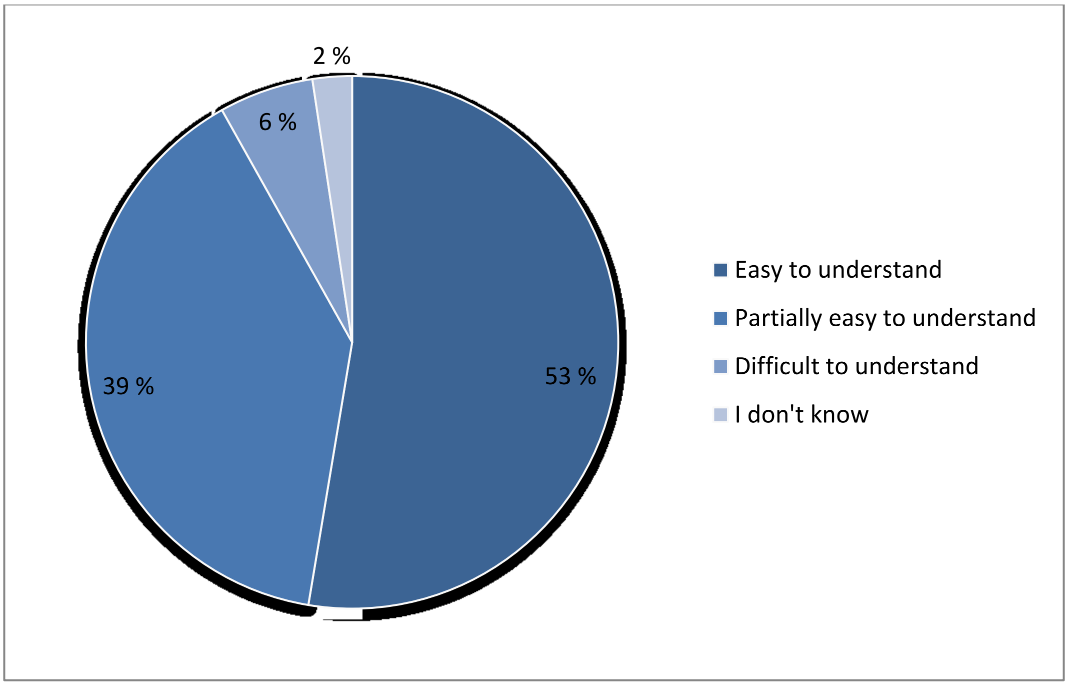

Figure 13 Is the regulation easy to understand?

The future outlook of the UAS market according to operators own perceptions was surveyed with a 5 point scale from very positive to very negative. Operators were also given the possibility to clarify their answer in free text. Most operators 68% were either very positive or positive about their future. This shows that the UAS operators feel that the market and industry is moving towards a more positive future and this was expectable as the number of operators is growing rapidly (Finnish Tranport Safety Agency, 2017). The free text clarifications cited positive experiences from the market growing or operators being able to perform their old jobs more effectively with the help of UAS. New possibilities were cited to have opened up in movie industry and city design because of the capabilities offered by UAS. Other operators told that surveying forests or providing situational awareness in emergency situations had become much more efficient with the use of unmanned aircraft.

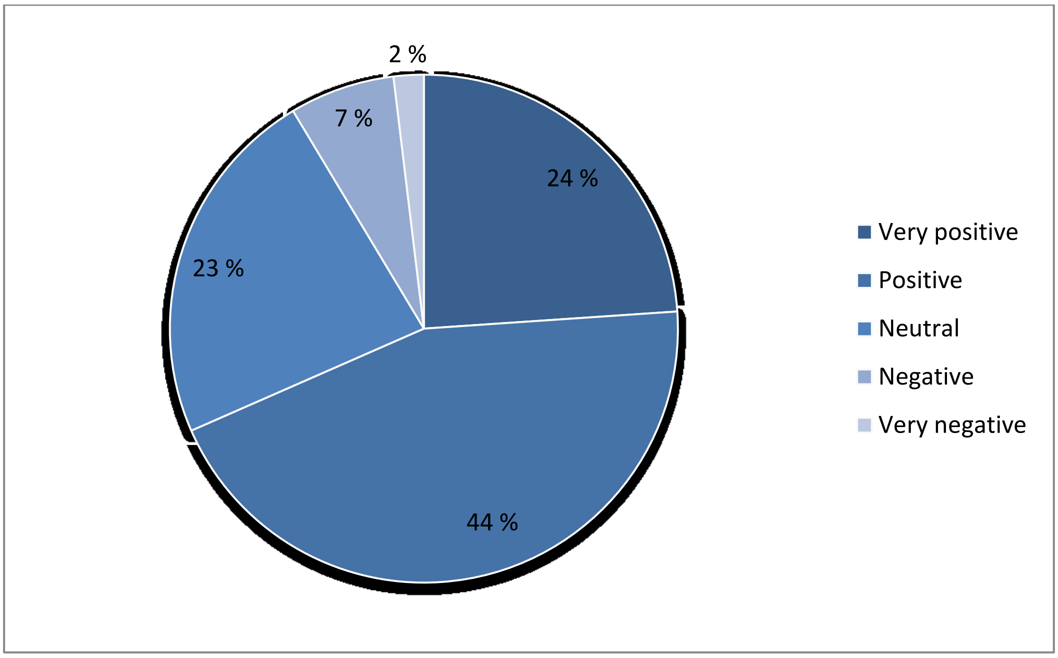

Figure 14 Future outlook according to operators

The negative future outlooks according to the text answers almost all were due to the fear of tighter future regulations making operations much more difficult, but some told of negative experiences from the market talking about excess of competition and hobbyists doing photography operations illegally without the required insurance. Many text answers even from operators with a positive future outlook stated that the fact that hobbyist had easier rules than commercial UAS operators felt unfair. Some of the answers asked for more responsibility for importers or shops selling UAS in informing hobbyists and manufacturers for designing safer UAS. Over all the market and regulation seems good from the operator’s point of view, but the uncertainty of future regulation changes was mostly causing the negative future outlooks. As Figure 14 shows the vast majority of operators have a positive outlook of future.

6 Evaluating risks

From the gathered results we can evaluate some of the basic risks related to unmanned aviation in Finland. However, the data is missing all hobbyists and therefore is not representative of all UAS flights in Finland. Also the risk to other aircraft cannot be evaluated from this study. Combining the reliability and accident data with collision test results from previous studies allows making crude estimations of local ground risk if population density and impact area can also be estimated. It is not possible to gather accurate enough flight location information through this type of a survey, but the possibility to gather accurate flight data could be possible from the new Droneinfo-mobile application published by Finnish Transport Safety Agency. The application has a function through which a flight notification can be made and these data points are gathered for future statistical analysis. Combining the reliability and crash probability estimates from this study to the flight notification data with a further mapping of population density, could yield a crude estimate of third party ground risk in Finland. However the ground risk estimate is impossible to be made only on the basis of this survey and the crash probability estimate is limited in its predictive value due to the sample lacking any hobbyists.

6.1 Probability of a collision with other aircraft

This study cannot provide an estimation of the air risk from UAS. The air risk should be evaluated from a reliable source of data or incident reports of sufficient quality. Current incident reports are not reliable as pilots report near misses with flying objects that can also be other objects than UAS. One method of estimating future numbers of near miss occurrences was to find out the numbers of Google searches for UAS internet shops (ATSB, 2017). This is a good method of estimating future occurrence numbers, but it does not help to find out the severity of a mid-air collision. In future the coming EU-regulation will mandate electronic identification from a distance to be possible on all UAS of certain categories operated in EU with the U-Space system (SESAR Joint undertaking, 2017). After these systems are operational it will not only be possible to calculate a very accurate air risk estimate, but to actively alert UAS pilots of entering into airspace that is prohibited and to catch the users that violate rules. For now one possibility could be to do this type of air traffic analysis for manned aircraft around airports and draw maps of high risk areas where UAS flights would pose the highest risk. The simple empirical risk assessment from the world wide accident record must be that the probability of a collision is small and concentrated close to airports at lower altitudes.

Severity of a collision between UAS and manned aircraft is still unknown and under research. Without knowing the severity of impacts, assessing air risk for UAS is impossible. Compared to bird strike frequencies the UAS risk is much lower, but most of the worry is from the uncertainty of the severity and the growing reported incident rate. As the Virginia Techs simulation (Song, 2016) has estimated UAS are expected to cause more damage to aircraft than an equally sized bird in a collision. Still unknown is whether a common sized UA of around 1.4kg to 800g will cause catastrophic damage to a jet engine when ingested. No actual test of a jet engines tolerance to UAS impact has yet been performed, but this has been proposed by many. The problem is what type of a UAS should be tested and who would pay for this? Jet engines are extremely expensive and manufacturers are not willing to impose more design restrictions for themselves without an order from governments.

ASSURE research group has a project for evaluating UAS impacts (ASSURE, 2015) with manned aircraft and they are planning to at least conduct more simulations of impacts.

One controversial study (BALPA, MAA, UK Department for Transport, 2016) attempting to quantify the severity of a mid-air collision between manned aircraft and UAS claimed that a UAS weighing around 1.2kg would not cause critical damage to a windscreen of an airliner, but a 4kg UAS would. This study is widely criticised for only releasing conclusions and not providing any evidence for its claimed results. The opaque nature of the study with no methods or test data released combined with the fact that parties financing the research have vested interest against unmanned aviation, makes the claims of the study practically empty. The only possible conclusion from this study could be that the 1.2kg class UAS cannot cause critical damage to an airliners windscreen since these parties would have claimed so if they had any grounds to support the claim.

Areas of high air traffic

One way to estimate mid-air collision risk is through looking at the most likely collision areas in Finland. High traffic areas are the most likely places for a collision to take place, but emergency helicopters are also exceptionally vulnerable to collisions with UAS due to their lower flight altitudes and less stringent windscreen hardening requirements than commercial aeroplanes. Helicopter landing sites are not listed anywhere according to traffic numbers, but hospitals and military bases are the most likely candidates for frequent traffic. Commercial aviation traffic from airports is reported on a regular basis and the most congested airport in Finland is Helsinki-Vantaa. Finland had in total 110954 air transport landings during 2016 and Helsinki-Vantaa EFHK airport had 82154 landings that year (Finavia, 2016). This is 74% of Finland's total air traffic and means that the majority of Finland's air traffic is taking place in the same county where 28% of all commercial UAS operators' flights took place.

The UAS flight concentration taken from professional pilots is a bad estimate to use for the air risk since the sample group is the most aware of the restrictions around airports and thus the least likely UAS user group to violate airport airspace. The hobbyists are considered to be the risk group that violates airport airspace due to not knowing the restrictions or ignoring them. However, it should be noted that traditional model airplane hobbyist are not considered to be a problem, but rather new UAS pilots that buy their aircraft from a shop and start flying without any training. The best estimate that can be made is that UAS flight numbers relate closely to the population size of the area and thus it is likely that Uusimaa is the busiest area also with hobbyist flights. As said before it is impossible to calculate the air risk based on this study, but simply looking at these statistics it is easy to say that in Finland the focus should be on Helsinki-Vantaa airport when it comes to air risk from UAS. Some form of a protective system around EFHK airport could prevent most of the possible mid-air collisions. The coming U-Space system will be able to deal with cooperative UAS systems and take care of the problem, but will the system be implemented soon enough?

6.2 Probability of Technical failure

Reliability of UAS is an important basic metric gathered from this study. During 2016 26.8% of operators answered that their UAS experienced technical failures. This fraction makes sense when taking into account that the median for numbers of flights in a year was 30 and the probability of experiencing a technical failure is once every 83.3 flights. Many operators fly so few times in a year that the yearly probability for technical failures is small. Slightly over half of the technical failures were data link problems which are not necessarily failures that will lead to a crash. The other two major failure modes were battery and propeller failures. The frequencies for battery and propeller faults were around once every 900 flights for propellers and around 1100 flights for batteries. Technical faults that fell under the category of other had a frequency of once every 317 flights.

It is important to notice that many faults were hidden under the category "Other" and further studies should aim to find out what types of technical faults fall under these unknown types of failures. The survey didn't find a pronounced difference in reliability between helicopter and aeroplane type UAS. This is likely because of the small number of aeroplane type UAS being used by the operators who participated in this survey and the reduced accuracy of the results when assessing aeroplane type UAS. To gain a better understanding of UAS technical failures, operators should be encouraged to report these incidents regularly. Even if the faults are very minor such as a radio link loss or a faulty battery charge indication it would benefit the larger understanding of UAS reliability. Maybe in the future we can read technical reliability studies of UAS performed by consumer information magazines exactly like car magazines today.

6.3 Probability of UAV falling on a person or property

The general public is mostly worried of privacy violations or third party damages from UAS. The ground risk from small multicopters is not a very big concern since most of the unmanned aircraft in hobbyist use are very light weighing often around 1.2kg. Light weight multi-copters have a relatively low impact severity estimate based on recent collision tests (ASSURE, 2017) and (Campolettano, 2017). However, flights above crowds are seen as extremely risky due to the low reliability estimate of UAS on the market and the very high likelihood of hitting a person. Just as the new studies (ASSURE, 2017) (Campolettano, 2017) of impact severity have shown, there is significant risk involved when flying above a crowd with a UAS weighing around 3.1kg or more. Fortunately most of the UAS operators that reported having flown above crowds actually clarified that they had flown just next to a crowd and never directly on top of one. This shows good judgement from the part of the operators that are hired to these types of jobs. From the data of this survey it was possible to calculate the correlations between reported technical failures and crashes. The Pearson correlations were calculated using SPSS software and the results are shown in Table 24.

I calculated the correlations between different types of technical faults and crashes, but none of the correlations was very strong. The highest correlations between crashes and faults are with propeller/rotor and battery failures. Both of these correlations are significant at the 0.01 level making the finding very reliable, but the actual correlations are not very strong. The fact that these two types of failures correlated stronger with crashes than radio link faults was not a surprise, but the actual amount of correlation is useful for anyone trying to calculate probability of a given fault leading to a crash. If future surveys are conducted with a similar method a more detailed technical fault categorisation should be used with the possibility given to participants to clarify answers in free text.

Table 24 Correlations of technical faults to crashes

Technical fault type		Number of crashes
Fault in radio link	Pearson Correlation	.142*
	Sig. (1-tailed)	.020
Fault in electric motor	Pearson Correlation	.043
	Sig. (1-tailed)	.268
Fault in combustion engine	Pearson Correlation	.[b]
	Sig. (1-tailed)	.
Fault in servo	Pearson Correlation	.130*
	Sig. (1-tailed)	.030
Fault in propeller/rotor	Pearson Correlation	.315**
	Sig. (1-tailed)	.000
Fault in airframe	Pearson Correlation	.171**
	Sig. (1-tailed)	.007
Fault in batteries	Pearson Correlation	.236**
	Sig. (1-tailed)	.000
Fault in fuel supply	Pearson Correlation	.[b]
	Sig. (1-tailed)	.
Other	Pearson Correlation	.084
	Sig. (1-tailed)	.114

*. Correlation is significant at the 0.05 level (1-tailed).

**. Correlation is significant at the 0.01 level (1-tailed).

b. Cannot be computed because at least one of the variables is constant.

6.4 The most risky type of aerial work with UAS

One of the goals of this study was to find out what is the most risky type of aerial work with UAS. Correlations were calculated from the gathered data between numbers of aerial work flights, crashes and occurrences using SPSS. The only correlations that were significant were powerline inspections that correlated with occurrences and test flights that correlated with crashes. Even though these correlations are significant meaning trustworthy the strength of the correlations was weak. The fact that there were no more significant correlations would suggest that there isn't enough data gathered in this study to draw a definitive conclusion as to what type of aerial work is the most dangerous. Test flights are logically the most likely to end up in a crash, but with really no other aerial work types to compare to, the conclusion cannot be made in this study.

Because the correlations between crashes and occurrences are not reliable enough to draw conclusions in this study, the only factor that can be known when comparing aerial work types is the location where the work is being done. The severity of possible consequences from a crash can be compared and by this metric flights directly above crowds of people are the most dangerous. This is not a statistically confirmed fact, but rather a logically argued statement. The fundamental difference between risks of operation with manned aircraft and unmanned aircraft is the fact that a crash of a UAS does not necessarily cause any risk. The economic loss is of course important to the operator, but from the view point of total safety level nationwide, the fact that UAS are falling to the ground with no injuries to third parties is still a safe operation.

Table 25 Correlations of aerial work types to crashes and occurrences

Aerial work type		Crashes	Occurrences
Photographing, videotaping	Pearson Correlation	-.098	.020
	Sig. (2-tailed)	.158	.774
Press, media	Pearson Correlation	.082	-.028
	Sig. (2-tailed)	.240	.689
Powerline inspection	Pearson Correlation	.010	.188**
	Sig. (2-tailed)	.891	.006
Gas pipe inspection	Pearson Correlation	.068	-.006
	Sig. (2-tailed)	.325	.929
Inspection of masts or wind power plants	Pearson Correlation	-.015	.115
	Sig. (2-tailed)	.826	.097
Inspection of buildings or roofs	Pearson Correlation	-.052	-.002
	Sig. (2-tailed)	.456	.975
Inspection of other constructions, e.g. bridges	Pearson Correlation	-.040	-.022
	Sig. (2-tailed)	.565	.746
Logistics	Pearson Correlation	-.032	-.016
	Sig. (2-tailed)	.646	.821
Ship emission measurements	Pearson Correlation	.[b]	.[b]
	Sig. (2-tailed)	.	.
Measurement of radiation or other emissions	Pearson Correlation	.[b]	.[b]
	Sig. (2-tailed)	.	.

Measurement of mobile phone networks or other telecommunication networks	Pearson Correlation	-.053	.029
	Sig. (2-tailed)	.446	.676
Agricultural work	Pearson Correlation	-.078	-.035
	Sig. (2-tailed)	.262	.612
Forestry work	Pearson Correlation	.025	.008
	Sig. (2-tailed)	.721	.907
Providing an overall situation picture for an entity in command of other operations	Pearson Correlation	.094	-.009
	Sig. (2-tailed)	.178	.903
Aircraft external inspections	Pearson Correlation	.068	-.006
	Sig. (2-tailed)	.325	.929
Mapping or charting	Pearson Correlation	-.055	-.016
	Sig. (2-tailed)	.430	.819
Lidar or other sensor	Pearson Correlation	.068	.019
	Sig. (2-tailed)	.325	.780
Test flights for development of new devices or functions	Pearson Correlation	.268**	-.016
	Sig. (2-tailed)	.000	.822
Search and rescue services	Pearson Correlation	.097	.090
	Sig. (2-tailed)	.161	.197
Surveillance	Pearson Correlation	-.017	-.023
	Sig. (2-tailed)	.807	.742
Ore prospecting or other soil survey	Pearson Correlation	.[b]	.[b]
	Sig. (2-tailed)	.	.
Scientific research	Pearson Correlation	.025	-.016
	Sig. (2-tailed)	.721	.813
Tasks using a thermographic camera	Pearson Correlation	-.019	.113
	Sig. (2-tailed)	.780	.102
RPAS flight training	Pearson Correlation	.039	-.020
	Sig. (2-tailed)	.575	.770
Other	Pearson Correlation	-.020	-.032
	Sig. (2-tailed)	.776	.642

**. Correlation is significant at the 0.01 level (2-tailed).

b. Cannot be computed because at least one of the variables is constant.

7 Conclusions

This study set out to clarify what types of activity UAS operators are actually conducting in Finland for the first time at least to my or Finnish Transport Safety Agency's knowledge. The study was only possible after the first Finnish regulation on remotely piloted aircraft became active during the latter part of year 2015 and required commercial operators to register. The statistics gathered of general UAS operations around Finland in this study have given the first concrete look at the industry. Simply the knowledge of what is being done, where and how much, has cleared much of the unknowns around UAS operations in Finland. The finding that UAS flight hour distribution is closely related to the population distribution is a finding that can be used to estimate total UAS activity in Finland and to plan the use of Aviation authority's resources. After all, it makes little sense to focus on air risk around airports that are located in regions with very limited numbers of flight activity while Helsinki-Vantaa airport sees three quarters of the manned air transport aviation in Finland and the capital region an estimated one quarter of unmanned aviation.

The general statistics of numbers of UAS operated, flight numbers and flight hours give a picture of the typical operator as a small scale business doing photography or filming with the occasional help of a UAS. In this survey it was estimated that during 2016 there were 949 active UAS operators in Finland. The general statistics show that the entry level of starting UAS operations is low for people coming from outside of traditional aviation and the use of new tools such as UAS can be experimented on and adopted easily to a wide range of applications. Larger scale operators were a minority, but they conducted a sizeable proportion of all flights. After photographing the most common aerial work types in order were mapping, test flights, media and search and rescue services. The fact that test flights are third most common type of UAS activity would suggest that in future there will be completely new operations and manufacturers in Finland. Largest of operators participating in this survey were flying hundreds of times a year doing more complicated types of aerial work such as power line inspections in BVLOS. A small surprise was the fact that power line survey was not more common as air space reservations for this type of activity have caused a lot of workload to Finnish aviation authority.

The biggest limitation of this survey is the sampled population. The fact that all hobbyists are excluded from the sample significantly limits the generalizability of this study. It is unfortunate that there are very few ways of reliably contacting or identifying hobby users of unmanned aircraft. Until registration will be necessary also for hobbyist a large portion of UAS users possibly even the largest group will be operating so that the aviation authority will have very little information of their activities. One possible way of spreading information to hobbyists would be to demand shops that sell UAS to give out information leaflets with every sold aircraft. This would alleviate some of the risk from users that are ignorant of the current rules, but still it would not make gathering of data possible. A second idea of a method for gathering information of hobbyist activities in Finland would be to increase the numbers of Droneinfo mobile application users and start conducting statistical analysis of the flight notifications made through the application. With time eventually new EU regulations will make registration of hobbyists also mandatory and then better statistical analyses can be conducted of UAS operations not just in Finland but in Europe.

A major unknown factor of safety has been the reliability of UAS and numbers of occurrences. In this study an estimate for both of these questions was given from the gathered answers. For all of the operators participating in this study, technical faults happened once every 83.3 flights. This estimate includes radio link failures that accounted for around 50% of all the faults. This estimate is useful also for operators and hobbyist when estimating the running cost of a UAS. The numbers of crashes that operators reported amounted to one crash every 225.6 flights. This is a very important statistic when evaluating any UAS operations risk. Before this study, there was no estimate of UAS crash probability based on data that could have been used for example when the current Finnish regulation was drafted. During this study's literature review no study came across that would have given an estimate for commercial UAS crash probability. It will be interesting to compare numbers when other studies come up with new estimates for crash probability and what techniques those studies will have used to form the estimate.

In this survey, accidents, incidents and occurrences were asked separately from crashes and an estimate of 160 accidents, 140 incidents and1700 occurrences can be given for the year 2016. This is a projection to all of the estimated 949 active operators and using an estimate of 70690 total UAS flights during 2016. It should be noted that of the reported occurrences control link losses were the dominating type with a proportion of 73.4%. Using the occurrence data results in estimates of accidents happening once every 420 flights, incident once every 486 flights and occurrences once every 40 flights. This shows that crashes, accidents and technical faults estimates are in conflict and this could be a result of operators understanding the definitions differently. The survey was designed with some overlapping questions so that the previous answers could be verified by a later one. It is unfortunate that the answers differ from one to the next slightly but using a conservative approach choosing always the least reliable or safe estimate can be done if this study's estimates are used in other works. The results of crash and occurrence probabilities are significant and very useful in any risk assessments of UAS operations. Finding out what is the riskiest type of aerial work proved to be unachievable from the gathered data due to a lack of reliability for most aerial work types. If this study is turned to a longitudinal one the additional data could be used to answer this question later. The only reliable correlations between crashes and aerial work flight hours were for test flights and powerline inspections. Since these were the only two reliable correlations determining more aerial work types reliably for a comparison is needed.

My recommendation for future research on the basis of this study is turning this questionnaire into a longitudinal study. The survey should be improved in questions asking technical faults, accidents and crashes. These topics should be inquired in more detail while the division of flights around Finland and to different aerial work types could be made easier to answer or separated to another questionnaire. A longitudinal study could identify trends in unmanned aviation that could be then taken into account when aviation authority is preparing plans for inspections or simply spreading information. The primary recommendation from this thesis is not for any research but for an action to improve safety of UAS flights in Finland. Whatever they are called drones, UAS or model aircraft, all shops selling these systems should always handout information leaflets with content on safe flying rules and places to find more information. This simple action would make sure that the large new hobbyist group stays informed of the necessary flying rules.

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List of Appendices

Appendix 1. Introductionary letter to survey in English

Dear unmanned aviation operator

My name is Henri Hohtari and I am currently finishing my master's in Aalto-university School of Engineering. As part of my master's thesis I created a questionnaire of unmanned aviation in Finland during 2016 in co-operation with Finnish Transport Safety Agency Trafi. The purpose of the questionnaire is to find out the realities of unmanned aircraft operations in Finland. This clarification of the big picture is very valuable to Trafi and the development of unmanned aviation.

Answering the questionnaire requires approximately 10 to 15 minutes of your time. The questions regard general statistics of your unmanned operations in Finland during the year 2016. All participants to the questionnaire will remain anonymous to ensure that you can answer honestly even about negative incidents and experiences without fear of consequences. Please, do not write your name to any of the open text answers to ensure your identity stays hidden. The results of the survey will be published in my master's thesis at the Aaltodoc publication library and I will send a copy of the thesis to Trafi.
If you decide to participate in the survey, please try to answer the questions honestly up to your best knowledge. Participation in the questionnaire is voluntary and you can abort answering at any point.

Thank you for the time you are using for my master's thesis. The results will be utilized in Trafi to develop authority services and functions. Your email address was taken from Trafi's unmanned aviation operator register and the addresses will not be given to any parties outside of Trafi. Your email will only be used for this message and one reminder letter.

If you want to ask something regarding the questionnaire from me personally, you can contact me by email.

Best Regards
Henri Hohtari

Link to the questionnaire

Appendix 2. Questionnaire

Unmanned aviation in Finland during 2016

1. Did you have any flights with unmanned aircraft during 2016? *

- ◯ Yes
- ◯ No

2. What types of unmanned aircraft you operated during 2016? *

Mark how many of each type of aircraft you used

Helicopter / Multicopter	______
Aeroplane	______
Helicopter-Aeroplane Hybrid	______
Airship	______
Other	______

Sum of numeric fields equals: 0

3. Estimate how many flights you performed in Finland during 2016? *

Flight means an operation between one take-off and landing

Number of flights	______

Sum of numeric fields equals: 0

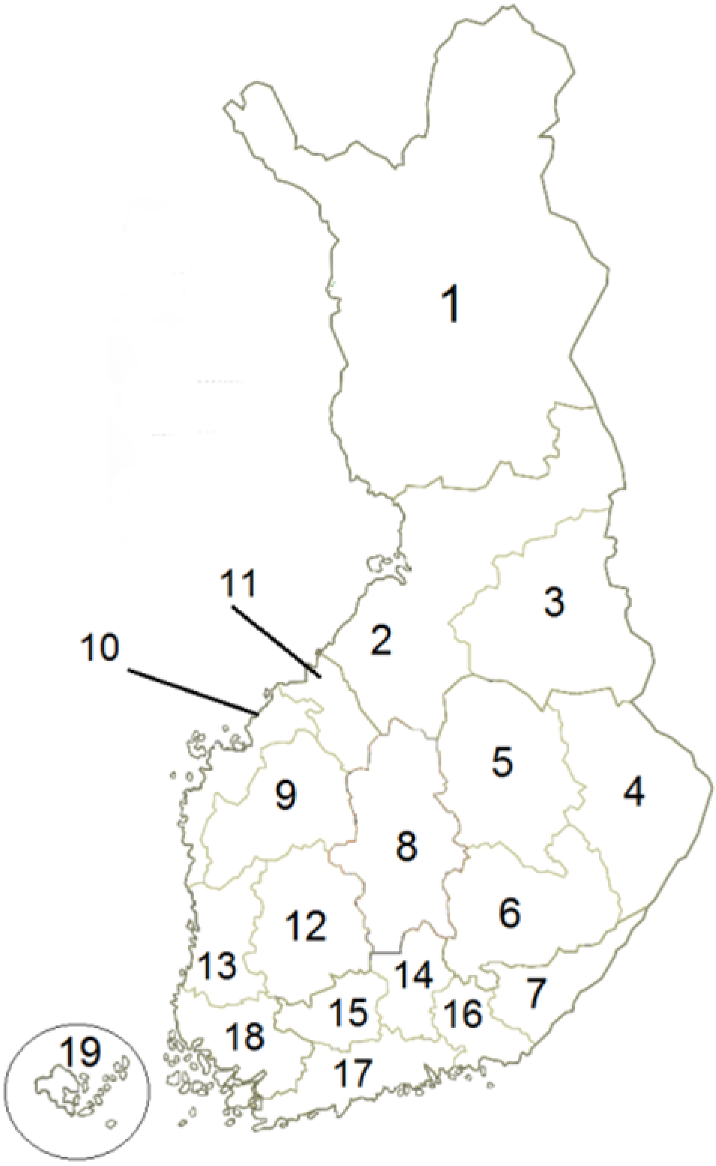
4. Estimate how many minutes one flight lasted on average? *

Average time of flight (min)	______

Sum of numeric fields equals: 0

5. Estimate the division of all flights during 2016 by province in percentages.

1. Lappi
2. Pohjois-Pohjanmaa
3. Kainuu
4. Pohjois-Karjala
5. Pohjois-Savo
6. Etelä-Savo
7. Etelä-Karjala
8. Keski-Suomi
9. Etelä-Pohjanmaa
10. Pohjanmaa
11. Keski-Pohjanmaa
12. Pirkanmaa
13. Satakunta
14. Päijät-Häme
15. Kanta-Häme
16. Kymenlaakso
17. Uusimaa
18. Varsinais-Suomi
19. Ahvenanmaa



The percentages must add up to 100.

1 Lappi	2 Pohjois-Pohjanmaa
3 Kainuu	4 Pohjois-Karjala
5 Pohjois-Savo	6 Etelä-Savo
7 Etelä-Karjala	8 Keski-Suomi
9 Etelä-Pohjanmaa	10 Pohjanmaa
11 Keski-Pohjanmaa	12 Pirkanmaa
13 Satakunta	14 Päijät-Häme
15 Kanta-Häme	16 Kymenlaakso
17 Uusimaa	18 Varsinais-Suomi
19 Ahvenanmaa	

Sum of numeric fields equals: 0

6. Estimate the percentages of all flights during 2016 according to operation type.

The percentages must add up to 100.

Photographing, videotaping	Press, media
__________	__________
Powerline inspection	Gas pipe inspection
__________	__________
Inspection of masts or wind power plants	Inspection of buildings or roofs
__________	__________
Inspection of other constructions, e.g. bridges	Logistics
__________	__________
Ship emission measurements	Measurement of radiation or other emissions
__________	__________
Measurement of mobile phone networks or other telecommunication networks	Agricultural work
__________	__________
Forestry work	Providing an overall situation picture for an entity in command of other operations
__________	__________
Aircraft external inspections	Mapping or charting
__________	__________
Lidar or other sensor	Test flights for development of new devices or functions
__________	__________
Search and rescue services	Surveillance
__________	__________
Ore prospecting or other soil survey	Scientific research
__________	__________
Tasks using a thermographic camera	RPAS flight training
__________	__________

7. Estimate how many flights you did over a crowd of people during 2016? *

Number of flights	______________________

8. How did you ensure the safety of these flights in the case of an aircraft falling to the ground?

____

____

____

9. Estimate how many flights you did over densely populated areas during 2016? *

Number of flights	______________________

10. Estimate how many flights you did beyond visual line of sight during 2016? *

Number of flights	______________________

11. Did you have a need to fly closer than 5km from an airport or fly higher than 50m inside the airport control zone during 2016? *

◯ Yes

◯ No

◯ I don't know

12. How many times did you contact air traffic control to ask a permission to deviate from normal rules inside an airport control zone? *

Jos ei yhteydenottoja merkitse 0

Number of requests	______________________

13. During 2016 were you involved in any occurrences, incidents or accidents? *

For example a nearly avoided collision would be an incident and losing control link to a drone would be an occurrence

- ◯ Yes
- ◯ No

14. Estimate the numbers of occurrences, incident and accidents you were involved in during 2016 *

Estimate the numbers by category. If no events in a category mark 0.

Losing control link (occurrence)	
Technical fault (occurrence)	
Incident	
Other occurrence	
Accident no person injured	
Other Accident	

Sum of numeric fields equals: 0

During what types of operations did the occurrences, incidents or accidents happen?

15. Estimate the division of occurrences, incidents and accidents according to visibility condition during flight *

Estimate in percentages of all events. The percentages must add up to 100

Events while drone was in visual line of sight	
Events while drone was beyond visual line of sight	

Sum of numeric fields equals: 0

16. Estimate the distribution of occurrences, incidents and accidents according to flight area *

Estimate in percentages of all events. The percentages must add up to 100

Events over densely populated areas	______
Events over remote areas	______

Sum of numeric fields equals: 0

17. Estimate the distribution of occurrences, incidents and accidents according to control method *

Estimate in percentages of all events. The percentages must add up to 100

Events while drone in direct pilot control	______
Events while drone following predefined waypoints	______
Events while drone following dynamically set waypoints	______

Sum of numeric fields equals: 0

18. Did you make occurrence reports from the events? *

◯ Yes

◯ No

19. Did you know about the requirement for making occurrence reports? *

◯ Yes

◯ No

20. Do you feel that making the report is too difficult? *

- ◯ Yes
- ◯ No
- ◯ I don't know

21. Have you taken an insurance against third party damages according to EU-requirements? *

- ◯ Yes
- ◯ No

Aircraft reliability

22. Did your aircraft experience any technical faults during 2016? *

- ◯ Yes
- ◯ No
- ◯ I don't know

23. Estimate numbers of faults to the most suitable categories *

If no faults in a category mark 0.

Fault in radio link	
Fault in electric motor	
Fault in combustion engine	
Fault in servo	
Fault in propeller/rotor	
Fault in airframe	
Fault in batteries	
Fault in fuel supply	
Other	

Sum of numeric fields equals: 0

24. What types of drones were the faults in? *

Estimate in percentages of all aircraft faults. The percentages must add up to 100

Helicopter / Multicopter	
Aeroplane	
Helicopter-Aeroplane Hybrid	
Airship	
Other	

Sum of numeric fields equals: 0

25. Did any of your aircraft fall down during 2016? *

◯ Yes

◯ No

26. How many of your aircraft fell during 2016? *

Number of falls	

Sum of numeric fields equals: 0

27. Estimate how many of the falls were controlled? *

Example of a controlled fall: With a parachute

◯ All uncontrolled

◯ Most uncontrolled

◯ Approximately half controlled

◯ Most controlled

◯ All controlled

28. Estimate what reasons led to the aircraft falling *

Estimate percentages of all falls. The percentages must add up to 100.

Human error	
Equipment malfunction	
Third party	
Other	

Sum of numeric fields equals: 0

29. Do you think Finnish aviation regulation on use of remotely piloted aircraft and model aircraft is easy to understand? *

◯ Regulation is easy to understand

◯ Regulation is partially easy to understand

◯ Regulation is difficult to understand

◯ I don't know

30. What makes you feel this way?

____

____

____

31. How do you see the future of unmanned aviation from your perspective? *

◯ Very positive

◯ Positive

◯ Neutral

◯ Negative

◯ Very negative

32. What makes you feel this way about the future?

____

____

____

Thank you very much for answering.

33. Do you want to give feedback on the survey or tell something other related to the survey?

____

____

____