UiT Norges arktiske universitet

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Investigation of UAV related incidents and accidents

A study on UAV (drone) related incidents and accidents

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Abstract

To this day, there is a lack of research on UAV (drone) related incidents and accidents. Knowing why these happen, what potential outcomes they may have and how to avoid them from occurring, can be crucial. There is, furthermore, potentially a lack of transparency in the unmanned aviation industry, regarding reporting of incidents. This thesis aims to contribute to exactly this: an increased transparency in the unmanned aviation industry.

Through the use of deduction, induction and abduction, qualitative and quantitative data has been identified and reviewed, in order to attempt to answer the following research questions:

- What are the potential causes and consequences of UAV related incidents and accidents, and how can they be avoided?
- How is the process of incident reporting in the unmanned aviation industry compared to the manned aviation industry, and should it be revised?
- Do the current rules and regulations regarding the use of UAVs have a sufficient concern for safety, or should they be reassessed?

In order to prepare conclusions within one set of regulations, only incidents occurring in Norway have been assessed. By identifying and analysing 154 incidents and accidents that have occurred over a total flight time of approximately 8200 hours, and by reviewing literature related to the research questions, it has been found that

- UAV incidents and accidents often may be prevented by an UAV operator being competent and does not suffer from fatigue
- to this day the outcomes of the identified UAV incidents and accidents have not yet been critical, but in a worst case scenario many of them had the potential of being so
- the process of incident reporting in the unmanned aviation industry should be revised, as there currently are no reasons to report incidents as the incidents are not analysed nor shared with the public
- there exist several important risk reduction measures that currently are not included as a part of rules and regulations, but that may assist in preventing UAV incidents
- the current set of rules and regulations regarding the use of UAVs do have a good concern for safety, still they can be improved by adding or revising some relevant rules or regulations as discussed further in the thesis.

Preface and acknowledgements

This thesis is submitted as a fulfilment of the requirements for the master's degree in Technology and Safety in the High North at UiT – The Arctic University of Norway. The thesis marks the end of 5 years at the university, of which the first three years studying the bachelor's degree in drone technology and the latter two years studying the master's degree as mentioned. The thesis has been carried from January to June 2022.

I would like to show my appreciation and thank my supervisor, Prof. Ove Tobias Gudmestad, who has guided me through the writing of the thesis. His vast knowledge on most subjects, and especially on how to write a master's thesis, has been helpful from day one. The state of the thesis would not have been the same without him and his expertise.

Thank you to the head of the Technology and Safety in the High North study course, Prof. Javad Barabady. Thank you for always taking time out of your busy schedule to help me with my questions about the thesis and other subjects.

At last, but definitely not least, I would like to express my gratitude to the companies that contributed with data towards the writing of this thesis. Due to censorship, none of them will be mentioned. The companies that participated know who they are. Without them, this thesis could not have been carried out.

Those who would like a copy of the excel sheet (appendix A), containing identified incidents and accidents and analyses of them, can send a request via e-mail to me (Sigurd.Haugse@gmail.com).

Sigurd Haugse, Tromsø, 30.05.2022

Sigurd Haugse, Tromsø, 30.05.2022

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Abbreviations and word explanations

AGL	Above Ground Level
AIBN	Accident Investigation Board Norway
AMSL	Above Mean Sea Level
Distr.	Distribution
EASA	European Union Aviation Safety Agency
ETA	Event Tree Analysis
FAA	Federal Aviation Administration
Fly-away	"An interruption or loss of the command and control link where the pilot is unable to affect control of the aircraft and the aircraft is no longer following its pre-programmed procedures resulting in the UAV not operating in a predictable or planned manner" (Law Insider, n.d.-a)
FTA	Fault Tree Analysis
HAZID	Hazard identification
ICAO	International Civil Aviation Organization
MCS	Minimal Cut Set
N/D	Not Defined
NCAA	Norwegian Civil Aviation Authority
NDA	Non-Disclosure Agreement
NOTAM	Notice To Airmen

NTSB	National Transportation Safety Board
PDSA	Plan-Do-Study-Act
PRA	Preliminary Risk Assessment
SAR	Search And Rescue
SMS	Safety Management System
SoC	Severity of Consequence
UAS	Unmanned Aircraft System
UAV	Unmanned Aircraft Vehicle
VLOS	Visual Line Of Sight
VSL	Value of Statistical Life

1 Introduction

In this chapter an introduction to the thesis is presented. This introduction covers the background of the thesis, the aims and objectives, the research questions, the limitations and at last a description of the structure of the thesis.

1.1 Thesis background

Most of us have heard the buzzing sound of a drone, or seen one. These flying objects, also known as Unmanned Aerial Vehicles (UAV), are everywhere and can be used for many purposes. Even though the talk and use of UAVs has escalated quickly in recent years, they have been around since the 19th century in the form of, for instance, unmanned balloons (Prisacariu, 2017). With an accelerating use of UAVs, there may be an increase in incidents and accidents regarding UAV operations. Avoiding these can be valuable to many.

New methods for working out operations are from time to time implemented, and this is often due to wanting to make operations safer and more efficient. Since the 1980s, we have seen a drastic decrease in number of deaths in the petroleum industry. With a fatality accident rate (FAR, in this example fatality per 100 million hours worked) of about 16 in 1985, to a FAR of about 1 in 2019 (HSE Now, 2020). This may be due to that new methods of working have been implemented and/or that the safety equipment used for the given operations has improved. With high-risk operations as those done in the petroleum industry, using unmanned systems to execute operations instead of direct human power may contribute to lowering this FAR even more. This does not only apply for the petroleum industry, but also for other industries. To be able to increase efficiency and profit, and to lower risk, implementing new methods for working is important. Methods like this can, for instance, be to use cars instead of horses and carts. Another method may be to use UAVs. With this follows a need to focus on safety.

The regulation of what incidents to report in the unmanned aviation industry state that "for unmanned aircrafts under 150 kg, however, there is only a reporting obligation if the aviation accident or aviation incident, or other safety related case, resulted in, or could have resulted in, fatal or serious person injury or an aircraft other than the unmanned aircraft that was involved" (Samferdselsdepartementet, 2020). Currently there are few UAV related incidents and accidents that are or have been reported to the Norwegian Civil Aviation Authority (NCAA) nor the Accident Investigation Board Norway (AIBN), according to the NCAA (Martinsen, 2017). Most of the incidents that are reported are not analysed further in any way either, according to an oral conversation between NCAA and the author of this thesis (02.12.21). As a result of this, there may be a lacking amount of data of what causes UAV related incidents and accidents and what should be done to prevent them from happening. A low number of reported incidents, and that these reports are not shared with the public, may be an indication that there is a lack of transparency in the unmanned aviation industry. This is critical to be able to assure a high level of safety and to expand the use of UAVs.

UAVs have been around for quite some time, but the full potential of them is only barely being utilized. This applies for a number of industries, and especially those that deal with high-risk operations. Some people may still be sceptical, do not trust UAVs and hesitate with implementing them into their business or industry. As the use of UAVs has accelerated in mainly the last decade, people have not been exposed to UAVs for a long period of time yet. When commercial airplanes were first presented, people were also sceptical to those, but by being exposed to them over time people have become less sceptical (exposure therapy). This may also be the case for the use of UAVs. However, another factor that influences the trust to something, is data and analyses that proves something wrong or right. By analysing incidents and accidents, carrying out risk assessments and coming up with risk reduction measures, the trust may increase. One factor that is important for coming up with good risk reduction measures is transparency.

Transparency is important to ensure a high level of safety. As Leape et al. stated in their report from 2009: "Transparency – the free, uninhibited sharing of information – is probably the most important single attribute of a culture of safety" (Leape et al., 2009). Without transparency it can be difficult to maintain a high level of safety. Meaning, instead of increasing safety by looking at past unwanted events that have actually happened and implementing risk measures according to those unwanted events, safety will have to be attempted to be increased by identifying possible events that the analysts think can happen. As stated earlier in this chapter, there are indications that there is a lack of transparency in the UAV industry, and the scenario described above (increasing safety by identifying possible events) may have been utilized by the NCAA when making rules and regulations, and risk reduction measures, regarding UAV operations. With more transparency, these risk reduction measures may have been made better and more pertinent. This could have then resulted in an improved safety related to the use of UAVs. With high-risk operations, this should be prioritized.

UAV operations may in some cases be categorized as high-risk and complex operations, according to a definition of a high-risk operation (The Britannica Dictionary, n.d.). The more complex and high-risk an operation is, the more concern for safety is needed. Currently, and with years to come, UAV operations are high-risk, and the risk may increase significantly when UAVs become bigger, operate more over people, and when they start to freight people and other load. Focusing on safety around these operations and especially making these operations safer by analysing past events is and will be important. There are reasons to why both Europe and the US have not yet permitted high-risk operations with UAVs, such a freight of people. The systems are ready, however the NCAA currently do not allow one to do so yet (Frantzen, 2021b). If the transparency in the UAV industry was better, analyses could have already been carried out and relevant risk reduction measures could have been implemented. This again meaning that those kinds of operations could have already been permitted to this day, but may not be so due to a lack of transparency. Again, this does not just apply to the UAV industry, but also others. Transparency is not only a direct key to an increase of safety, but also an indirect key for efficiency and improvement of operations. Transparency may contribute to lowering the number of accidents that happen, and thus save lives.

The last decade there have been several publicly known incidents and a few accidents related to UAVs. Last year, in 2021, new rules and regulations regarding UAVs came into force for Norway (and EU). The background for this was according to the NCAA that UAVs have become publicly available to an extent that there was a need for stricter regulations (Frantzen, 2021a). In other words, no incident(s) or accident(s) triggered the implementation of these rules and regulations. This also applies for the writing of this thesis. It is all based on the precautionary principle and a desire of being ahead of unwanted events to improve safety. However, before starting to write this thesis, the NCAA and one of Europe's largest UAV companies were contacted by the author of this thesis (02.12.21 and 22.12.21 respectively), and both were positive to the aim of the thesis and agreed that there is a benefit and a demand of such research.

UAVs are all around us, and they have come to stay. They can be used for many purposes, ranging from search and rescue (SAR) operations to inspections of offshore wind turbines, and everything in between. With an increased use of UAVs, safety measures should be taken. Being ahead of unwanted events is a key factor for being able to utilize the benefits of UAVs while still maintaining a high level of safety and keeping the reputation of them good among the world's population.

Identification and analyses of actual UAV incidents and accidents have to this day not yet been carried out, that is known to the public. Currently, based on the lack of transparency in the UAV industry, most companies that operate with UAVs only learn from their own experiences. With an increase in transparency, it may be easier for companies to learn from each other as well, which may increase the overall safety in the UAV industry (this corresponds with what Leape et al. stated in 2009, (Leape et al., 2009)). This thesis will hopefully contribute to this increase in transparency.

With this background in mind, the aim with associated objectives of this thesis were elaborated.

1.2 Aim and objectives

The thesis aims to investigate UAV related incidents and accidents in order to

- contribute to transparency of unwanted events in the unmanned aviation industry,
- this may result in a decrease in both the frequency of incidents and accidents, and the consequences should they happen.

To achieve this aim, the following objectives were chosen:

- Conduct risk assessments for UAV related incidents and accidents by
    - collecting data about incidents and accidents related to the use of UAV from several Norwegian companies
    - carrying out several different risk assessments methods and charts to analyse the collected data
    - carrying out hazard identification analysis to identify possible incidents and accidents related to the use of UAVs in civil service
    - identifying risk mitigation measures for the use of UAV.
- Compare the reporting systems of manned- and unmanned aviation.
- Recommend updated rules and regulations for use of UAVs in different industries.

1.3 Research questions

The following research questions were defined to assure that the study of this thesis was directed towards achieving the aim of the research, with each question associated with their respective objective (objective 1 associated with research question 1 and so on):

- What are the potential causes and consequences of UAV related incidents and accidents, and how can they be avoided?
- How is the process of incident reporting in the unmanned aviation industry compared to the manned aviation industry, and should it be revised?
- What are the current rules and regulations regarding the use of UAVs, and how can they be improved?

1.4 Limitations

The following limitations apply for this thesis:

- There may be sources of error within the collected data samples, as the companies that chose to participate with data may mostly be the ones that have not experienced any severe incidents/accidents.
- Insufficient sample size. The UAV industry is relatively new, meaning that there have not been a sufficient number of incidents/accidents yet to be able to get accurate results from the analyses.
- A lack of previous research on the topic. This affected the identified risk reduction measures. There may be more measures than the ones that are identified in this thesis. Also, due to this lack of previous research, it was not possible to compare the results of this thesis to other thesis' results on the same topic.
- Time constraints that caused analyses to not be carried out sufficiently thorough. E.g., causes for the incidents/accidents could have been analysed more thorough than only human-, UAS- and external errors.
- Limited access to the collected data. The causes and consequences of the incidents/accidents described by the participating companies were not always clear, resulting in that some causes and consequences were assumed and estimated by the author of this thesis.
- Identification of Norwegian UAV incidents only. The analyses' results may have been different if international incidents were included. Note that analysing Norwegian UAV incidents only, ensures that all incidents have happened under one set of regulations.
- Excluded identification of UAV incidents experienced by non-serious operators (e.g., hobby operators). The analyses' results may have been different if such incidents were included.

1.5 Thesis structure

The thesis consists of 5 main chapters, in addition to the introduction, the bibliography and the appendices. These 5 main chapters are, and contain, the following:

Chapter 2 presents relevant literature and theory needed to carry out and understand the analyses of this research.

Chapter 3 describes the methodology that was used to conduct this research.

Chapter 4 presents the results of the research in form of analyses, tables and charts that were prepared from the identified and collected data.

Chapter 5 includes a discussion of the results presented in chapter 4 and the literature review, based on the research questions of the thesis.

Chapter 6 presents a conclusion of the thesis in addition to recommendations for future research on the topic.

2 Literature review and theoretical background

This chapter presents all relevant literature and theory used to carry out and understand the analyses in this research. The findings also contribute to the discussions of the results of the research. The chapter consists of four subchapters, where each of the subchapters focus on their own aspect of the thesis. The four subchapters address the potential of, and the rules and regulations related to UAVs, different aspects of safety, hazards and risk management including analysis methods.

2.1 Unmanned Aerial Vehicles: their potential uses and the rules and regulations

This subchapter addresses background theory and literature regarding unmanned aerial vehicles and their potential, in addition to a presentation of the rules and regulations concerning the use of these vehicles that are relevant for this thesis.

2.1.1 "Drones"

The term "drone" is often used to describe radio piloted aircraft vehicles. However, the term does not specify that the referred object is an aerial vehicle. A drone may be defined as a radio piloted unmanned vehicle or "any unmanned aircraft or ship that is guided remotely" (Dictionary, n.d.-c). Other, not as common, terms used to describe a radio piloted aircraft vehicle are UAS and UAV. The two latter terms are those that are mainly used in this thesis.

An Unmanned Aerial System (UAS) is defined by EASA as "An unmanned aircraft and the equipment to control it remotely" (European Union Aviation Safety Agency, 2021). An Unmanned Aerial Vehicle (UAV) on the other hand can be defined as an aircraft without any pilot onboard. This latter one is what is commonly known as a "drone" to most people. The difference between these two terms is therefore that UAS refers to the whole system containing the aircraft and the controllers on ground, while UAV only refers to the aircraft itself. These are the definitions that are used in this thesis.

UAVs have been used for decades. In the later years, the use of them has increased substantially, and they have become easily obtainable by the public. UAVs have the potential to perform operations that are currently done by man, with a higher productivity and a lower risk, in most sectors. The following list includes types of operations and sectors that UAVs currently assist in, including some that they have the potential to assist in (based on a journal article by Kardasz et al. (Kardasz et al., 2016)):

- package delivery
- inspections of infrastructure
- mapping
- freight of people
- search and rescue
- real estate
- agriculture
- filmmaking
- law enforcement.

2.1.2 UAV rules and regulations

This thesis concerns incidents and accidents related to the use of UAVs in Norway. To be able to understand why an incident has been reported (or noted internally by an operating company), it is important to know the rules and regulations that applied during the incident.

Norway had its own set of rules and regulations regarding the use of UAVs until 31.12.20, but from this date all countries in the EU and countries within the European Economic Area got a new set of rules and regulations made by the European Union Aviation Safety Agency (EASA) (European Union Aviation Safety Agency, n.d.-b). The following rules and regulations are the general ones that are relevant for this thesis and that apply for most operators of UAVs (some companies operate UAVs without operating under the following rules, however they have other rules and regulations they must follow. Those rules and regulations are unknown to the publicity and are therefore not accounted for in this thesis). The rules and regulations for the most part overlap from the previous set of rules and regulations to the new set. The rules and regulations are (retrieved from NCAA, (CAA Norway, n.d.)):

- The UAV must be at least 5 kilometres away from airports.
- The UAV must be at least 30 metres away from third person.
- The UAV must be at least 150 metres away from third party houses, residential areas and industry areas.
- No flying over crowds of people (third person).

- No flying near/over/within the following areas: restricted airspace, some nature conservation areas, embassies, prisons and military- areas and vessels.
- The UAV must be at a maximum of 400 feet from ground level.
- The operator or observer must have Visual Line Of Sight (VLOS) to the UAV at all times.
- The UAS must have a system (failsafe) that ensures that the UAV can land autonomously, should a loss of control/link happen (This was only a regulation until 31.12.20, meaning it was only applicable with the old set of rules and regulations).

Scenarios where one or more of these regulations have been exceeded may be noted internally by the operating company. Should the scenario have exceeded any of the demands for when to report a scenario to the NCAA (see subchapter 1.1, paragraph 3, for the demands), they are obligated to be reported.

With the new set of rules and regulations, that apply in all countries in the EU and countries within the European Economic Area, it is possible to exceed the general rules and regulations if the company that does so have implemented enough risk reduction measures (made their own rules and regulations) and has the operation plan approved by the given country's Civil Aviation Authority (Luftfartstilsynet, n.d.-e). Such risk reduction measures may include one or several of the following (examples from NCAA (Luftfartstilsynet, 2020)):

- Equipping the UAV with a parachute.
- Have a system (failsafe) that ensures that the UAV can land autonomously, should a loss of control/link happen.
- Only operate the UAV over sparsely populated areas.
- Operate with a UAV that has low impact energy (e.g., a low weight UAV).

With the new set of rules and regulations, that apply in all countries in the EU and countries within the European Economic Area, there are also demands to register as a UAV operator, pay the yearly operator fee in addition to completing a course in UAV rules and regulations and passing a written exam (Luftfartstilsynet, n.d.-f). To operate in higher risk categories there are demands for passing one more written exam (Luftfartstilsynet, n.d.-f).

2.2 A concern for safety

This subchapter addresses theory and literature regarding safety in general, in addition to how safety is taken care of in the aviation industry with a special focus on reporting of incidents and accidents in both the manned- and unmanned aviation industry.

2.2.1 A need to focus on safety

There are numerous definitions of safety. They differ in wording, but they often have a common denominator that they define safety as a condition where nothing, or few acceptable scenarios, goes wrong. The international Civil Aviation Organization (ICAO) defines safety as "the state of which the possibility of harm to persons or property damage is reduced to, and maintained at or below, an acceptable level through a continuing process of hazard identification and risk management" (Chacin, 2014). With this understanding of safety, there are both positive and negative sides of working towards increasing safety.

"We cannot deny there are some expenses (and some risks) in implementing a Safety Management System. Most of these costs and risks, however, are more than off-set by the good that comes from a Safety management System" (Rochester Institute of Technology, n.d.). By focusing on safety in a company, and implementing a safety management system (SMS), it is possible to achieve, amongst other factors, according to Yoon et al. (Yoon et al., 2013), Jazayeri and Dadi (Jazayeri & Dadi, 2017) and Rochester Institute of Technology (RIT) (Rochester Institute of Technology, n.d.), one or more of the following:

- increased productivity
- improved safety consciousness of workers
- improved work culture
- assist in assuring that operations are done legally
- improved company image
- improved public image and reputation
- lower insurance costs
- reduced management costs
- prevention of accidents.

As stated by RIT, implementing safety management systems comes with cons in addition to the pros (Rochester Institute of Technology, n.d.). By implementing such a system to a company, the company may also, according to RIT (Rochester Institute of Technology, n.d.), be introduced to, amongst others, the following negative factors:

- high costs of implementation of a SMS
- time-consuming.

High expenses can be a factor both when having a safety management system and when not having one. It can be costly to implement and run a safety management system, and at the same time it can be costly to not have a SMS because it may be likely that incidents and accidents happen more frequent and cost more to deal with (Bottani et al., 2009). Figure 2-1 shows a relationship between the cost of accidents/incidents and the cost of a SMS.

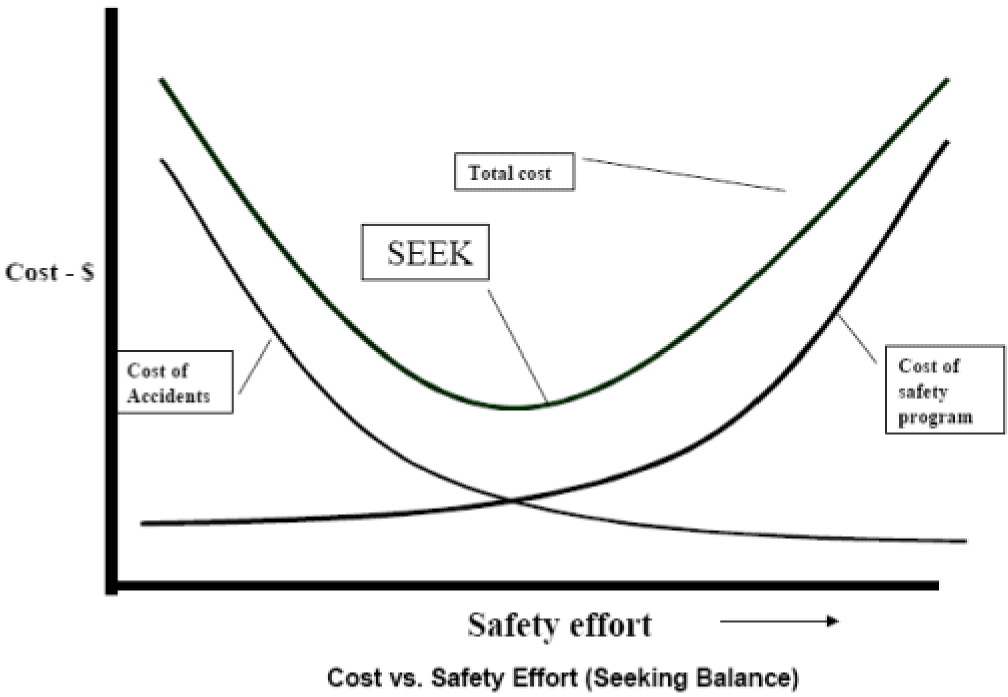

Figure 2-1 The connection between cost and safety effort retrieved from (Bates et al., 2011).

Figure 2-1 shows that implementing a SMS without any concern for expenses may not be worth it (concerning cost as the only factor), and that finding a "golden mean" (around the "SEEK" point on Figure 2-1) may be the most optimal way to go to meet positive sides of a SMS and at the same time a fewer number of the negative ones.

2.2.2 Incident- and accident reporting

Incident reporting is technique that amplifies awareness about operations that can go wrong, so that preventive and corrective measures can be taken (Mahajan, 2010). It is a process of reporting and managing. Reporting of incidents is often referred to as a "reporting culture" if one can report without any fear of blame, and a "just culture" if one can report without any fear of blame if the incident/accident was unintentional. This latter one is the culture type it is aimed to have in the manned aviation industry and was the recommended culture type by James Reason in 2000 (Reason, 2000). Reporting in this thesis concerns both reporting of incidents and reporting of accidents.

The definition of an incident related to unmanned aircrafts that is used in this thesis, is the definition by the European Union Aviation Safety Agency (EASA) that has defined this as "an occurrence, other than an accident, associated with the operation of an aircraft which affects or could affect the safety of operation" (EASA, 2021). In other words, an incident is a scenario that deviates from the original plan of an operation.

The definition of an accident related to unmanned aircrafts that is used in this thesis, is the definition by the National Transportation Safety Board (NTSB) that has defined this as "An occurrence associated with the operation of any public or civil unmanned aircraft system that takes place between the time that the system is activated with the purpose of flight and the time that the system is deactivated at the conclusion of its mission, in which: (1) Any person suffers death or serious injury" (Federal Aviation Administration, n.d., p. 830). In this thesis, this definition of an accident is extended to also include occurrences where there were any outcomes that included any form of damage. That includes damage to equipment or third-party belongings.

Incidents and accidents "… provide an untapped source of data" stated by the US Coast Guard according to Johnson (Johnson, 2003). The Transportation Safety Board of Canada has identified a number of reasons for why reporting should be done, whereas some of them are that these reports can, based on findings by Johnson (Johnson, 2003),

- "Help to find out why accidents don't occur"
- "Provide a reminder of hazards"
- "Data can be shared"
- "… reporting schemes are cheaper than the cost of an accident".

A limitation to incident reporting is that it can be time consuming and "both expensive to set up and to maintain" (Johnson, 2003). In addition, a study based on data from 384 aviation employees conducted by Under and Gerede in 2021, it was found that "employees did not participate in voluntary reporting due to factors of silence based on relational and prosocial factors, disengagement, quiescence and acquiescence, along with fear and defensiveness" (Under & Gerede, 2021). These stated factors may indicate that reporting of incidents and accidents may be negative when a proper reporting culture is not present.

EASA, which works with rules and regulations regarding both unmanned and manned aircrafts, has stated that one of their main roles is to "… be aware of safety deficiencies and disseminate related information for establishing corrective actions" (European Union Aviation Safety Agency, n.d.-a). Both this statement by EASA and the statements about reporting collected from Johnson's report from 2003 may indicate that incident reporting is important for safety.

2.2.3 Incident reporting in the manned aviation industry

The definition of manned aviation according to online dictionaries is aircrafts that are "… operated by direct physical contact from a human or humans" (Law Insider, n.d.-c).

According to the NCAA, all aviation incidents and accidents must be reported to the NCAA. If the incidents and accidents are of serious extent, they should also be reported to the AIBN (Luftfartstilsynet, n.d.-b). "According to the reporting ordinance, persons in aviation are obligated to report aviation incidents that may constitute a significant risk to aviation safety" (Luftfartstilsynet, n.d.-b). This applies for countries in Europe. All reports are, according to the NCAA, used for analyses and measures to improve safety (Luftfartstilsynet, n.d.-b).

A focus point of incident reporting in the manned aviation industry concerns the "just culture". A "just culture" highlights the importance of learning from each other instead of apportioning blame. "A just culture is meant to balance learning from incidents with accountability for their consequences" (Dekker, 2009). The "just culture" is there for everyone to learn from each other without being punished, but where negligence, intentional violations and destructive actions are not tolerated. By having this "just culture", an organization accepts that making errors is a part of being a human and that no one should be punished for these errors, but rather let others learn from them to prevent future similar incidents.

According to the NCAA they received 148 incident reports in 2006, and 7424 reports in 2017 (Luftfartstilsynet, n.d.-a). This increase in reporting may, stated by the NCAA, be due to easier ways of reporting, an improved reporting culture or clearer demands for what should be reported (Luftfartstilsynet, n.d.-a).

2.2.4 Incident reporting in the unmanned aviation industry

Unlike manned aviation, unmanned aviation may be defined as aircrafts that are operated without any direct influences from humans from within the aircraft.

In 2016, Norway got a reporting obligation regarding UAV incidents. Paragraph 3 in "Regulations on the duty to report and notify in the event of aviation accidents and aviation incidents" states that all UAV related incidents where someone died or were serious injured, or if the incident could have resulted in this, are mandatory to report (Samferdselsdepartementet, 2020). In addition, all scenarios with close passage between unmanned- and manned aircraft must also be reported.

The NCAA does not have an overview of all other incidents and accidents that UAV operators experience, according to Eirik Svare in NCAA (Martinsen, 2017). 'Other' referring to incidents other than those that are obligated to report. Svare also stated in an interview in 2017 that "we also have no ambitions to get an overview of such. Those who operate drones are responsible for ensuring safety when flying" (Martinsen, 2017).

The NCAA believes that there exist dark figures regarding incident reporting in the unmanned aviation industry, according to an oral conversation between the NCAA and the author of this thesis (02.12.21). The NCAA also stated in the same conversation that most of the incidents that are reported are not analysed further in any way.

2.3 Hazards and unwanted events

This subchapter addresses definitions and elaborations on hazards and unwanted events. This includes what they are, which potential causes to them that are identified in this thesis, potential outcomes of them, and what can be done to reduce the frequency of them happening and the outcome should they happen.

2.3.1 Hazard vs. unwanted event

"A hazard is any source of potential damage, harm or adverse health effects on something or someone" (Government of Canada, Canadian Centre for Occupational Health and Safety, 2022). Examples of hazards related to UAV operations can be wind, battery, fog, precipitation and telemetry. These are factors that have the potential to cause harm, but not without further ado.

“An unwanted event is a situation or condition where there is a loss of control of the hazard that leads to harm” (Government of Western Australia, n.d.). Or “The first event in a sequence of events that, if not controlled, will lead to undesired consequences (harm) to some assets” (Rausand & Haugen, n.d.-a). Examples of unwanted events related to UAV operations can be ice accumulation on UAV, fatigue, low temperatures, disruption of operator’s vision, helicopter traffic in operation area and loss of telemetry. Unwanted events are relative to the system that is analysed.

While hazards are anything that can cause harm, unwanted events are scenarios where a hazard is no longer under control for a given system. However, a hazard can also be an unwanted event. E.g., strong wind can for some systems be an unwanted event, but for other systems it can be a hazard and at the same time not necessarily an unwanted event (if the system can withstand the given wind strength).

The analyses concerning hazards (for instance, HAZID (hazard identification) and preliminary risk assessment) in this thesis, concerns unwanted events and not hazards, based on the definitions of those addressed in this subchapter.

2.3.2 Potential causes

The following subchapters address the potential causes of unwanted events that are analysed in this thesis. All causes are categorized into the following 3 causes: human-, UAS and external error.

2.3.2.1 Human error

There exist a number of definitions of a human error. However, most of them have the common denominator that human error concerns “an action or decision which was not intended” (HSE, n.d.).

NASA defined human error in a report from 2020 as: “Either an not intended or desired by a human or a failure on the part of the human to perform a prescribed action within specified limits of accuracy, sequence, or time that fails to produce the expected result and has led or has the potential to lead to an unwanted consequence” (Null et al., 2019). This is the definition that is used in this thesis.

2.3.2.2 UAS error

Unmanned Aircraft System error are all errors (error is defined in the dictionary as a "deviation from accuracy or correctness" (Dictionary, n.d.-b)) that are related to the UAV and its coherent equipment. This involves errors related to both software and hardware. Examples of UAS errors can be

- GPS error
- battery error
- telemetry error
- motor error
- landing gear error.

2.3.2.3 External error

From the dictionary, external is defined as an adjective describing something that is "of or relating to the outside or outer part" (Dictionary, n.d.-a). Error is defined as "a deviation from accuracy or correctness" (Dictionary, n.d.-b), as stated in the previous subchapter.

Based on the two definitions of external and error, external error can be viewed as a deviation from expectations due to an outside, extraneous part. In other words, an error that is due to something or someone that is not directly associated with the given operation. Examples of this kind of error related to UAV operations can be

- third person enters the operation area
- manned aircraft traffic enters the operation area
- animals enter the operation area
- all weather-related phenomena.

2.3.3 Potential consequences

Through hazard identifications and when analysing the collected qualitative data, the potential consequences and the actual consequences were made quantitative. The consequences were ranked according to Table 2-1 (the consequence table), which was made specifically for this thesis. Based on the severity of a consequence, the higher the rank it gets assigned in a consequence table. With each hazard or unwanted event, there exist multiple areas of consequences. Common ones, according to Summer et al. (Summers et al., 2012) and the

University of Bergen (University of Bergen, 2021), are environmental-, man-, reputation-, operation- and economic consequences.

The range of the severity of consequence in the consequence table varies, but often ranges from 1-5 (or A-E), 1-10, or anything in between, where the highest number represents the most severe outcome.

The ranking of a consequence in this thesis is based on the findings of Summers et al. (Summers et al., 2012), Cox Jr. (Anthony (Tony) Cox Jr, 2008) and those implemented by the University of Bergen (University of Bergen, 2021), and include five different variables. These variables are man, environment, economical, operation and reputation.

The man category in the consequence table addresses any possible consequence to people. This includes absence from work and any form of injuries (from the least severe injury to death). To be able to categorize and rank a loss of life correctly in the consequence table, it is crucial to realise that a life has an economical cost in the eyes of risk management. In 2021, Keller et al. identified 1455 studies to find an estimated value of a statistical life (VSL). They found that the VSL varied by work sector, countries and other factors, but had a median of $5.7 million (Keller et al., 2021).

The environmental category in the consequence table addresses any possible consequence to the environment. This includes the level of damage and the recovery time of the impact. Examples of damages to the environment can be oil spill, forest fires and contamination of lakes.

The economical category in the consequence table addresses any possible economic consequence. This means any type of economic loss due to an unwanted event. This includes damages to personnel, own property (UAS, cars etc.), third person property, environment, other people, rebuilding reputation and more. For high-risk operations as those concerning UAVs, the level of economic loss may range from $0 to several million $.

The operation category in the consequence table addresses any possible consequences to the operation. This includes any delay or stoppage of the operation.

The reputation category in the consequence table addresses any possible consequences regarding the reputation of the company that was involved. This relates to if the reputation of the company was weakened in any way due to the unwanted event. Maintaining a good reputation is critical for any company as it may result in economic loss, and is therefore an important variable of a consequence table. "… reputation is perhaps the most important single asset the company has" (Murray & White, 2005).

Table 2-1 The consequence categories used in this thesis.

Severity of consequence

Consequence	Man	Environment	Operation	Reputation	Economical	Grading
Minimal	* No absence * Non-critical first aid	* Insignificant damage * Short recovery time	* Insignificant damage to building or machinery * Activity stop for less than one day	* Insignificant negative attention * No impact on credibility and respect * No impact on funding sources	<$1.000	1
Minor	* Shorter absence * Need for medical treatment	* Minor damage * Relatively short recovery time	* Minor local damage to a building or machinery that can be repaired in a short amount of time. *Activity stop for less than one week	Negative attention that is limited to units / activities and can lead to the following: * Influence on credibility and respect * Weakened local cooperation * Some reduction in recruitment	$1.000-10.000	2
Moderat	* Absence for up to a month * Medical treatment	* Moderat damage * Relatively long recovery time	* Loss of or damage to parts of building mass or important machines * Activity stop for less than one month	Significant negative attention that concerns faculty / departments and can lead to the following: * Weakened credibility and respect * Weakened regional cooperation * Weakened recruitment of employees. * Reduction in financing	$10.000-50.000	3
Major	* Absence for up to 1 year * Persistent health problems	* Major damage * Long recovery time	* Loss of or damage to parts of the building mass or important machines * Activity stop for between one month and one year	National negative attention that can lead to the following: * Weakened credibility and respect * Weakened national cooperation * Difficult to recruit employees * Significant reduction in financing	$50.000-500.000	4
Critical	* 50-100% incapacitated for work * Loss of life	* Critical damage * Very long lasting or non-reversible damage	* Loss of or serious damage to critical parts of the building / operating unit * Activity stop for more than one year	National and international negative attention that may lead to the following: * Significant loss of credibility and respect * Weakened national and international cooperation * Significant reduction in financing	>$500.000	5

2.3.4 Risk reduction measures

Beullac et al. defined a risk reduction measure in 2016 as "… a technical and/or organizational element, necessary and sufficient to ensure a safety function. Safety functions are functions whose objectives are to reduce the probability and/or the consequence of undesirable events" (Beullac et al., 2016). These are measures that can be implemented to reduce the risk of a hazard. As stated by Beallac et al., the measures can either focus on reducing the frequency of an unwanted event happening or the consequence should it happen. This, frequency and severity of consequence (often multiplied with each other), is also a commonly taught definition of risk (Cox, 2009). This again resulting in that risk reduction measures concerns both reducing frequency and severity of consequence.

Risk reduction measures are often identified and implemented if the risk of an operation is intolerable and needs to be lowered before the given operation can be carried out. When coming up with these measures and implementing them, they should follow the ALARP-principle. The principle is widely known in the industry of risk management and means that a risk should only be reduced to "as low as reasonably possibly". Meaning that this "involves weighing a risk against the trouble, time and money needed to control it" (Health and Safety Executive, n.d.). In other words, risk reduction measures should be realistic.

2.3.4.1 Frequency reduction measures

Frequency reducing measures focus on reducing the frequency of an unwanted event from happening. Examples of frequency reducing measures related to UAV operations can be

- regular UAV service and check-ups
- to use ice prevention equipment
- to read weather forecasts before operations
- to equip the UAV with cladding so that it can withstand precipitation
- having a competent UAV operator.

2.3.4.2 Consequence reduction measures

Consequence reducing measures focus on reducing the severity of consequence should an unwanted event happen. Examples of consequence reducing measures related to UAV operations may be

- to equip the UAV with a parachute
- to have the UAV programmed with fail-safes (e.g., algorithms that enables makes the UAV automatically return to home and land)
- to clear the operation area of people.

2.4 Risk management and analysis methods

This subchapter includes theory and literature related to the risk management process and the analysis methods that are used in this thesis.

2.4.1 Risk management

Risk management concerns the whole process of managing risk, and mainly involves the following four steps:

- identifying hazards
- assessing and analysing the hazards
- treat and control the hazards

- monitor the hazards.

These steps are the ones from IRGC 2005:44, but with steps 3 and 4 merged into step 3 here (Aven & Renn, 2010). The first step, identifying hazards, involves identifying hazards and finding potential causes for the hazards to happen. The second step involves analysing the hazards to find potential outcomes/consequences and a ranking of the hazards to get an understanding of which hazards that should be prioritised to implement risk reduction measures for. The third step addresses treating the hazards, meaning identifying and implementing risk reduction measures. The fourth and last step involves monitoring the hazards, or monitoring the implemented risk reduction measures, to determine if the hazard is controlled with the current measures or not. These steps, and risk management in general, are a cyclic process and should be carried out continuously. Figure 2-2, from the international organization for standardization (ISO), shows this process as described above.

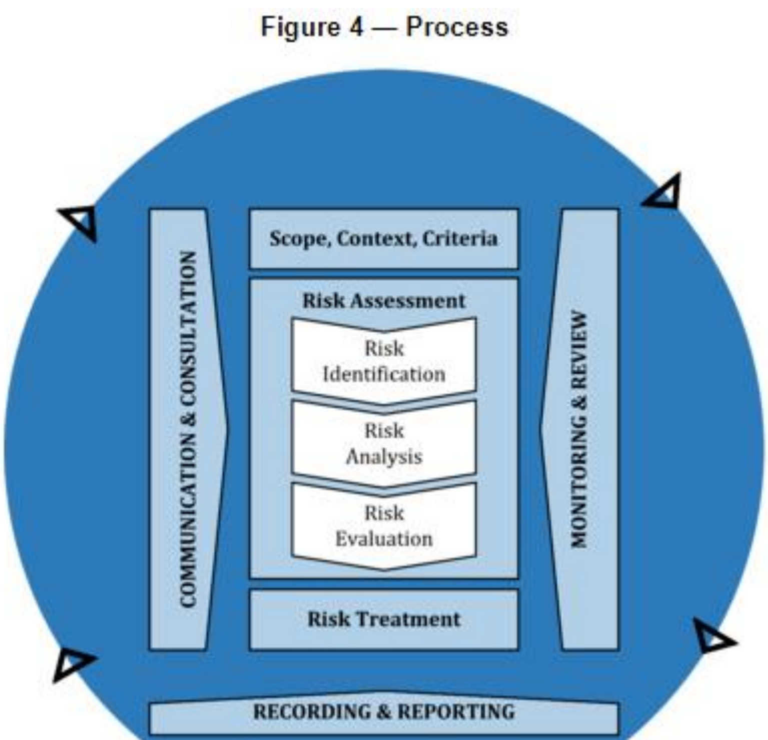

Figure 2-2 The process of risk management, adopted from (ISO/TC 262, 2018)

The next four subchapters address the risk analysis methods that are used in this thesis, which are all a part of the risk management process of the thesis. The ordering of them follows the order of a risk management process (the PRA is placed as the third subchapter, but could also be the first and second. See subchapter 2.4.4). The control stage is excluded, because the risk reducing measures that are identified later in this thesis have not been put into action. Therefore, it is not possible to control the measures.

2.4.2 Fault tree analysis

A fault tree analysis (FTA) analyses the possible events leading up to the initiating (top) accidental event (the hazard) (Lundteigen & Rausand, n.d.). The FTA uses a top-down approach, consisting of (normally) multiple events that can cause the initiating event. These events relate to gates of Boolean logic, either an OR-gate or an AND-gate, meaning that an event can happen either if <u>one</u> of the sub-events happen (OR-gate) or if <u>all</u> the sub-events happen (AND-gate). Figure 2-3 shows how some types of events and types of gates can look in an FTA.

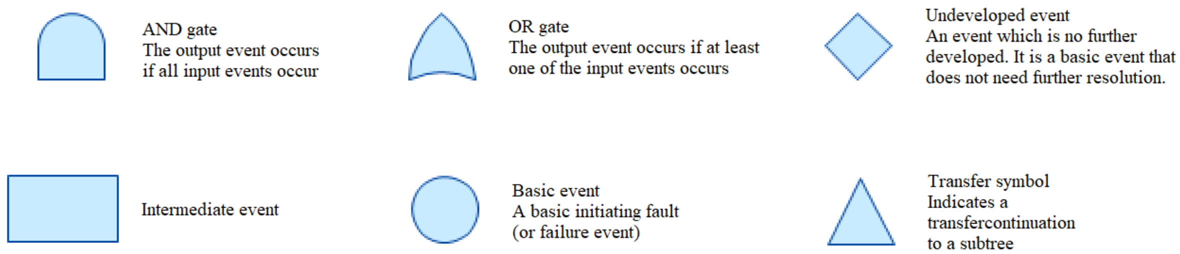

Figure 2-3 The types of events and types of gates in an FTA, adapted from (ConceptDraw, n.d.).

The idea of the FTA is to be able to identify any possible basic event that can cause a system to fail. Sometimes there are also multiple basic events that together are needed to trigger the top event. Both single basic events and multiple basic events together can lead to the occurrence of the top event. These events are known as cut sets. Should a given set of events be the minimal number of events that can still cause the top event to occur, they are known as minimal cut sets (MCS). In an FTA where the desired outcome is to find these cut sets, the FTA is a qualitative analysis. Should the probabilities for the minimal cut sets be calculated, which again can be used to calculate the probability of the top event occurring, then the FTA can be viewed as a quantitative analysis (Xing & Amari, 2008).

Figure 2-4 shows a simple example of an FTA, where it is attempted to find the basic events of why there is no light in the room.

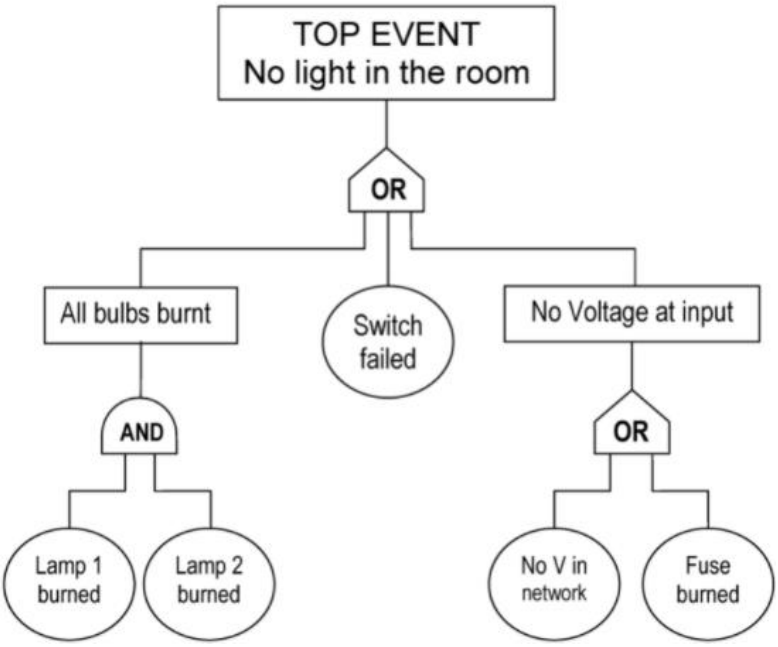

Figure 2-4 Example of a fault tree analysis adopted from (Menčík, 2016).

Like most analysis methods, the fault tree analysis does have its disadvantages. Depending on the needs of the analyst, the cost of development can be high (Lee et al., 1985). According to Sohag Kabir (Kabir, 2017), there may be multiple reasons to this, thereby that the FTA method only analyses one given scenario at a time and that it is mostly a manual process. In addition, a limitation of the analysis method is due to the Boolean logic. The method doesn't account for if an event is degraded, only if the event is not working (Fussell, 1975).

Carrying out an FTA can be viewed as a part of the first step in a risk management process.

2.4.3 Event tree analysis

An event tree analysis (ETA), unlike the fault tree analysis, is a technique used to identify the possible outcomes of an initiating accidental event (hazard). The ETA is applicable for most scenarios of risk identification, and is often used to describe the "… logical connection between the potential successes and failures of defined safety systems or safety functions" (Čepin, 2011). In other words, the ETA can be used to identify and analyse the failure or success of safety functions (safety barriers) of a system. "Most well-designed systems have one or more barriers that are implemented to stop or reduce the consequences of potential accidental events" (Rausand, n.d.). Based on if these safety barriers of the initiating event fails or not, the outcome of the initiating event will differ.

In addition to identifying possible outcomes of an accidental event, and the failure or success of safety barriers, through carrying out an ETA, the frequency or probability of each outcome may also be calculated. "… The occurrence probability of a specific path can be obtained by multiplying the probabilities of all subsequent events existing in a path" (Hong et al., 2009). This way an ETA can assist in choosing which outcomes that are the most important to focus on implementing barriers for, which can save resources in the form of both time and money. Figure 2-5 shows what an ETA can look like, in addition to how the frequency calculations are done.

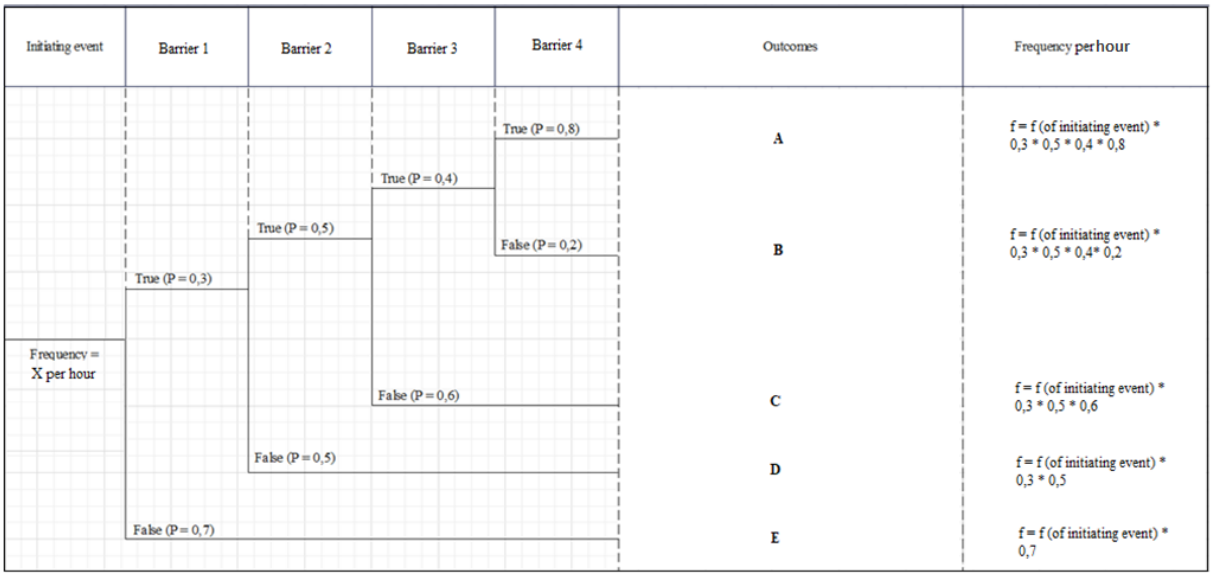

Figure 2-5 The outline of an event tree analysis.

Event tree analyses does have its flaws and limitations. As with the FTA, an ETA can be time consuming as the analysis method can only analyse one single initiating event per ETA that is carried out (Rausand, n.d.). With complex systems that contain a large number of hazards, carrying out ETAs for every single hazard can be time consuming, costly or even unrealistic.

Another flaw of the ETA method is an often lack of data for calculating correct/precise probabilities. As stated by Refaul Ferdous et al. in 2009, "The objective data available to estimate the *likelihood* is often missing (or sparse), and even if available, is subject to incompleteness (partial ignorance) and imprecision (vagueness)" (Ferdous et al., 2009).

Carrying out an ETA can be viewed as a part of the second step in a risk management process.

2.4.4 Preliminary risk assessment

A preliminary risk assessment, also known as a preliminary hazard assessment, is a combination of both a qualitative and a quantitative risk assessment and addresses a situation that involves hazards (Rausand & Haugen, n.d.-b). The name “preliminary” dictates that this assessment type should be carried out before performing an activity that contains a hazard. The assessment contains the following steps:

- Identifying unwanted events (hazards). HAZID.
- Analysing the hazards to find potential causes of them happening and potential outcomes should they happen.
- Estimate a frequency of how often the hazards happens and grade the potential outcomes.
- Calculate the risk index of the hazards.
- Come up with risk reduction measures. This can help to lower the chance of the unwanted events happening, and the consequence if they would happen.
- Re-calculate the risk index of the hazards.

The risk index is a multiplication between the frequency of the unwanted event happening and the severity of consequence should it happen. In this thesis, the risk index ranges from 1-25 where 25 is the highest and the most severe rank. In other words, both the grading of the frequency and the grading of the severity of consequence ranges from 1-5. A wider range of ranks allows for a clearer distinction between high-risk hazards. The risk index indicates if a hazard is acceptable or tolerable to work with, or if more risk reduction measures have to be implemented. To determine this, an acceptance level table is used. The ranking also helps to determine which unwanted events that should be prioritized to implement risk reduction measures for, if one has to choose between several unwanted events.

Tables Table 2-2, Table 2-3 and Table 2-4 show the frequency table, the risk matrix and the risk tolerability table used in this thesis. Table 2-4 shows if an unwanted event is acceptable or if risk reduction measures have to be implemented.

Table 2-2 The frequency table used for the PRA in this thesis.

Frequency		
Frequency	**Description**	**Value**
Very rare	Extremely unlikely. Expected 1 time per 1000 flights.	1
Rare	Very unlikely, but credible. Expected 1 time per 100 flights.	2
Probable	Less likely, but does happen. Expected 1 time per 10 flights.	3
Frequent	Expected to occur frequently. Expected up to 1 time per flight.	4
Continuous	Expected to occur almost continuously. Expected more than 1 time per flight.	5

Table 2-3 The risk matrix used for the PRA in this thesis, adapted from (Federal Aviation Administration, 2019).

Risk matrix							
Frequency	Very rare	5	5	10	15	20	25
	Rare	4	4	8	12	16	20
	Probable	3	3	6	9	12	15
	Frequent	2	2	4	6	8	10
	Continuous	1	1	2	3	4	5
			1	2	3	4	5
			Minimal	Minor	Moderate	Major	Critical
Severity of consequence							

Table 2-4 The risk tolerability table used for some analysis methods in this thesis.

Risk tolerability		
Tolerability level	**Risk index**	**Recommended measures**
Unacceptable	15, 16, 20, 25	Safety measures must be implemented before the operation takes place.
Tolerable	5, 6, 8, 9, 10, 12	Safety measures should be considered and the risk should be reduced to as low as reasonably practical (ALARP).
Acceptable	1, 2, 3, 4	The risk is acceptable, and no measures are required.

A PRA can be filled out by carrying out FTA, ETA and bow tie analyses in advance. From the FTA one finds potential causes of an unwanted event, the ETA gives the potential outcomes, and the bow tie analysis can be used to identify possible risk reduction measures to lower the risk index.

A flaw, and in some ways a strength, of the PRA is that it often addresses the worst-case outcomes of a hazard (Liovin, 2007). If there is even the tiniest probability of a human injury, or death, as an outcome of a hazard, the severity of consequence will be high. With high-risk operations there is often a possibility of human injuries or death as an outcome should something unintended happen. This can lead to a large number (often all of them) of the analysed hazards to have high ranked severity of consequences in the PRA, which again can make it difficult to choose which hazard to focus on implementing risk reduction measures for.

Carrying out a PRA can be viewed as a combination of the first, second and third step in a risk management process.

2.4.5 Bow tie analysis

While an FTA analyses the possible events leading up to an event and an ETA analyses the possible outcomes of an event, a bow tie analysis "… is an approach that integrates a fault tree (on the left side) and an event tree (on the right side) to represent causes, threat (hazards) and consequences in a common platform) (Shahriar et al., 2012). The bow tie analysis method is a form of risk assessment used to analyse potential hazards with the events leading up to a hazard and the consequences if the hazard should happen. In addition, and a major part, a bow tie analysis includes identification of safety barriers that can prevent the hazard from happening (preventive barriers) and barriers that can mitigate the consequences (recovery barriers). These barriers are located on the left and right side of the knot of the bow, respectively. By identifying, correcting and implementing new barriers, the analysed event should be less likely to occur and less harmful should it occur. "The main advantage of the Bowtie concept is that it provides a visual representation of risk, including not only each applicable element, but more importantly, the relationships between them" (Alizadeh & Moshashaei, 2015). Figure 2-6 shows these relationships and the outline of a bow-tie analysis.

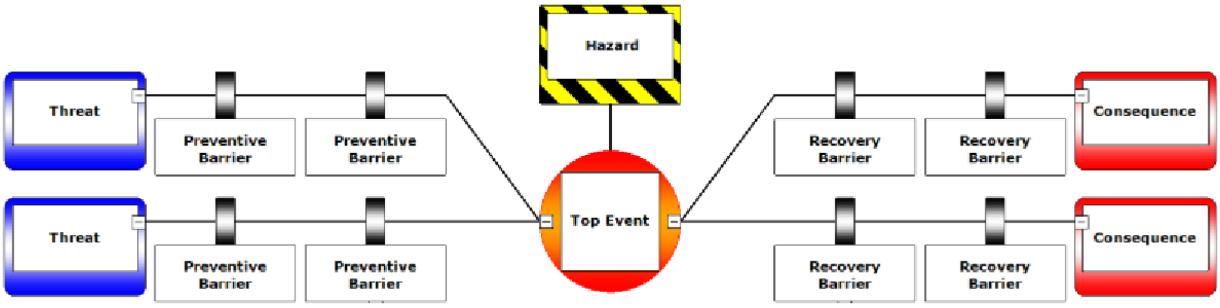

Figure 2-6 Outline of a bow tie analysis adapted from (cgerisk, n.d.)

The identified risk reduction measures (safety barriers) from the bow tie should follow the ALARP-principle, as described in subchapter 2.3.4.

Carrying out a bow tie analysis can be considered as a part of the third step in a risk management process.

2.4.6 Charts

"… The preparation of tables and graphs is a crucial tool in the analysis and production/publication of results, given that it organizes the collected information in a clear and summarized fashion" (Duquia et al., 2014). The use of charts is a data analysis method that is used to visualize data. There are different kinds of charts, where each of them is better suited for a given set of data than another. One of the more important factors of a chart is that they should be easy to understand. "… Every table or graph should be self-explanatory, i.e., should be understandable without the need to read the text that refers to it refers" (Duquia et al., 2014). The charts prepared to visualize data in this thesis are pie-, bar- and pareto charts.

3 Methodology

This chapter addresses the methodology that was used to conduct this thesis. This includes the following:

- an outline of the research approach
- the type of literature review that was conducted in this thesis
- how the data collection was done
- how the data was analysed
- which choices that were made towards choosing the respondent group for data collection
- how references were chosen
- reliability and validity
- the research process of the thesis.

3.1 Research approach

The research questions of the thesis are based on the objectives of the thesis, which again are chosen in order to attempt to achieve the aim of the thesis. To be able to carry out a research study that attempts to answer the research questions and fulfil the given objectives, choosing a research approach is essential. A research approach can be either inductive, deductive or abductive (or a combination), and can include either quantitative- or qualitative data, or both.

3.1.1 Deduction, induction and abduction

The deductive approach is a top-down approach that in short is based on studying theories, then analysing data, and at last either verify or falsify the theories based on the analysed data (Berthele, 2011). The deduction method is truth preserving, meaning that if a theory is verified by the analysed data, the theory is guaranteed to be true (Kennedy & Thornberg, 2017). See Figure 3-1 for the following example: if the rule is true, and the cause is true, then the effect is guaranteed to be true. E.g., if we know that when there is precipitation then UAVs fail (rule), and there is precipitation (cause), then one can deduce that UAVs fail (effect).

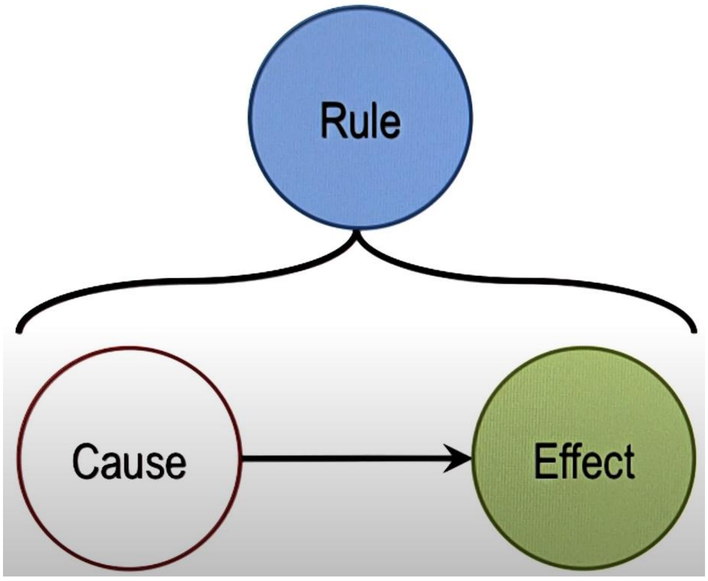

Figure 3-1 Understanding deduction, induction and abduction, adopted from (Udacity, 2015).

Induction is the bottom-up version of deduction, meaning the approach goes from collecting data to coming up with theories (Berthele, 2011). By using induction, a small, limited amount of data is collected, and a theory based on this sample is established. Again, using Figure 3-1 above, induction is: if observed repeatedly that precipitation (cause) causes UAVs to fail (effect), one can induce that when there is precipitation then UAVs will fail (rule). Using exclusively the induction method may not be common, as conducting research without using any earlier theory or research may be an uncommon phenomenon. However, "induction and deduction are thus valuable, often complementary, tools that facilitate problem solving" (Rothchild, 2006).

Abduction can be viewed as a combination of deduction and induction. As with induction, abduction also means going from data to theory, but by only using a small amount of data to come up with a logical reasoning (hypothesis) for why a phenomenon is the way it is (Kennedy & Thornberg, 2017). Using Figure 3-1: If we know that precipitation causes UAVs to fail (effect), and we see a failed UAV (effect), then we can argue (abduct) that the UAV failed due to precipitation.

During the period of working on this thesis, data was collected and analysed to attempt to find common denominators and theories, in addition to that, literature and background theory related to the topic also was read and used. For the data collection, which was a small sample, and analyses of this data, the inductive approach was used. When studying literature and background theory, the deductive method was used. However, given that there was not much earlier literature and studies done on the topic of the thesis, the induction method was used to a greater extent than the deduction method. In addition to using both the inductive and the deductive approaches, the abductive approach was also used. Through HAZID and PRA of unwanted events related to the use of UAVs, it was possible to find logical causes to why the outcomes (and triggers) of some given unwanted events could be as they were. Therefore, it may be argued that all of the three approaches (deduction, induction and abduction) were used to conduct this thesis. In 1994, Ho concluded in one of his articles that a combination of the three should be applied "in order to achieve a comprehensive inquiry" (Ho, 1994), which strengthens the choices of the used approaches for this thesis.

3.1.2 Quantitative- and qualitative data

There exist several types of data, but in research it is common to distinguish between two main categories of data: quantitative and qualitative (Ercikan & Roth, 2006). Quantitative data is data that is numerical or countable and is often used in research to compare or quantify a scenario. Quantitative data may, for instance, be collected with measuring instruments (thermometer, altimeter etc.). Qualitative data on the other hand is information that describes characteristics in the form of words (and not numbers), and is often gathered through interviews, observations or focus groups (Davis, 2012).

The research of this thesis, that concerns collecting written reports of incidents and accidents and analysing these data, can be said, based on the definitions in the paragraph above, to be addressing qualitative data. However, some of the qualitative data was later analysed in a quantitative way, by giving a score to the severity of consequence. In this way it was possible to calculate a risk index for the unwanted events, so that the data could be quantified, measured and compared. This again made it possible to see which unwanted events one should prioritize to implement risk reduction measures for (as described in subchapter 2.3.4).

3.2 Systematic literature review and theoretical background

When conducting a research and using the deductive approach, there exist multiple approaches one can choose between. This includes, amongst others, literature reviews and theoretical backgrounds (Kraus et al., 2020).

A literature review may be either systematic or "conventional", according to Okoli and Schabram (Okoli & Schabram, 2010). The conventional, most common, literature review (also known as a "theoretical background") is "the section of a journal article that gives the theoretical foundations and context of the research question, and helps to bring the research question into focus" (Okoli & Schabram, 2010). According to Okoli and Schabram, this kind of literature review "… serve as a section of primary research article that provides the theoretical foundation for the main study that is the subject of the article"(Okoli & Schabram, 2010). The systematic literature, however, is conducted using a "systematic, rigorous standard" where the purpose is to review literature in a field, without any primary data, according to Okoli and Schabram.

As stated earlier, there is a lack of published research on the subject that this thesis addresses. Therefore, based on the definitions of the two kinds of literature reviews addressed in the paragraph above, the type of literature review/theoretical background (chapter 2) in this thesis may be viewed as a conventional literature review (a theoretical background), and not a systematic literature review. Due to this lack of literature on the field of study, it was not possible to compare the results of this thesis to other thesis' results on the same topic. This is also stated as a limitation of the thesis.

3.3 Data collection

The data collected during this thesis is primary data. Unlike secondary data, which is collected by someone else for another primary purpose, primary data is data that has not been published before and is gathered specifically for a given research (Johnston, 2014). Several companies in Norway that operate with UAVs were contacted and asked for data regarding incidents and accidents concerning UAV operations. Only Norwegian companies were contacted in order to limit contacted companies to those who have flown by the same rules and regulations (and the same reporting culture) for all their operations. Collecting data from companies that have followed different rules and regulations may affect the results of the analyses.

The data sheets collected were of varying design, meaning they had to be read and understood by the author of this thesis. Through e-mails, the data that was asked for was the following:

For every incident/accident:

- date of the incident/accident
- the type of UAV
- the flight hours since last inspection/maintenance on the UAV
- the weather data during the operation
- a description of what happened
- the consequences
- the cause of the incident/accident.

Other data: The company's total number of flights and total flight hours.

The reasoning for the different data that was asked for:

- The date of the incident/accident was used to identify if the number of UAV incidents and accidents has gone down or up through the years.
- Information about the type of UAV was used to identify if some types of UAV's experienced incidents/accidents more often than others. This information was also used to classify the weights of the UAV's, to identify if some weight classes experienced incidents/accidents more often than others.
- Information about the flight hours since last inspection/maintenance on the UAV was used to identify if the incident/accident could have happened due to a lack of maintenance.
- Information about the weather data during operation was used to identify if the incident/accident could have happened due to bad weather or weather that exceeded the specifications of the used UAV.
- Information about the description of what happened was used to identify the possible cause of the incident/accident if the specific cause was unknown.
- Information about the consequences was used to identify the average consequential loss of a UAV incident/accident, in addition to allow one to calculate (estimate) a severity of consequence using the table in subchapter 2.3.3.
- Information about the cause of the incident/accident was used to identify and find potential common denominators of what causes UAV incidents and accidents.
- Information about the company's total number of flights and total flight hours was used to calculate the frequencies of how often incidents and accidents happen.

Table 3-1 shows an example of what was answered through e-mail.

Table 3-1 Example of collected data

Date of incident/accident	10.07.2020
Type of UAV	(Censored by author of the thesis, UAV weight class stated instead) Weight class: 2 (See the weight class table in appendix A, Table A 1)

<table>
<tr><td>Flight hours since last inspection/maintenance on the UAV</td><td>N/D</td></tr>
<tr><td>Weather data during operation</td><td>Weather data as seen below, however the UAV operator stated that the wind was not more than 5-7 m/s during the flight operation.
<table><tr><th>Nedbør (døgn)</th><th>Maksimumstemperatur (døgn)</th><th>Høyeste vindkast (døgn)</th><th>Høyeste middelvind (døgn)</th></tr><tr><td>-</td><td>13,4</td><td>17,1</td><td>13,3</td></tr></table></td></tr>
<tr><td>A description of what happened</td><td>Loss of all control which resulted in the UAV having a fly away and a crash with a mountain wall.</td></tr>
<tr><td>Consequences, if any</td><td>Loss of UAV.</td></tr>
<tr><td>Cause of the incident/accident</td><td>1. Fly-away probably due to incorrect loading of map data.
2. Lack of control due to software error. Abortion order was manually sent and registered in the autonomous flight software, but the software did not pass it through to the UAV.</td></tr>
<tr><td>The company’s total number of flights and total flight time</td><td>765 flight and 153 flight hours.</td></tr>
</table>

In the initial e-mail that was sent to the companies that were contacted for data during the data collection period of this thesis, it was not only asked for data, but the author of this thesis also offered to have meetings with the companies to explain the thesis and what the data would be used for. This was done in a hope of getting more companies to contribute with data, so that fewer of them were to reject the request of participating with data because they may not have understood the thesis objectives through the written e-mail.

During the period of data collecting (see subchapter 3.8, Table 3-5, for specific start- and end dates) there were sent multiple e-mails to the contacted companies, and multiple meetings were held. Note that a minimum of three e-mails were sent to each of the contacted companies, even the ones who did not answer the e-mails. This was done to urge the companies to respond.

Table 3-2 shows the amount of communication that was done between the author of this thesis and the contacted companies during the data collection period of this thesis:

Table 3-2 The amount of communication that was done to collect data.

Activity	**Amount**
E-mails sent by the author of this thesis	220
Online meetings held between the author of this thesis and contacted companies	10

To ensure that as many companies as possible were willing to participate and share their data, it was suggested that the companies could share the data they had without editing it in any way. It was also stated that all data would be censored for personal details. This was done to hopefully make more companies contribute with data, in addition to ensuring that no persons or companies were to receive blame or a bad reputation. The author of this thesis would then read, sort, censor, understand and analyse the shared data. This way, the amount of work for the companies would be minimal, in order to hopefully increase the probability for the companies to agree to share their data.

Figure 3-2 shows a flowchart of how the data collection and the data processing was done.

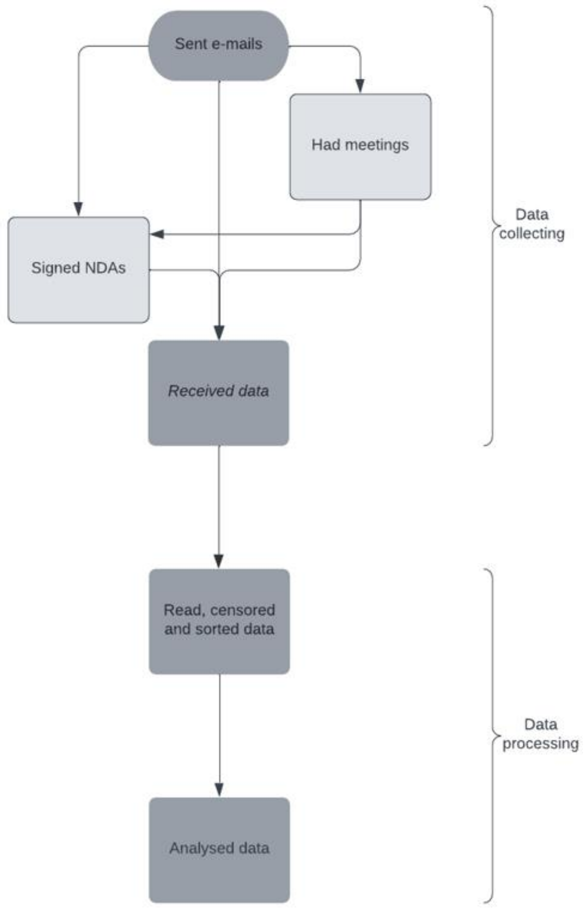

Figure 3-2 Flowchart for data collection and data processing.

By the end of the data collection period (see subchapter 3.8, Table 3-5, for specific start- and end dates), the statistics for the contacted companies were as following:

Table 3-3 Statistics about the contacted companies.

Total number of companies that were contacted:	39	
Number of contacted companies that contributed with data:	11	28 %
Number of contacted companies that did not contribute with data:	16	41 %
Number of contacted companies that did not respond:	12	31 %

Table 3-4 Statistics about the contacted companies that did not participate with data.

Out of those who did not share any data, the reasons were:		
1. They did not have any data to contribute with:	1	6,3 %
2. They did not want to share their data:	0	0,0 %
3. They were positive to the thesis, but did not have the capacity to contribute with data:	9	56,3 %
4. They were willing to contribute with data, but never did:	6	37,5 %

3.4 Data analyses

During a research process, after collecting data, analysing this data is an important next step where the aim often may be to systematically recap, illustrate, look for common denominators and evaluate data (RCR Northern Illinois University, n.d.). This section addresses which analysis methods that were applied for this thesis, why they were applied and how mathematical calculations were carried out.

Based on the objectives of this thesis, especially the ones addressing identification of causes and consequences of incidents and accidents in the UAV industry in addition to coming up with risk reduction measures to reduce the frequency and consequences of them happening, some of the collected data were analysed to a greater extent with the use of multiple risk analysis methods to identify different parts of the objectives with each analysis method. For instance, bow tie analysis was used to identify risk reduction measures. The data that was chosen to be identified to a greater extent was data that scored a high risk-index in the preliminary risk assessment, in addition to collected data that was repeated multiple times that also presented a high ranked potential severity of consequence. Before further analyses were carried out, the information in the documents that were collected was first sorted and organized in a Microsoft Excel-sheet. Further analyses of the sorted data were also carried out in Microsoft Excel. The following paragraphs clarify how the analysis methods were used and why these methods were chosen.

After the data was sorted in Microsoft Excel, several charts (pie-, bar- and pareto charts) were made to present different aspects of UAV related incidents and accidents. The charts were, for instance, used to identify which causes of incidents and accidents had the highest frequency to be able to elaborate risk reduction measures where most needed. The types of charts were chosen based on the ease of understanding. The charts can be seen in chapter 4.

Regarding the data that were collected during this project, the causes and possible consequences were already known (for most of the cases). Some of this data was therefore directly analysed with a bow tie analysis to identify risk reduction measures, without being analysed with other methods before the bow tie. See subchapter 2.4.5 for how to carry out a bow tie analysis. The resulting bow tie analyses can be seen in chapter 4 (Figure 4-18 and Figure 4-22).

It was assumed that the collected data about UAV related incidents and accidents did not contain every possible scenario regarding what could go wrong during a UAV operation. Therefore, a preliminary risk assessment was in this thesis carried out to identify and rank unwanted events related to UAV operations (that was not included in the collected data), to identify the unwanted events of largest concern, in order to implement or correct presently used risk reduction measures.

To be able to rank hazards in a preliminary risk assessment (a PRA), a table of how to rank the severity of different consequences was prepared. See subchapter 2.3.3 (Table 2-1) for how the table looks for this thesis. The frequencies in the PRA were estimated from the collected data from the contacted companies, in addition to estimations from expert opinions. See the equation below (equation 1) for how the calculation of risk index in the PRA was carried out:

$$Risk\ index = \ Frequency * Severity\ of\ consequence \qquad (1)$$

By using a preliminary risk assessment to rank hazards, in combination with FTA, ETA and bow tie analysis to analyse and find risk reduction measures, it is possible to save time and cost by focusing on the most critical hazards. A PRA "helps to ensure that the system is safe" (Rausand & Haugen, n.d.-b). See subchapter 2.4.4 for how to carry out a preliminary risk assessment. The resulting PRA table can be seen in appendix B.

Fault tree analyses were in this thesis used to identify possible causes for the identified incidents and accidents. For these kinds of scenarios, fault tree analyses can be a valuable and efficient tool. The analysed scenarios were not very complicated, therefore especially in these kinds of scenarios, but also others, "fault trees provide an objective basis for analysing failure modes" (Lee et al., 1985) and they also represent "… an effective visualization tool for management as well as engineering" (Lee et al., 1985). See subchapter 2.4.2 for how to carry out a fault tree analysis. The filled-in fault tree analyses can be seen in chapter 4 (subchapters 4.12.1 and 4.13.1).

To calculate the probability of the top-event happening in the FTA, the following equation was applied (equation 2):

$$P\ (Top\ event) = 1 - (1 - MCS_1) * \ldots * (1 - MCS_n) \qquad (2)$$

, where MCS is an abbreviation for Minimal Cut Set minimal cut set, and those ranging from i=1 to i=n where n is the number of minimal cut sets.

To identify possible outcomes of the incident data that was collected from the contacted companies, event tree analyses were used in this thesis. For identifying possible outcomes, meaning using ETAs in a qualitative approach, this analysis method can "be a good basis for evaluating the need for new / improved procedures and safety functions" (Rausand, n.d.). See subchapter 2.4.3 for how to carry out an event tree analysis. The filled-in event tree analyses can be seen in chapter 4 (Figure 4-17 and Figure 4-21).

To calculate the frequencies of the outcomes of the ETA, the following equation was applied (equation 3) (see also subchapter 2.4.3, Figure 2-5, for an example of how the calculations are carried out):

$$f\ (of\ a\ given\ outcome) = f\ (of\ the\ initiating\ event) * P\ (of\ barrier\ 1\ failing\ or\ not) * \ldots * P(of\ barrier\ n\ failing\ or\ not) \qquad (3)$$

3.5 Respondent group

The group of respondents who contributed with data towards this thesis were chosen based on the list of The Norwegian Civil Aviation Authority of approved high risk UAV operators (Luftfartstilsynet, n.d.-c). In this setting, "high risk UAV operators" refers to those operators that have applied for operating in the "specific" UAV category (European Union Aviation Safety Agency, n.d.-c). In addition, some companies that had an approvement of operating in the RO3 category (the highest risk category of the UAV rules and regulations, as applicable until 01.01.2021) were also contacted. The choice of contacting only operators within these two categories was done due to a desire of excluding operators who fly as a hobby (or non-professionally) who may not be experienced UAV operators nor know the applicable rules and regulations.

The respondent group consists of companies that only do UAV related operations (referred to as "drone companies"), in addition to companies that do UAV related operations as a smaller part of their other main work (referred to as "other companies"). This choice was made due to being able to identify possible differences in causes and consequences of UAV incidents between the two types of companies, in addition to a mindset of "the more the merrier" when collecting data. By including both types of companies, the ones that only do UAV related operations, and the ones that operate UAVs as a smaller part of their main work, the analyses consist of both serious, well-experienced UAV operators in addition to less experienced UAV operators. By excluding one or the other can affect the analyses results in this thesis by making the results looking unrealistically good or bad (few or many incidents/accidents respectively).

3.6 Critique of references

There are certain types of sources that are not used as references in this thesis, and certain types that are. The reasoning for this is to assure a high level of credibility of the citations, and to ensure that cited literature represents reinforcements of statements in the thesis. In general, any source that is used for a quote or a reinforcement of a statement in this thesis is a source in the form of a published scientific article in reputable books, journals or web pages with at least one citation. In addition, a reliable source was also chosen to be articles published by reputable authors, but that was not published (or available) in a published book or on a reputable web page. For inspiration for figures or copied figures used for illustrations the sources are more random.

Examples of sources that are used for quotes or reinforcement of statements are published (and cited) papers on the web pages ResearchGate and ScienceDirect. Examples of sources that were not used while conducting this thesis were web pages that are open for anyone to edit, e.g., Wikipedia.

3.7 Reliability and validity

Will similar studies give the same results as this in thesis, and do the methods in this thesis measure what they were supposed to? Are the measures in this thesis reliable and valid?

According to Sandberg, Joppe defines reliability as "… if the results of a study can be reproduced under a similar methodology" (Sandberg, 2016). If the results of a thesis are reliable, then another researcher should be able to achieve the same results himself given he uses the same method.

Whereas reliability addresses if the results are reliable and can be reproduced, validity addresses if these results are valid and correct. According to Sandberg, Joppe states that validity "determines whether the research truly measures what it was intended to measure… In other words, does the research instrument allow you to hit "the bull's eye" of your research object?" (Sandberg, 2016). This metaphor of the bull's eye is something also Neuman (Neuman, 2000) addresses. Figure 3-3, adapted from (Neuman, 2000), shows a visualized understanding of reliability and validity.

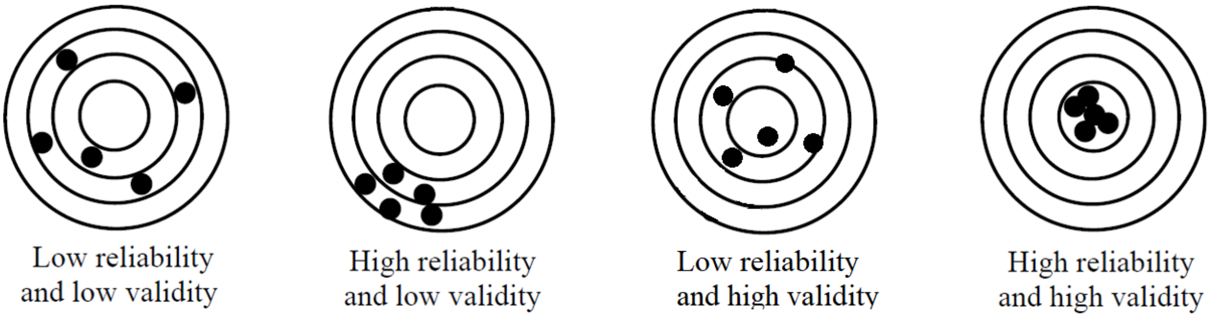

Figure 3-3 The differences and relationship between reliability and validity, adapted from (Neuman, 2000).

To ensure reliability of this research, the method used for data collection is described clearly. All of the data that was asked for are listed in subchapter 3.3, and another researcher should be able to ask for the same data and achieve the same results as in this thesis. This increases the reliability of the research method. However, given that some of the provided data was open to interpretation because of a lack of details from the provider, this opens for some lack of reliability.

Due to absence of existing research and literature related to the subject of this thesis, it is not possible to compare the results of this research to see if they correspond with other research's findings. Thus, such a comparison cannot be used to increase the validity of this research. However, the data used in this thesis is collected from reliable and professional companies and organizations. The amount of data collected for this research is also significant. These factors increase the validity of the research.

3.8 Research process

With a limited amount of time to carry out this research, productivity was key. To ensure a high level of productivity through the execution of this thesis, the PDSA (Plan-Do-Study and Act) method was exploited. According to Faiesal and Rasib (Faiesal & Rasib, 2018), a number of studies have been carried out and these strengthen the statement that implementation of the PDSA method will ensure a better productivity. In the light of the PDSA method, and with inspiration from Barabady (Barabady, 2005), the following figure (Figure 3-4) shows the research process of this thesis.

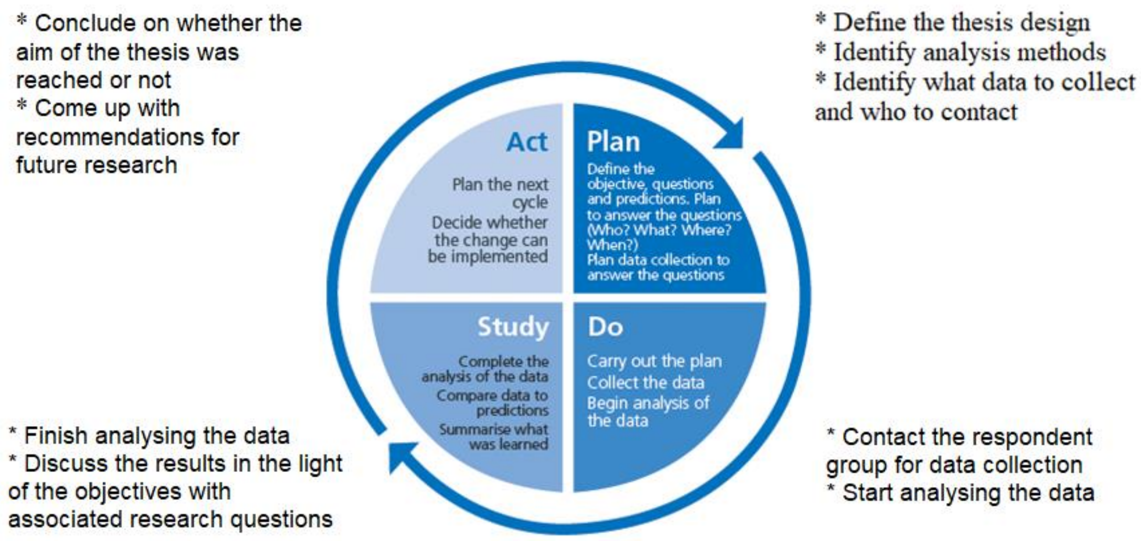

Figure 3-4 The research process for this thesis in the light of the PDSA method, adapted from (Barabady, 2005).

The planning of this thesis first started in October of 2021 with a discussion of the topic between one of Europe's largest companies applying UAV operations and the author of this thesis. They saw both the need and the benefit of conducting such research. Further on the topic was then brought to the attention of the NCAA by the author of the thesis in December of 2021. They also saw the benefit of such a thesis and addressed several topics of information that they especially wanted to see as a result of the thesis. Based on the positivity received from the two companies as described, the topic that was discussed was chosen to be the topic of this thesis. Later, in January of 2022, when contacting companies for data collection, the choosing of the given topic was strengthened based on even more positive feedback from those companies.

Table 3-5 shows when the different parts of the thesis were carried out. This was conducted in early January of 2022, but was adjusted several times due to some activities taking up more or less time than originally planned for (for instance the data collection part).

Table 3-5 The table shows the timeline of the process of this thesis.

Activity	**Start**	**Stop**
Planning of the thesis	01.10.21	07.01.22
Define the project outline	07.01.22	21.01.22
Data collection	11.01.22	01.05.22

Writing the first draw of the thesis	15.01.22	13.05.22
Review and finishing touches	13.05.22	30.05.22
Hand in the thesis	-	30.05.22

4 Results

The following subchapters in this chapter present key numbers, analyses and distributions of several categories based on the identified UAV incident and accident data. The table with the identified data can be seen in appendix A.

4.1 Key numbers on the collected incident and accident data

Table 4-1 shows the key numbers based on the identified UAV incident and accident data from appendix A. The frequencies are given as incidents/accidents per hour of flight time.

Table 4-1 Key numbers based on the identified UAV incident and accident data from appendix A.

Company ID	Type of company	Number of UAV flights	Flight time (h)	Number of incidents	Number of accidents	Frequency of incident	Frequency of accident	Frequency of either incident or accident
1	Drone company	6810	1804	0	3	0	0,001662971	0,001662971
2	Drone company	900	240	9	4	0,0375	0,016666667	0,054166667
3	Other company	765	153	2	2	0,013071895	0,013071895	0,026143791
4	Other company	9165	1879	11	29	0,005854178	0,015433741	0,021287919
5	Drone company	2928	2250	23	17	0,010222222	0,007555556	0,017777778
6	Other company	217	33	2	0	0,060606061	0	0,060606061
7	Other company	760	63	4	5	0,063492063	0,079365079	0,142857143
8	Drone company	4043	506	0	4	0	0,007905138	0,007905138
9	Drone company	1484	380	8	8	0,021052632	0,021052632	0,042105263
10	Drone company	3730	658	9	7	0,013677812	0,010638298	0,024316109
11	Drone company	372	255	0	7	0	0,02745098	0,02745098
Total		31174	8221	68	86	0,0082715	0,010461014	0,018732514

4.2 Distribution of causes of incidents and accidents

Figure 4-1 shows a distribution of causes of the identified UAV incidents and accidents, for all participating companies. See subchapter 4.1, Table 4-1, for key numbers behind the chart. The data used to prepare the chart can be seen in appendix A.

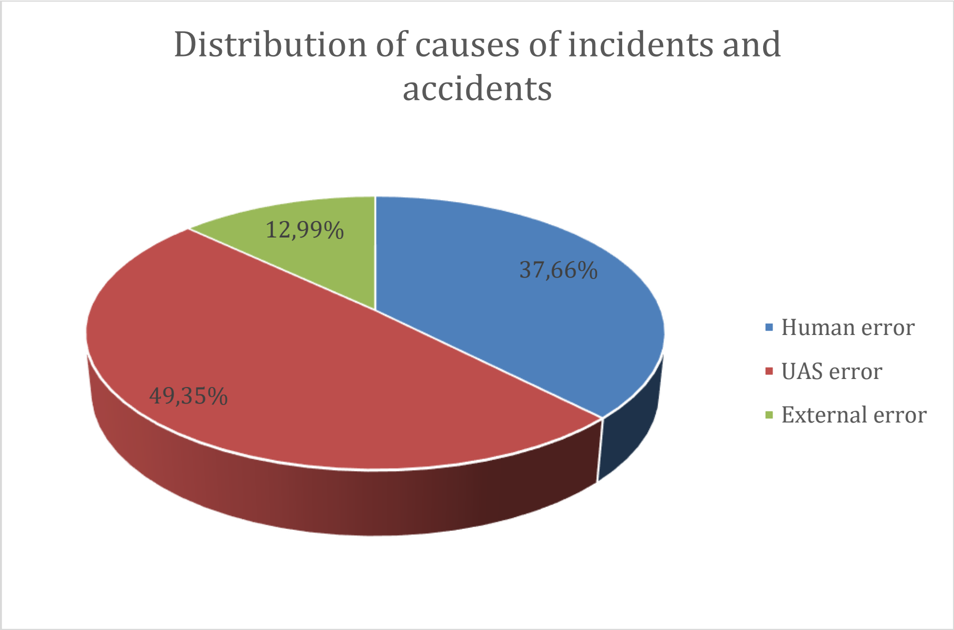

Figure 4-1 Distribution of causes of the identified UAV incidents and accidents from appendix A.

Figure 4-2 shows a Pareto chart of causes of the identified UAV incident and accidents. The bars represent the frequency of occurrence of each of the causes and the line represents the cumulative percentage of the causes. See subchapter 4.1, Table 4-1, for key numbers behind the chart. The data used to prepare the chart can be seen in appendix A.

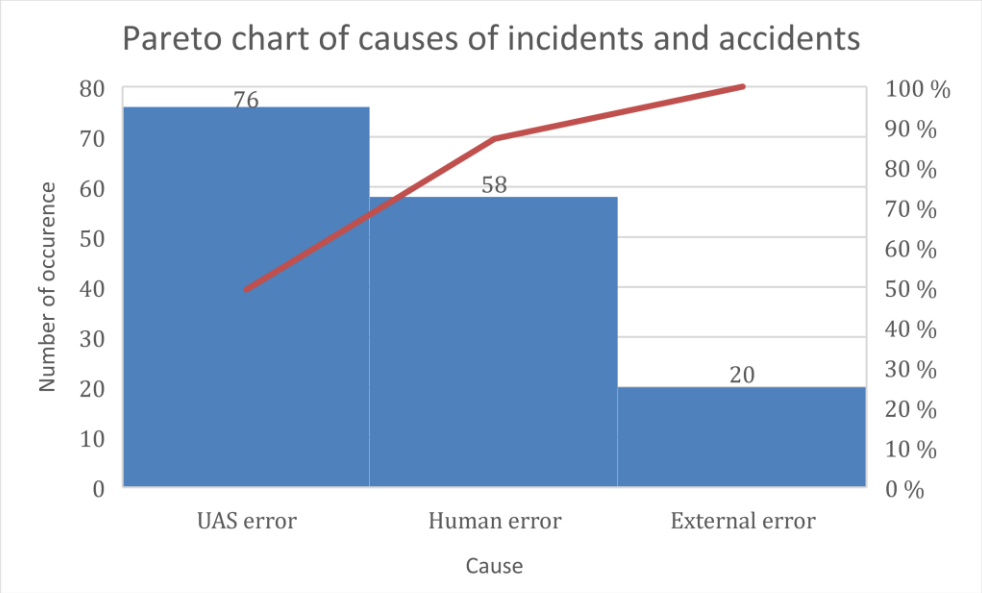

Figure 4-2 Pareto chart of causes of the identified UAV incident and accidents from appendix A.

4.3 Distribution of causes of incidents and accidents for "drone companies"

Figure 4-3 shows the distribution of causes of the identified UAV incidents and accidents for "drone companies". See subchapter 4.1, Table 4-1, for key numbers behind the chart, and subchapter 3.5 for the definition of a "drone company". The data used to prepare the chart can be seen in appendix A.

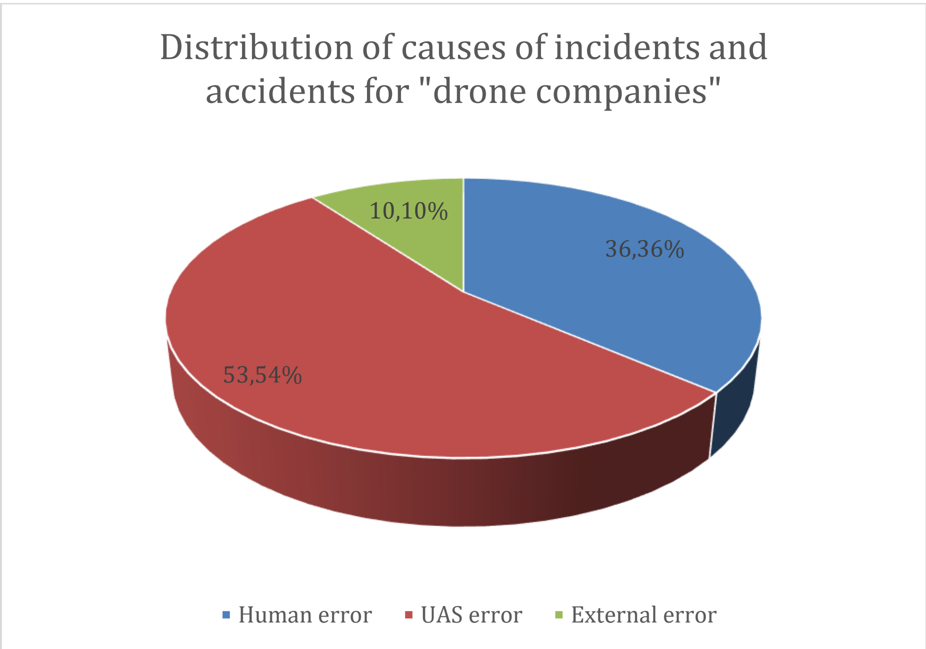

Figure 4-3 Distribution of causes of the identified UAV incidents and accidents for "drone companies".

4.4 Distribution of causes of incidents and accidents for “other companies”

Figure 4-4 shows the distribution of causes of the identified UAV incidents and accidents for “other companies”. See subchapter 4.1, Table 4-1, for key numbers behind the chart, and subchapter 3.5 for the definition of a “other company”. The data used to prepare the chart can be seen in appendix A.

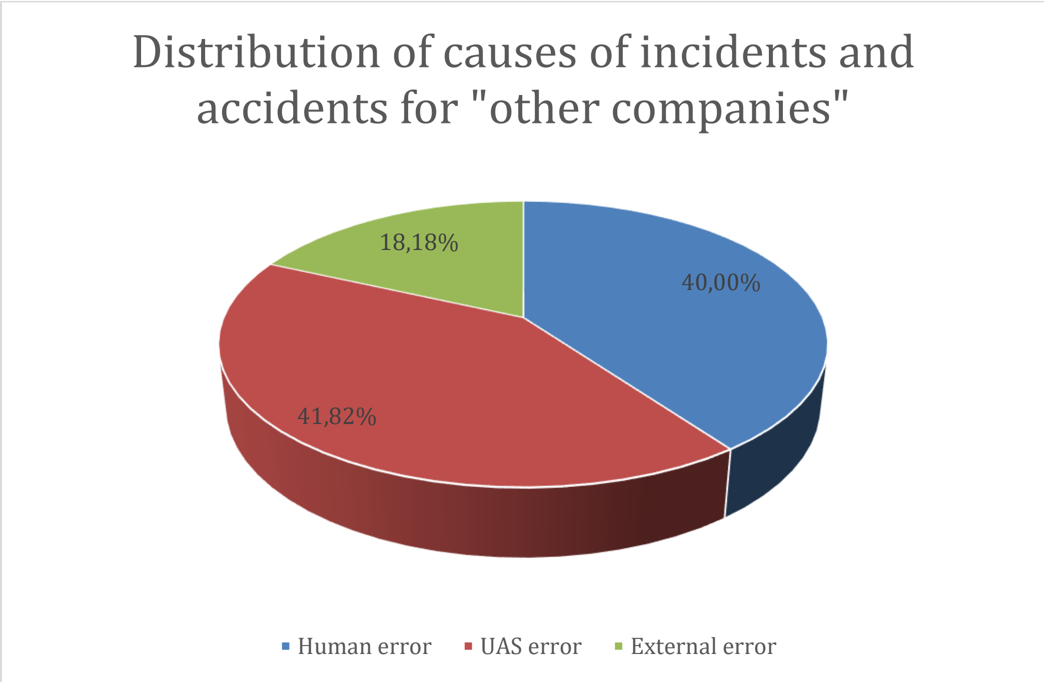

Figure 4-4 Distribution of causes of the identified UAV incidents and accidents for “other companies”.

4.5 Distribution of severity of consequence of accidents

Figure 4-5 shows the distribution of the severity of consequence of the identified UAV incidents and accidents. See subchapter 2.3.3, Table 2-1, for how the grading of the severity of consequence was chosen. The data used to prepare the chart can be seen in appendix A.

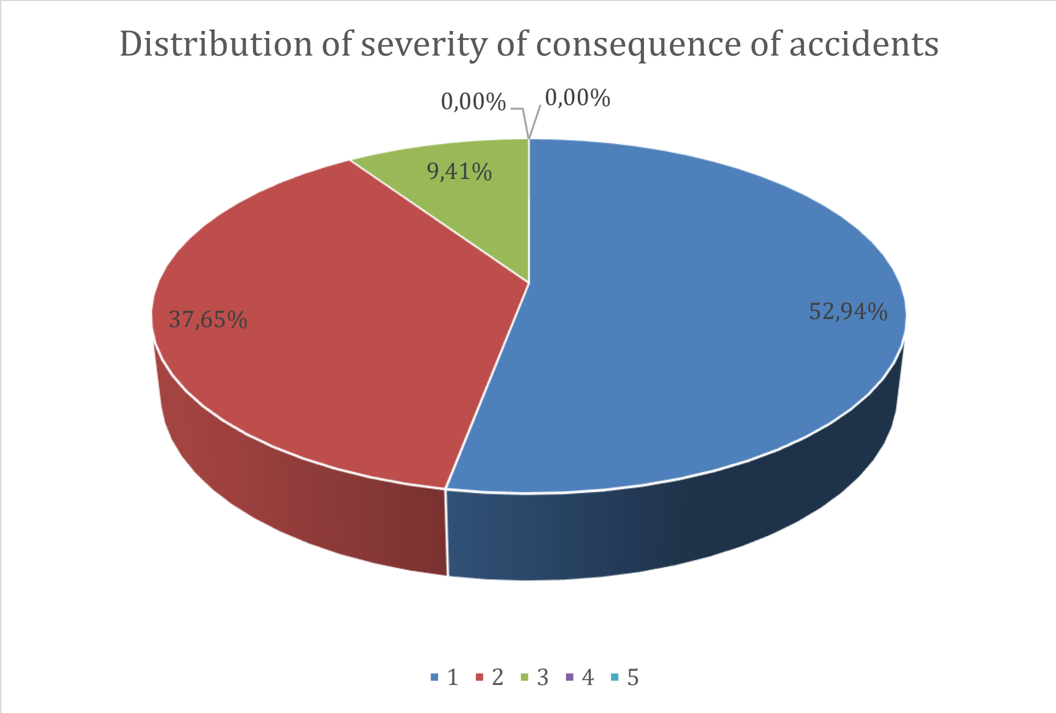

Figure 4-5 Distribution of the severity of consequence of the identified UAV incidents and accidents from appendix A.

4.6 Distribution of potential severity of consequence of incidents and accidents

Figure 4-6 shows the distribution of the potential severity of consequence of the identified UAV incidents and accidents. In other words, the distribution shows a fictious worst-case scenario outcome of the identified UAV incidents and accidents. See subchapter 2.3.3, Table 2-1, for how the grading of the severity of consequence was chosen. The data used to prepare the chart can be seen in appendix A.

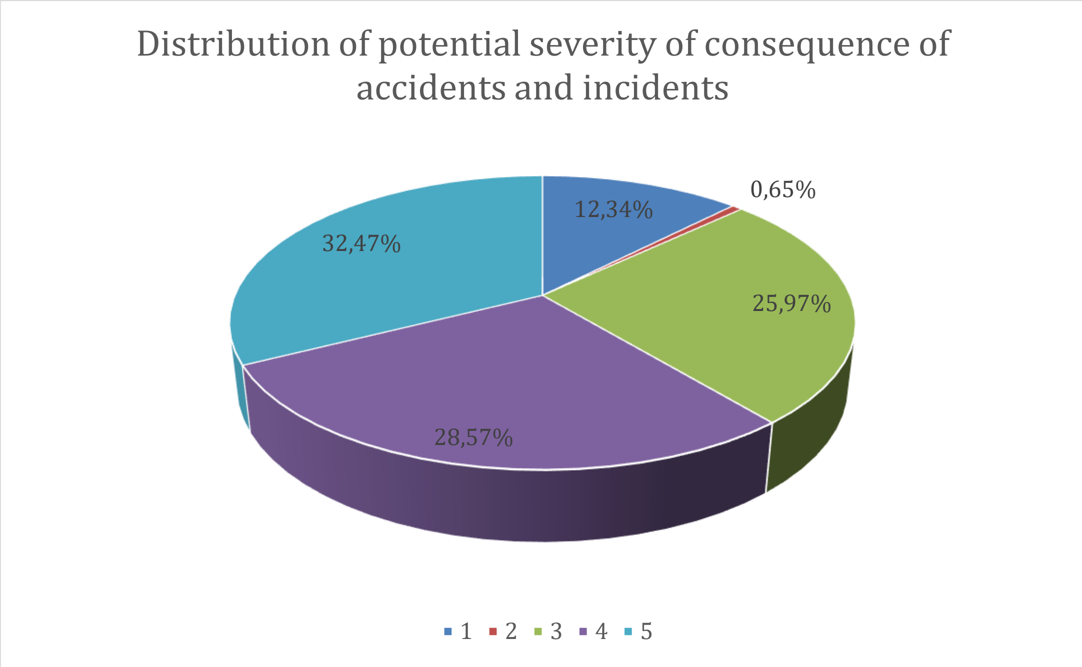

Figure 4-6 Distribution of the potential severity of consequence of the identified UAV incidents and accidents from appendix A.

4.7 Distribution of loss of link- and fly-away occurrences

Figure 4-7 shows the distribution of the loss of link occurrence compared to other occurrences, of the identified UAV incidents and accidents. Loss of link can be viewed as a loss of all communication to the UAV. A fly-away can be viewed as the aircraft no longer being controllable, resulting in the UAV not operating in a predictable or planned manner (often the UAV flies away uncontrollable and crashes). The data used to prepare the chart can be seen in appendix A.

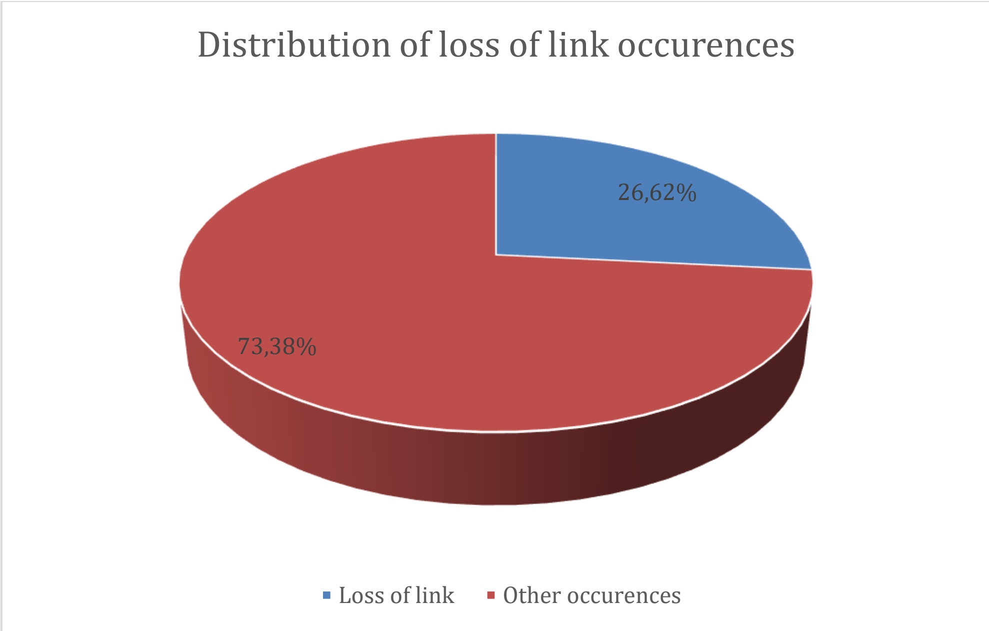

Figure 4-7 Distribution of the loss of link occurrence compared to other occurrences, of the identified UAV incidents and accidents from appendix A.

Figure 4-8 shows the distribution of the fly-away occurrence compared to other occurrences, of the identified UAV incidents and accidents. The data used to prepare the chart can be seen in appendix A.

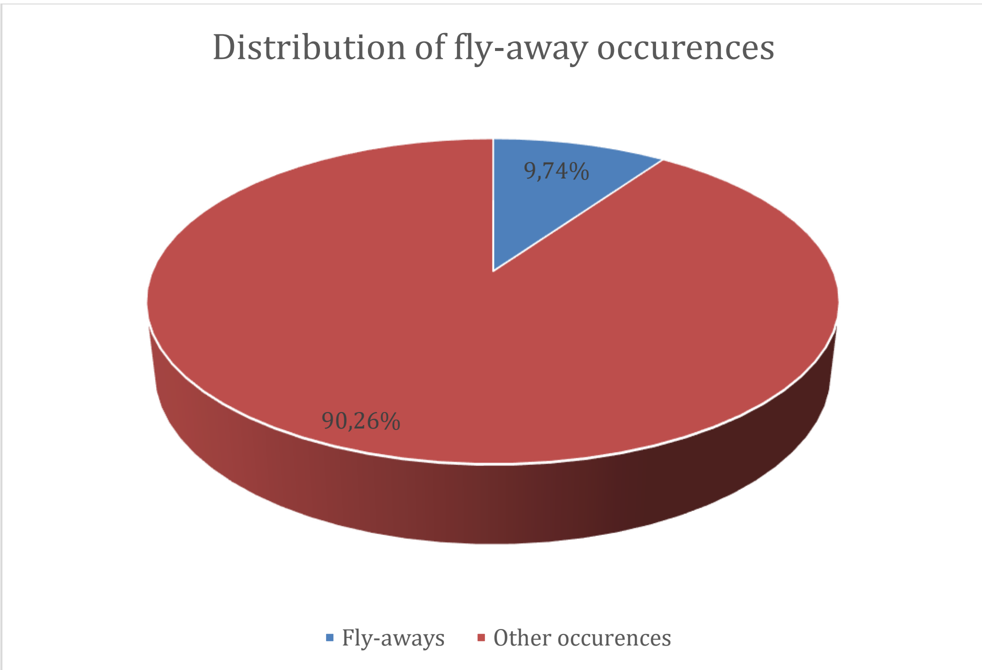

Figure 4-8 Distribution of the fly-away occurrence compared to all other occurrences, of the identified UAV incidents and accidents from appendix A.

4.8 Distribution of manned aircraft incidents

Figure 4-9 shows a distribution of manned aircraft incidents compared to other occurrences, of the identified UAV incidents and accidents. The data used to conduct the chart can be seen in appendix A.

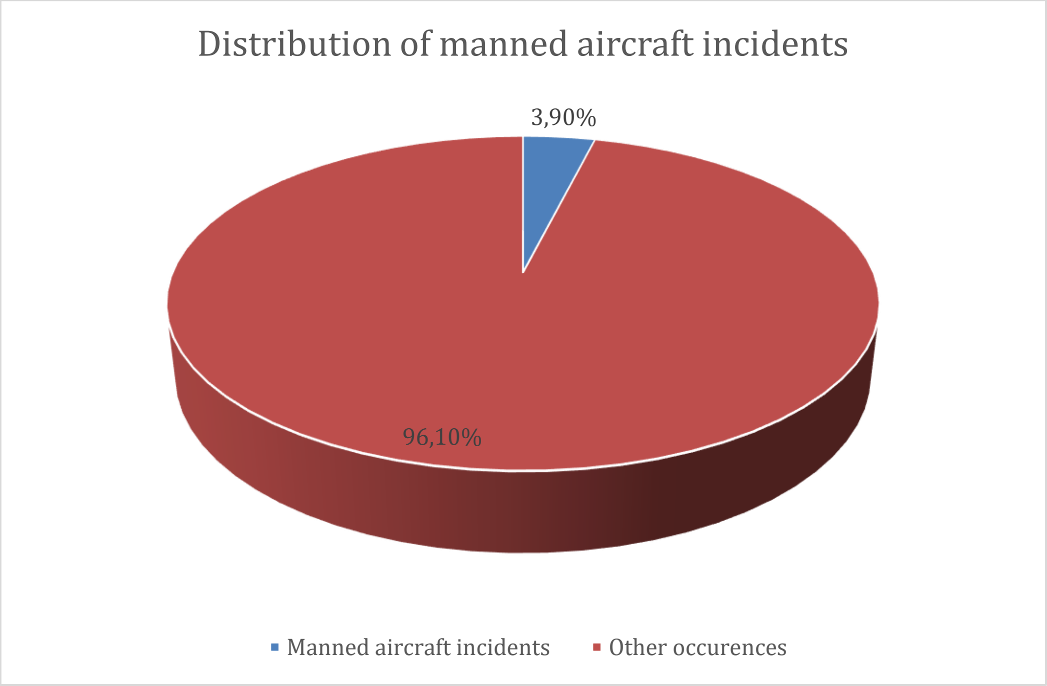

Figure 4-9 Distribution of manned aircraft incidents compared to other occurrences, of the identified UAV incidents and accidents from appendix A.

4.9 Table of chart data

Table 4-2 shows of all the data that is distributed in pie charts in subchapters 4.2 through 4.8. “SoC” in the table is an abbreviation of Severity of Consequence. The different numbers (ranging 1-5) after each “SoC” refers to the severity of consequence classes (see subchapter 2.3.3, Table 2-1). The table is based on the distributions in subchapters 4.2 through 4.8, which again are based on the identified incidents and accidents from appendix A.

Table 4-2 The data that is distributed in pie charts in subchapters 4.2 through 4.8.

Distribution	Human error	UAS error	External error	SoC 1	SoC 2	SoC 3	SoC 4	SoC 5	Fly-aways	Losses of link	Manned aircraft incidents
Distribution of causes of incidents and accidents	37,66 %	49,35 %	12,99 %	–	–	–	–	–	–	–	–
Distribution of causes of incidents and accidents for "drone companies"	36,36 %	53,54 %	10,10 %	–	–	–	–	–	–	–	–
Distribution of causes of incidents and accidents for "other companies"	40,00 %	41,82 %	18,18 %	–	–	–	–	–	–	–	–
Distribution of severity of consequence of accidents	–	–	–	52,94 %	37,65 %	9,41 %	0,00 %	0,00 %	–	–	–
Distribution of potential severity of consequence of accidents and incidents	–	–	–	12,34 %	0,65 %	25,97 %	28,57 %	32,47 %	–	–	–
Distribution of loss of link compared to total number of incidents and accidents	–	–	–	–	–	–	–	–	–	26,62 %	–
Distribution of fly-aways compared to total number of incidents and accidents	–	–	–	–	–	–	–	–	9,74 %	–	–
Distribution of incidents involving manned aircraft compared to total number of incidents and accidents	–	–	–	–	–	–	–	–	–	–	3,90 %

4.10 Distr. of frequencies of incidents/accidents vs. severity of consequence

Figure 4-10 shows the distribution of frequencies (occurrences per flight hour) of incidents/accidents vs. severity of consequence of the identified UAV incidents and accidents. See subchapter 2.3.3, Table 2-1, for how the grading of the severity of consequence was chosen. The data used to prepare the chart can be seen in appendix A.

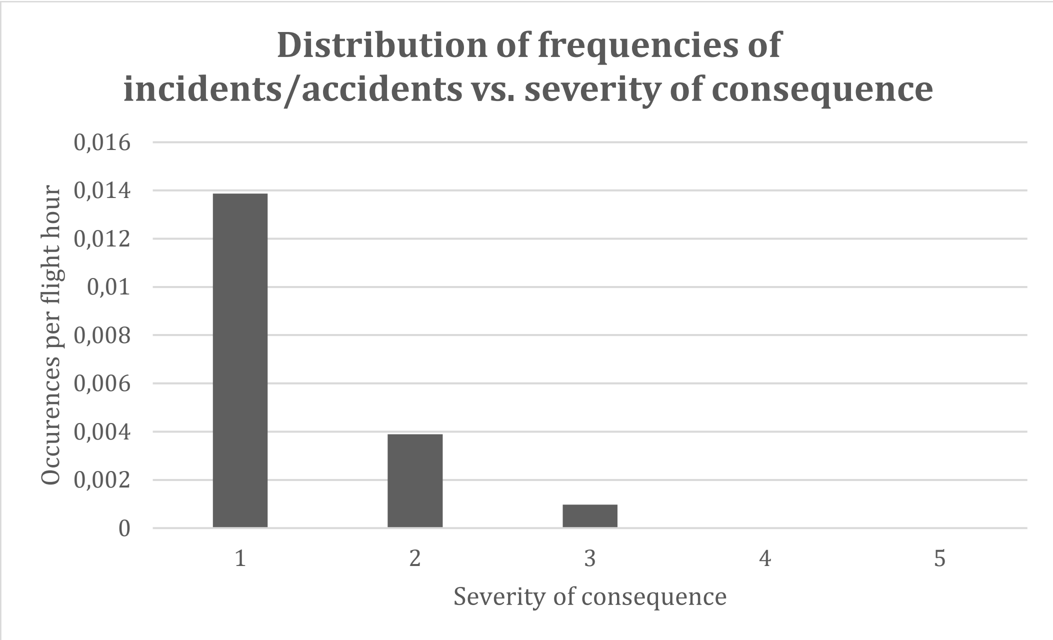

Figure 4-10 Distribution of frequencies (occurrences per flight hour) of incidents/accidents vs. severity of consequence.

4.11 Distr. of frequencies of incidents/accidents vs. potential severity of consequence

Figure 4-11 shows the distribution of frequencies (occurrences per flight hour) of incidents/accidents vs. potential severity of consequence of the identified UAV incidents and accidents. See subchapter 2.3.3, Table 2-1, for how the grading of the severity of consequence was chosen. The data used to prepare the chart can be seen in appendix A.

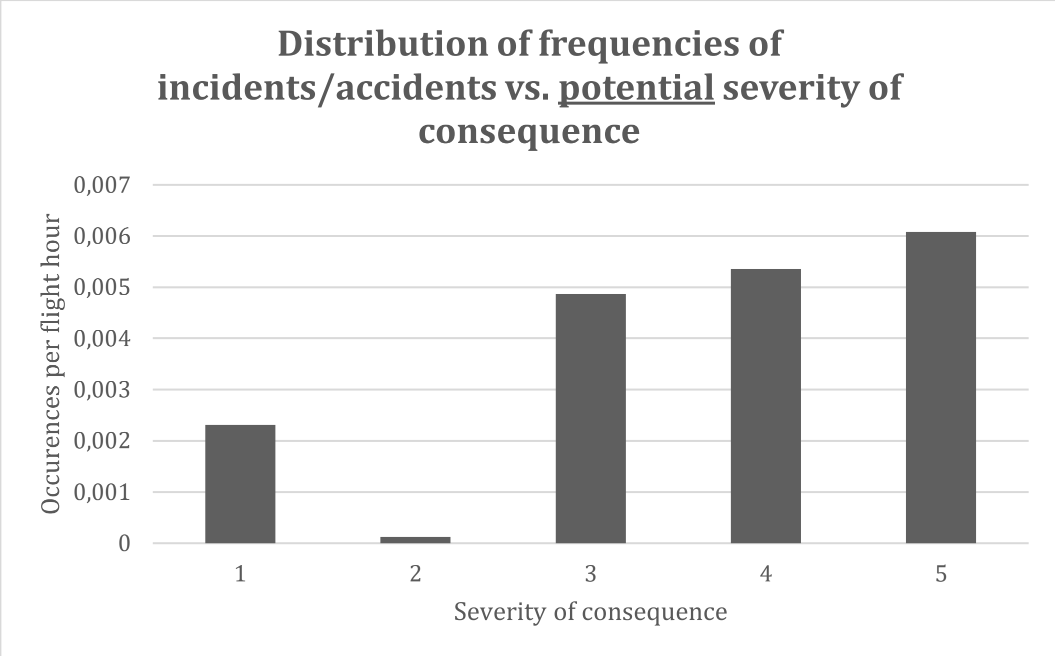

Figure 4-11 Distribution of frequencies of incidents/accidents vs. potential severity of consequence.

4.12 Analyses of the event "loss of link to UAV during autonomous flight"

This subchapter includes a further, more thorough, analysis of the event "loss of link to UAV during autonomous flight" carried out through applying three different analysis methods.

4.12.1 Fault tree analysis of the event

The following fault tree analyses the event "loss of link to UAV during autonomous flight". The transfer symbols (A, A1, A2 and A3) indicate that the rest of the tree can be found by looking further down in the subchapter at the corresponding transfer symbol. The choice of using transfer symbols was done due to the size of the tree being too large to fit every part of the FTA in one page. See subchapter 2.4.2 for theory on fault tree analysis.

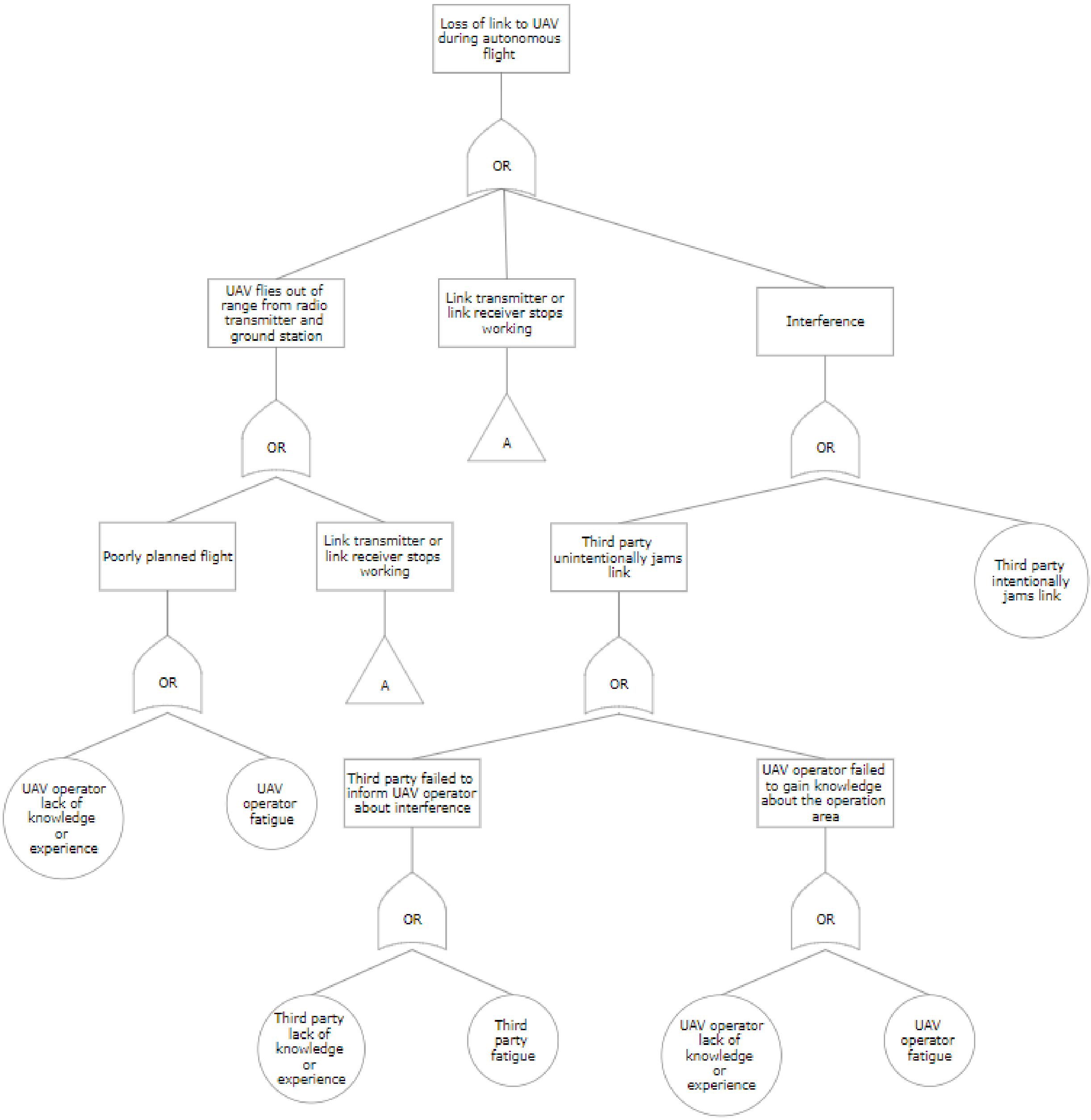

Figure 4-12 The first part of the FTA that concerns "loss of link to UAV during autonomous flight".

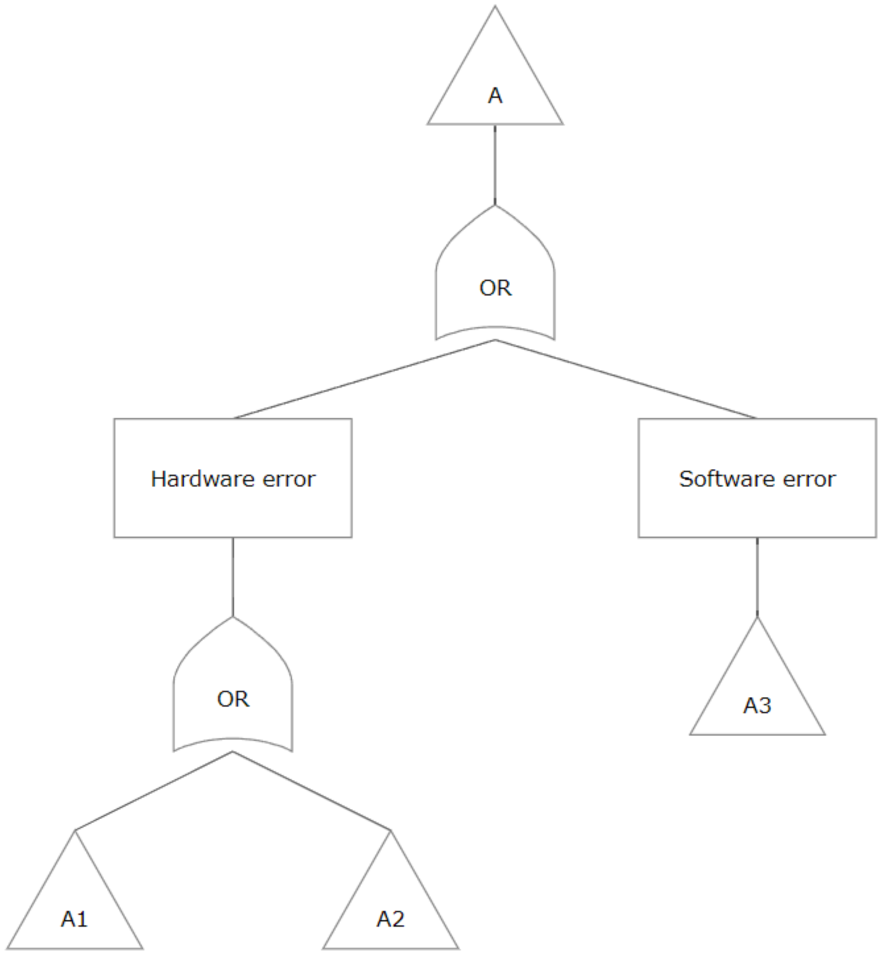

Figure 4-13 The second part of the FTA that concerns "loss of link to UAV during autonomous flight", and specifically the part of transfer symbol A.

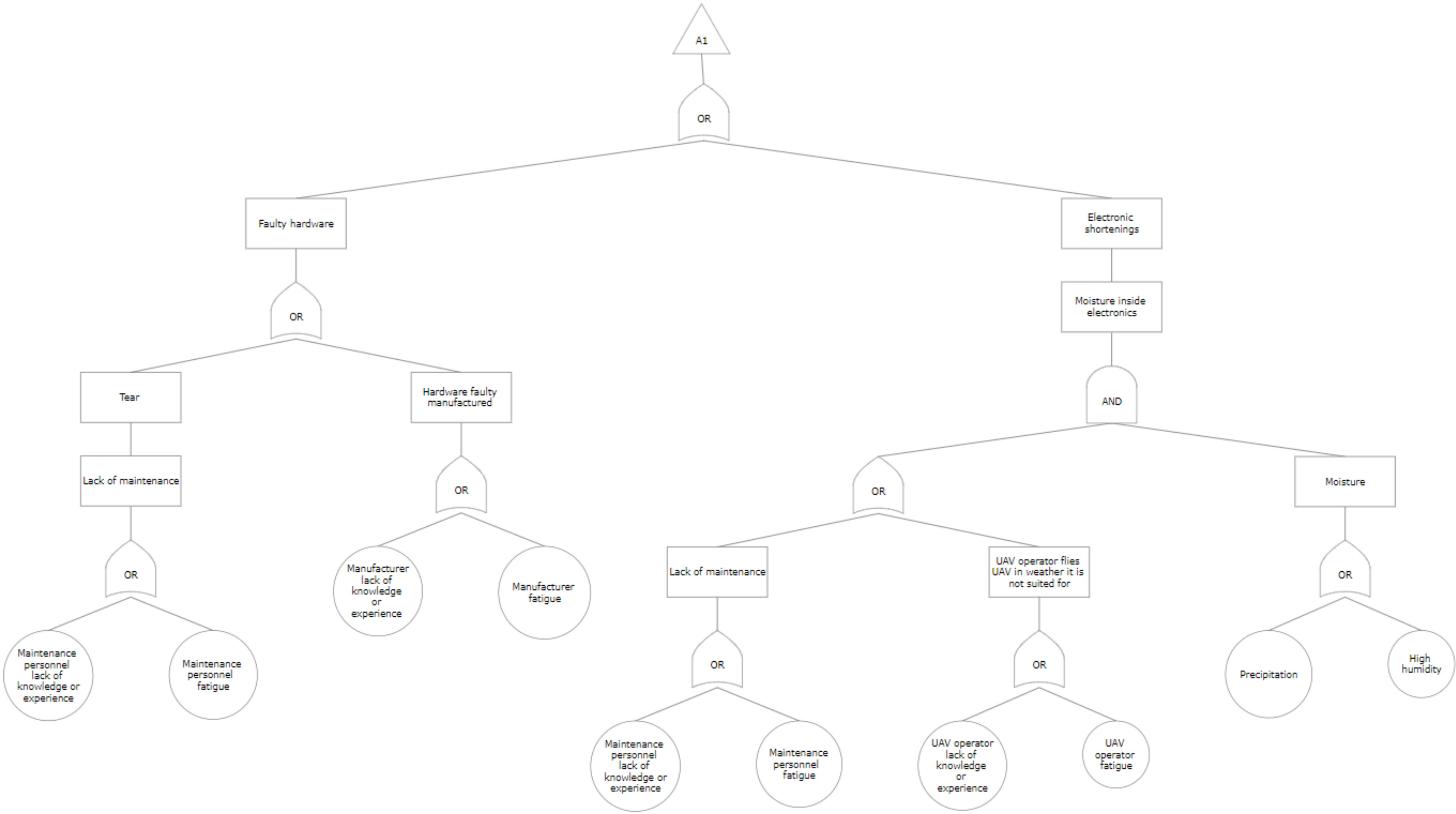

Figure 4-14 The third part of the FTA that concerns "loss of link to UAV during autonomous flight", and specifically the part of transfer symbol A1.

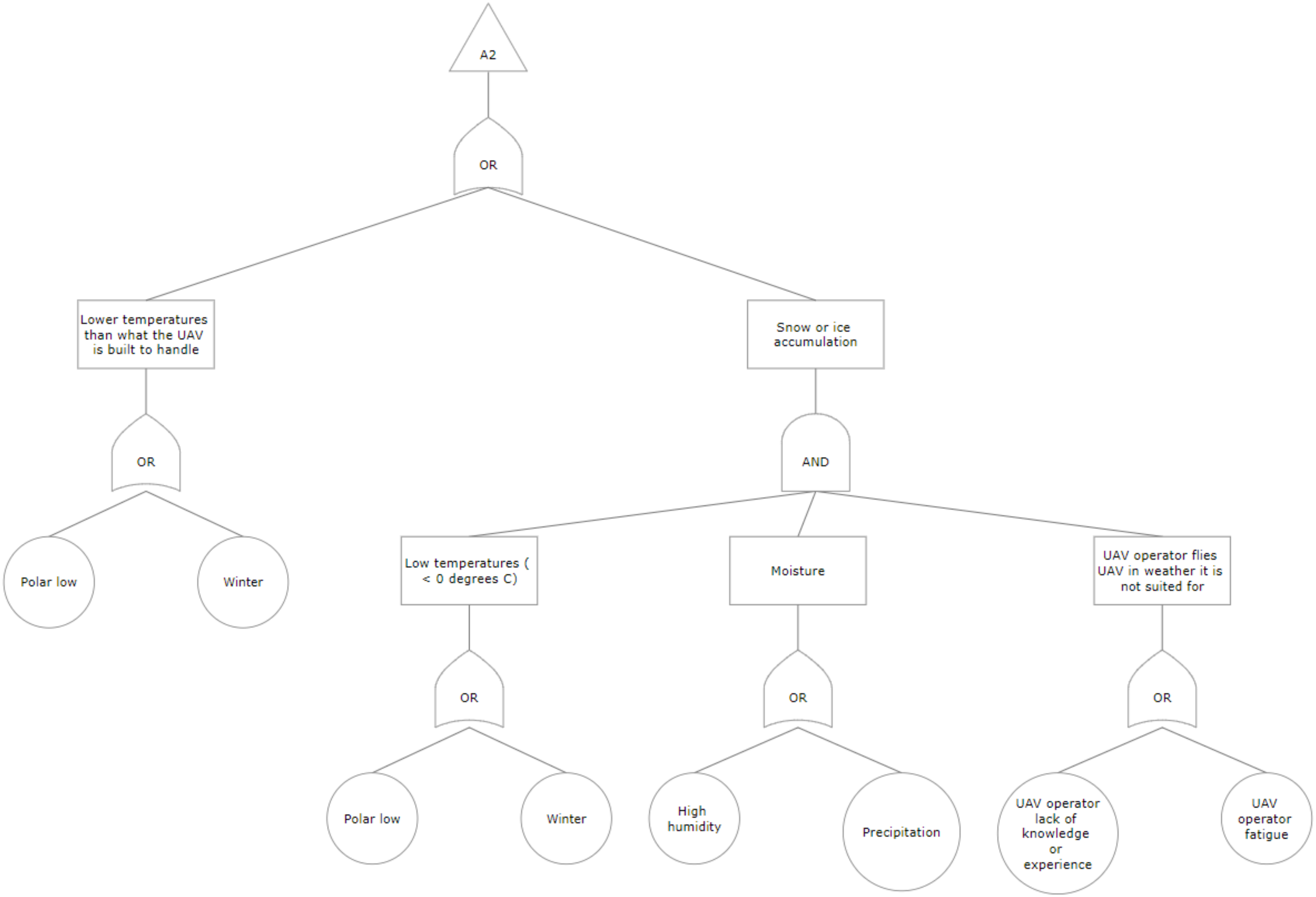

Figure 4-15 The fourth part of the FTA that concerns "loss of link to UAV during autonomous flight", and specifically the part of transfer symbol A2.

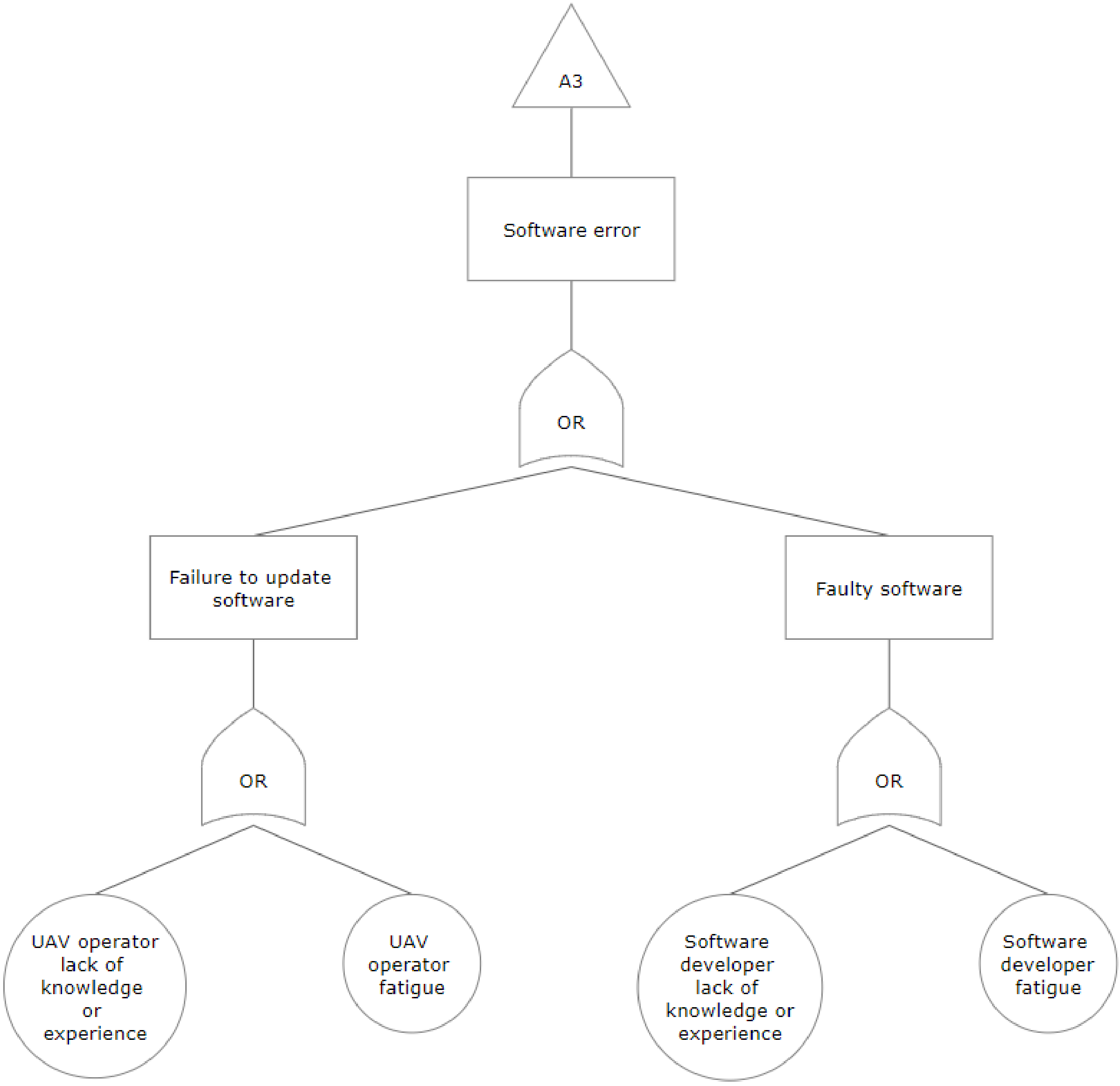

Figure 4-16 The fifth part of the FTA that concerns "loss of link to UAV during autonomous flight", and specifically the part of transfer symbol A3.

4.12.2 Event tree analysis of the event

The following event tree analyses the event "loss of link to UAV during autonomous flight". The frequencies of each outcome are calculated, and both these frequencies and the frequency of the initiating event are made-up and/or calculated from the identified data of UAV incidents and accidents (appendix A) (The frequency of the initiating event is calculated from the identified data and the probability of each barrier failing or not is made up). See subchapter 2.4.3 for theory on event tree analysis. The total frequency of the outcomes is the same as the frequency of the initiating event (0,005).

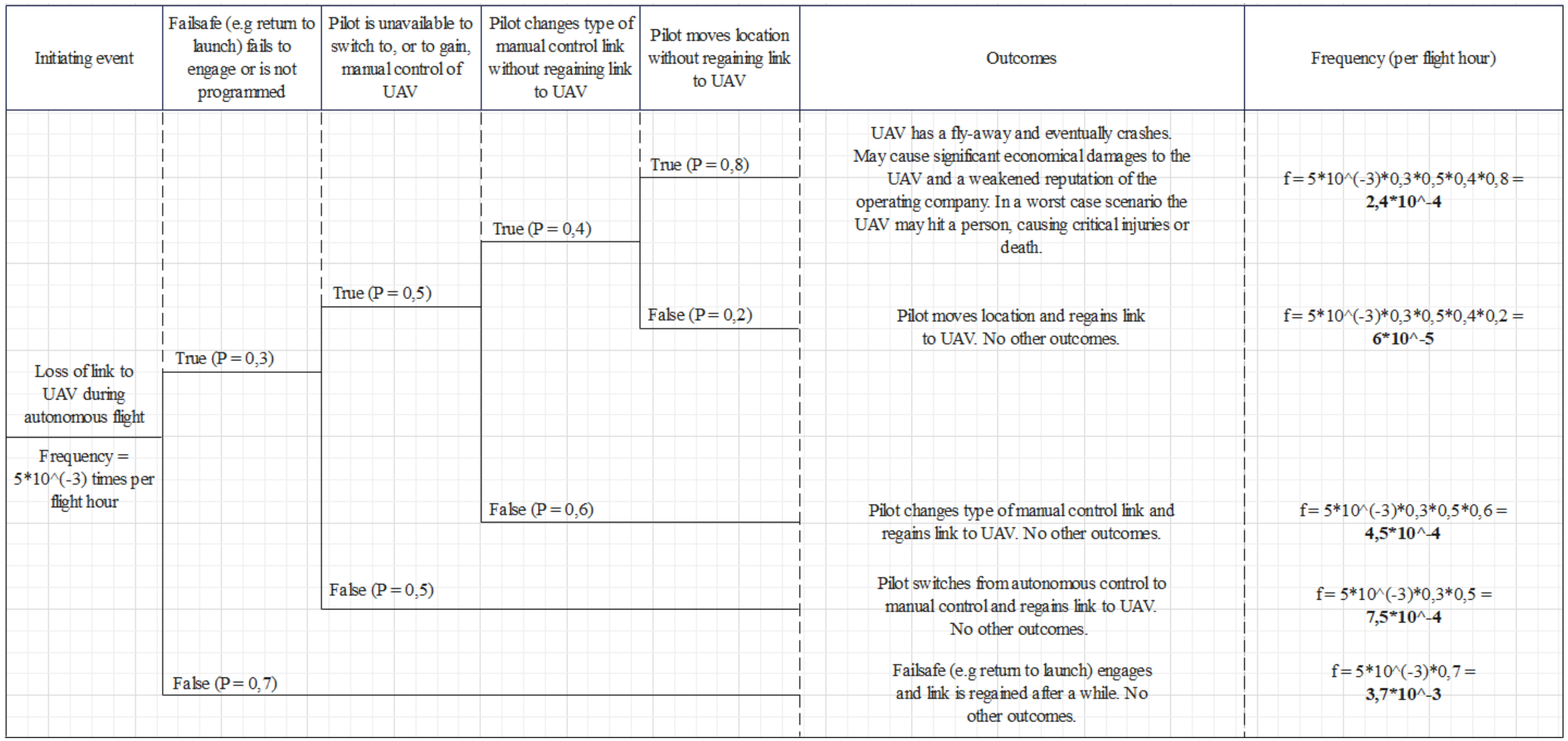

Figure 4-17 Event tree analysis of the event "loss of link to UAV during autonomous flight".

4.12.3 Bow tie analysis of the event

The following bow tie analyses the event "loss of link to UAV during autonomous flight". The orange circle represents the top event, the blue squares are potential threats/causes of the top event, the grey squares are risk reduction measures, the red square is the potential outcome of the top event, and the black and yellow lined square is the hazard connected to the top event. The causes are found through the FTA in subchapter 4.12.1 and the consequences are through the ETA in subchapter 4.12.2.

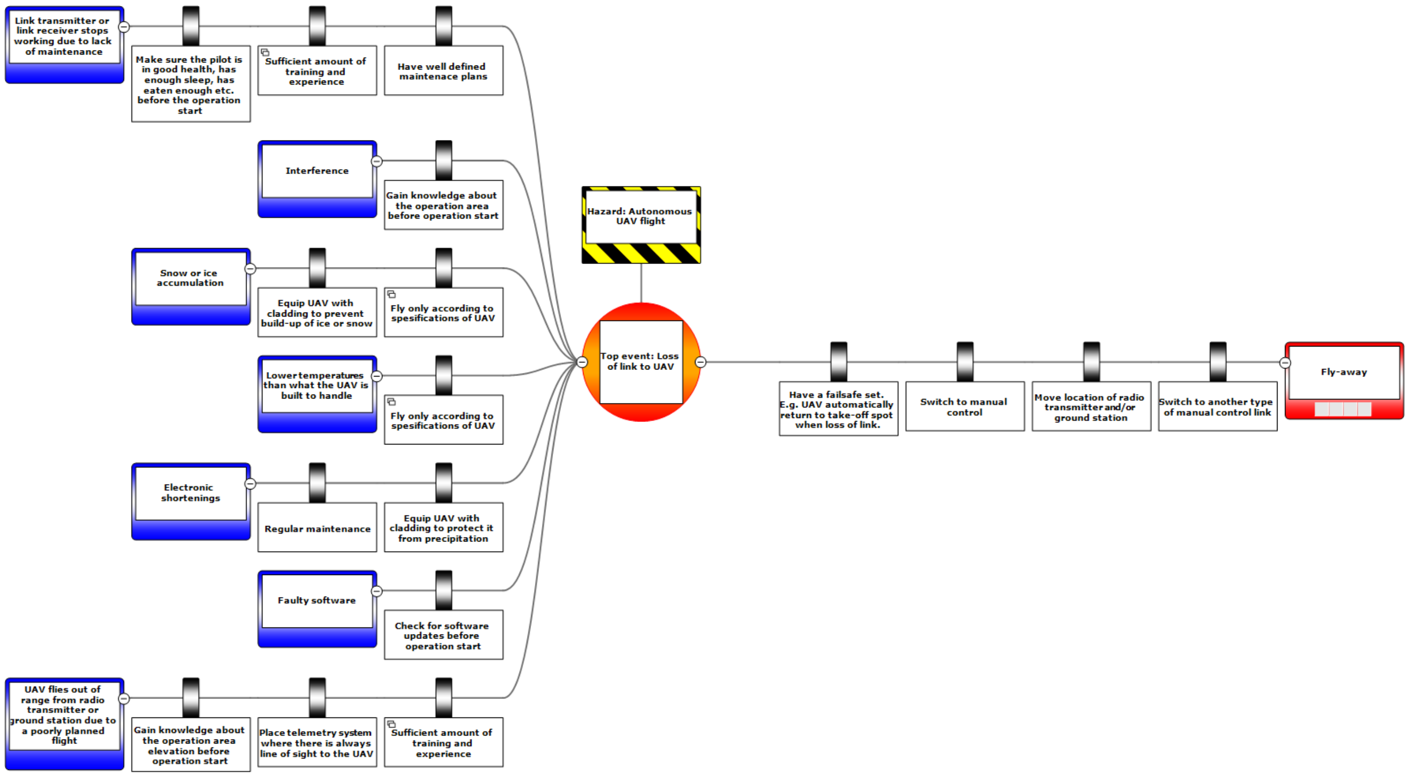

Figure 4-18 Bow tie analysis of the event "loss of link to UAV during autonomous flight".

4.13 Analyses of the event "manned aircraft heading towards UAV operation area"

This subchapter includes a further, more thorough, analysis of the event "manned aircraft heading towards UAV operation area" carried out through applying three different analysis methods.

4.13.1 Fault tree analysis of the event

The following fault tree analyses the event "manned aircraft heading towards UAV operation area". The transfer symbol (A) indicates that the rest of the tree can be found by looking further down in the subchapter at the corresponding transfer symbol. The choice of using transfer symbols was done due to the size of the tree being too large to fit every part of the FTA in one page. See subchapter 2.4.2 for theory on fault tree analysis. The probabilities are made up and/or calculated from the identified data of UAV incidents and accidents (appendix A).

The probability of the top event occurring is found by using the equation from subchapter 3.4 (equation 2). In the equation, "MCS" is short of Minimal Cut Set. See subchapter 2.4.2 for what a Minimal Cut Set is. The equation for calculating the probability of the top-event (manned aircraft heading towards UAV operation area) of this fault tree is the following:

$$
\begin{aligned}
P\ (top\ event) &= 1 - (1 - MCS_1) * \dots * (1 - MCS_n) \\
&= 1 - (1 - 0{,}02) * (1 - 0{,}08) * (1 - 0{,}01) * (1 - 0{,}001) * (1 - 0{,}0001) \\
&\quad * (1 - 0{,}0002) * (1 - 0{,}01) * (1 - 0{,}05) * (1 - 0{,}0001) * (1 - 0{,}02) \\
&\quad * (1 - 0{,}00001) * (1 - 0{,}05) * (1 - 0{,}0001) * (1 - 0{,}000001) \\
&\quad * (1 - 0{,}0002) \approx 0{,}22 \text{ per UAV flight hour}
\end{aligned}
$$

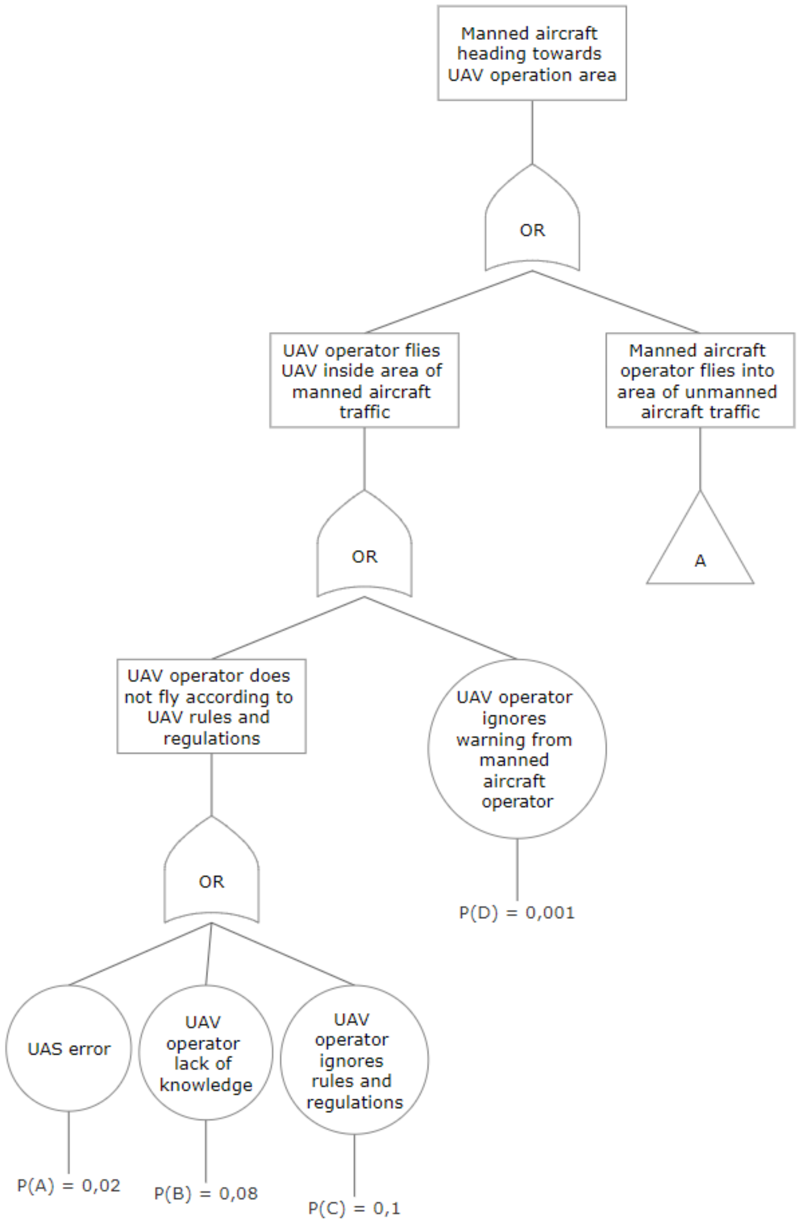

Figure 4-19 The first part of the FTA that concerns "manned aircraft heading towards UAV operation area".

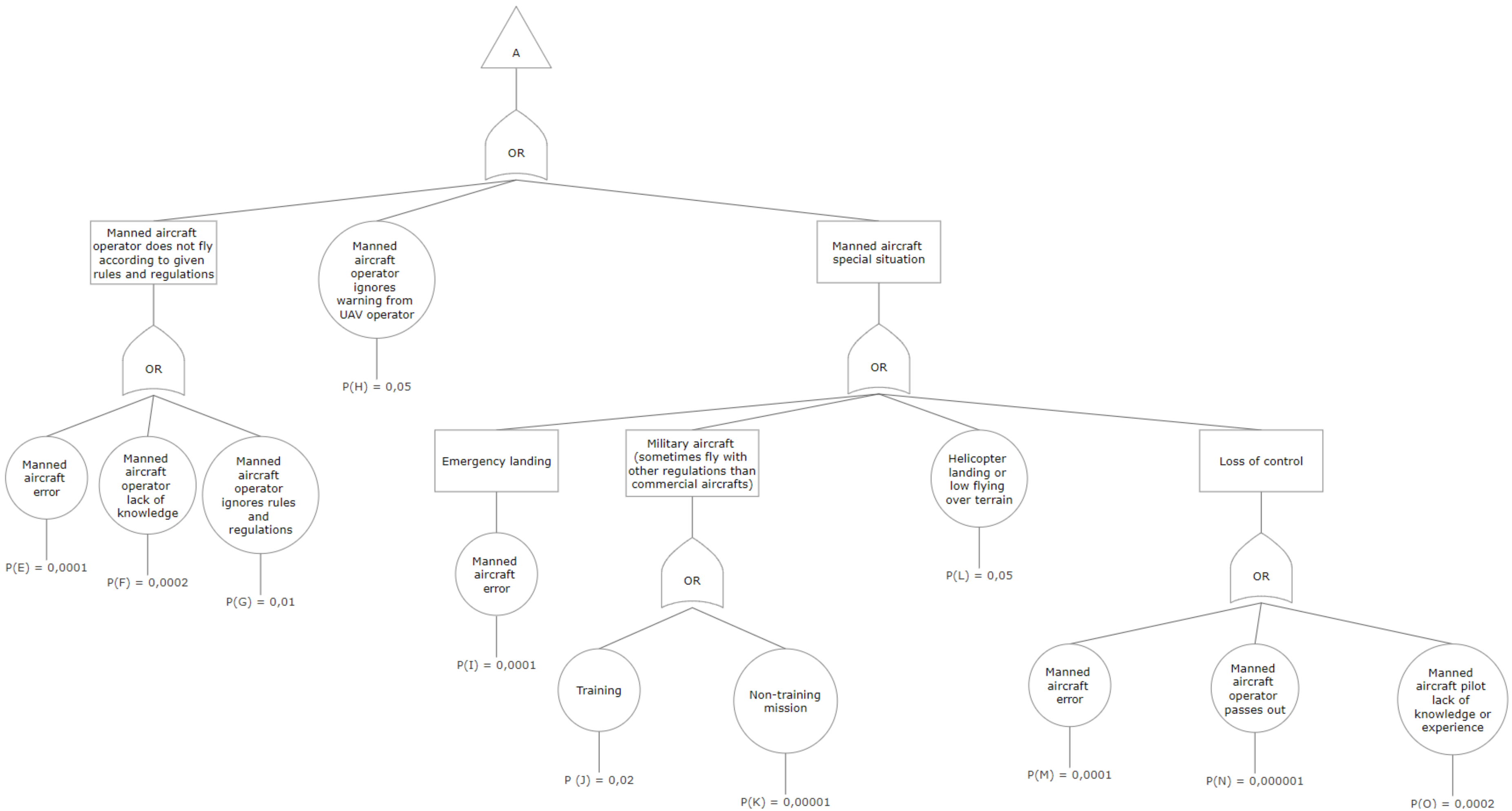

Figure 4-20 The second part of the FTA that concerns "manned aircraft heading towards UAV operation area", and specifically the part of transfer symbol A.

4.13.2 Event tree analysis of the event

The following event tree analyses the event “manned aircraft heading towards UAV operation area”. The frequencies of each outcome are calculated, and both these frequencies and the frequency of the initiating event are made-up and/or calculated from the identified incident and accident data of this thesis (appendix A) (The frequency of the initiating event is calculated from the identified data and the probability of each barrier failing or not is made up). See subchapter 2.4.3 for theory on event tree analysis. The total frequency of the outcomes is the same as the frequency of the initiating event (0,00075).

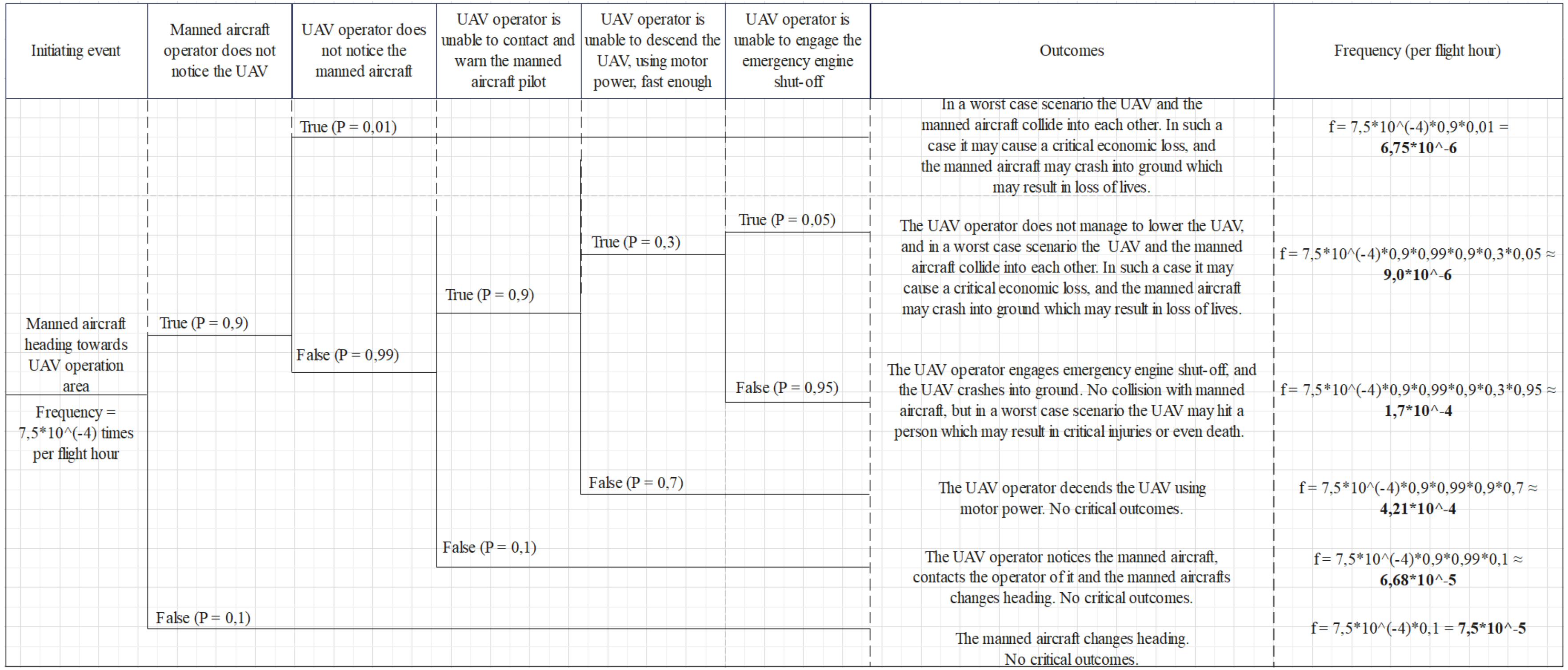

Figure 4-21 Event tree analysis of the event “Manned aircraft heading towards UAV operation area”.

4.13.3 Bow tie analysis of the event

The following bow tie analyses the event “manned aircraft heading towards UAV operation area”. The orange circle represents the top event, the blue squares are potential threats/causes of the top event, the grey squares are risk reduction measures, the red squares are the potential outcomes of the top event, and the black and yellow lined square is the hazard connected to the top event. The causes are found through the FTA in subchapter 4.13.1 and the consequences are through the ETA in subchapter 4.13.2.

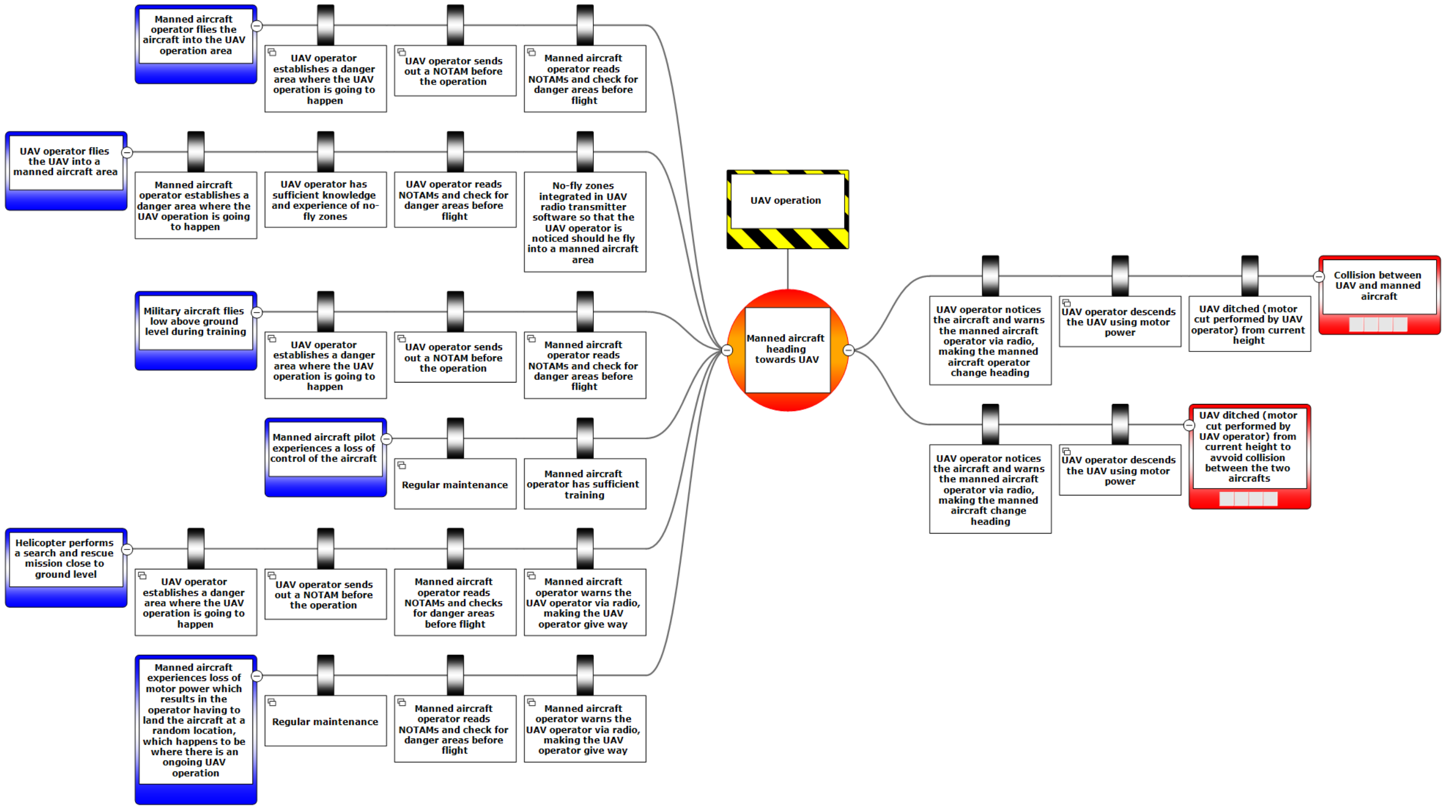

Figure 4-22 Bow tie analysis of the event “manned aircraft heading towards UAV operation area”.

5 Discussion of the objectives and their associated research question

This chapter presents a discussion of the results from the conducted analyses and literature reviews, with reference to the research questions of this thesis. The chapter is divided into four subchapters, where each of the first three subchapters includes a discussion of one objective of the thesis. The last subchapter presents a discussion of the analysis methods' limitations and self-criticism of the research findings.

5.1 Conduct risk assessments for UAV related incidents and accidents

The first objective of the thesis addresses conducting risk assessments for UAV related incidents and accidents. **The associated research question** is stated as the following: "What are the potential causes and consequences of UAV related incidents and accidents, and how can they be avoided?". Based on the results in chapter 4, this subchapter presents a discussion with reference to the given research question.

In the planning phase of the thesis the NCAA was contacted by the author of the thesis, and the topic of the thesis was discussed. The NCAA mentioned that they think there is a lack of reporting of incidents and accidents in the UAV industry. By looking at the frequencies of incidents and accidents for each of the companies in subchapter 4.1 (Table 4-1), the numbers may indicate that this is the case. In the most severe case, a company has experienced approximately 100 times more incidents and accidents than another company. Based on this, one can assume that the participating companies may have experienced more incidents and accidents than those that have been identified in this thesis (why this may be the case is discussed in the next subchapter (subchapter 5.2)). This is a weakness regarding the data that is used for preparing assumptions and discussing the research questions of the thesis. However, the results from the identified incidents and accidents are based on a reasonable number of UAV flight hours, and the data shows common denominators in causes, consequences and potential risk reduction measures. These results may therefore yet assist in discussing the associated research question of this subchapter.

It was chosen to analyse not just one, but two scenarios further than just using the preliminary risk assessment and the distributions in the form of charts. This was done in the interest of wishing to find common denominators for causes, consequences and risk reduction measures and not just coincidences by only analysing one scenario further. There do exist more causes, consequences and barriers (risk reduction measures) than the ones identified in the FTAs, ETAs and the BTAs, but those identified are examples and some of the ones that exist. The frequencies of the outcomes in the ETAs were calculated to emphasize that the outcomes are possible, but are rare to happen (the frequencies are calculated from the identified incident and accident data, and the probabilities are made-up). This was also the reason for calculating the probability of the top event in the FTA about manned aircraft encounters (subchapter 4.13.1). All analysis methods were conducted towards finding answers to the research question, which first addresses identifying causes of UAV incidents and accidents.

To be able to identify proper risk reduction measures to assist in avoiding UAV incidents and accidents, it was important to identify and analyse common causes of the incidents and accidents. Figure 4-1 and Figure 4-2 show distributions of causes of UAV incidents and accidents of the identified data, where approximately 49 % are UAS (Unmanned Aircraft System) errors, 38 % are human errors and 13 % are external errors (the numbers slightly differ between “drone companies” and “other companies”, see Figure 4-3 andFigure 4-4). These numbers indicate that most UAV incidents and accidents happen due to errors on the unmanned aircraft system. However, by analysing some of the most common identified scenarios (which also scored a high-risk index in the preliminary risk assessment (appendix A)) using fault tree analyses, it was found that several UAS errors (and external errors) have basic events (causes) that are human errors. E.g., lack of maintenance (see subchapters 4.12.1 and 4.13.1 for the FTAs). Thus, this indicates that implementing risk reduction measures for UAS errors is important, but perhaps more so for human errors.

Both the charts based on the identified incidents and accidents, and the fault tree analyses conducted for the two scenarios (subchapters 4.2, 4.12.1 and 4.13.1), indicate that most UAV incidents and accidents happen due to human error and errors on the unmanned aircraft system (UAS). The charts, and the event tree analyses, also show that the most common outcomes of UAV incidents and accidents have till now been of consequence class 1 and 2 (and some 3), which is not critical (see Figure 4-5 and Figure 4-10). However, Figure 4-6 shows that almost a third of all incidents and accidents that was identified in this thesis had the potential of having an outcome scoring a 5 (most severe score) in the severity of consequence table. What is more, Figure 4-11 also shows that, if the worst-case scenario would have happened for all of the identified incidents and accidents, the frequency of high severity of consequence occurrences would have been high. This is critical, and one may be lucky that we have had no severity 5 consequences of UAV incidents and accidents so far. Most likely, based on the scenarios that have happened and the consequences that could have been outcomes, there may be scenarios with severity 5 consequences in the years to come. Given that there are several scenarios where there have been close calls between manned aircrafts, and multiple fly-aways with crashes in residential areas etc., there may be loss of lives as outcomes. This should, and might, be somewhat prevented with rules and regulations, and with the proper risk reduction measures.

By identifying and reading the scenarios in appendix A, and by looking at the charts, event trees, fault trees and bow ties from chapter 4, it is possible to identify common denominators for some risk reduction measures that may assist in decreasing the frequency of incidents and accidents and decrease the severity of consequence should they happen. The following ones are the most important ones that the author of this thesis have identified:

- The use of a failsafe. This is a system that ensures that the UAV does an intended action automatically if a given requirement is met, e.g., making the UAV land if a loss of link occurs.
- Have an easily accessible button to switch from autonomous flight to manual flight, during autonomous flights.
- Having a competent UAV operator.
- Using checklists before flight.
- Have obstacle avoidance system enabled on the UAV while operating autonomously.
- Perform regular maintenance on the UAS.

The risk reduction measures listed above are elaborated further and discussed in subchapter 5.3, which addresses recommending updated rules and regulations for the use of UAVs.

5.2 Compare the reporting systems of manned- and unmanned aviation

The second objective of the thesis addresses the reporting systems of unmanned- and manned aviation. **The associated research question** is stated as the following: “How is the process of incident reporting in the unmanned aviation industry compared to the manned aviation industry, and should it be revised?”. Based on the background theory regarding this subject (subchapters 2.2.3 and 2.2.4), and the results in chapter 4, this subchapter presents a discussion of the given research question.

As discussed in subchapter 5.1, there are differences in frequencies of incidents and accidents for the companies that contributed with data for this research. Some have encountered up to approximately 100 times more incidents and accidents than others. Is this an indication of a poor or unclear reporting culture in the unmanned aviation industry, or does it imply that some companies are 100 times better than others at operating safely with UAVs?

Answering the above question is not easy as the frequencies of incidents and accidents for each operating company in the manned aviation industry is unknown (at least to the public). However, it is possible to find indications of why or why not the differences in frequencies are due to the reporting culture.

Currently, all UAV related incidents where someone died or were serious injured, or if the incident could have resulted in this, are mandatory to report. In addition, all scenarios with close passage between unmanned- and manned aircrafts must also be reported (Samferdselsdepartementet, 2020). This regulation regarding when to report incidents may be unclear to many. If an incident had the potential to result in loss of lives or serious injuries may be interpreted in different ways by different persons. If a UAV has a fly-away and crashes into a tree, the tree could have been a person. Some may assume in such a scenario that there was not a potential of serious injuries, while some think otherwise. This misunderstanding of which occurrences to report may be a factor contributing to that some companies have encountered more incidents and accidents than others. Looking at Table 4-1, it can be seen that the total frequency of incidents is lower than the total frequency of accidents. One may assume that it should be the opposite way around, meaning there should be more incidents than accidents (based on the definitions of incidents and accidents from subchapter 2.2.2). This may be another indication that the regulation of what incidents and accidents to report is unclear and not well defined. Now, do the companies misunderstand if an incident had the potential of resulting in serious injuries, or do they tell themselves that the incident probably did not have the potential of such to avoid having to file an incident report?

Looking at Table 3-4, most companies (that responded to the e-mail sent out by the author of the thesis) that were unable to contribute with data to this thesis stated that they could not contribute due to lack of capacity. However, if the companies have reported everything they are obligated to report, they should also have the reports filed and easily obtainable. This again means that the amount of work to share the data with the author of this thesis was limited. Stating that they “do not have capacity” to contribute with data may therefore be an indication that those companies have not reported incidents/accidents that they were obligated to report. This may be a strengthening factor of there being dark numbers in reporting of incidents and accidents in this unmanned aviation industry, as stated by the NCAA in an oral conversation between the NCAA and the author of this thesis (02.12.21). Although, why should the companies bother to report incidents?

Why should companies bother do report incidents, when the NCAA states that most incidents are not analysed in any way (stated by the NCAA in an oral conversation between the NCAA and the author of the thesis 02.12.21)? In the manned aviation industry "all reports are used for analyses and measures to improve safety" (Luftfartstilsynet, n.d.-b). This may motivate one to report incidents. In addition, in the manned aviation industry they aim to have a "just culture" (see subchapter 2.2.3). By having this "just culture" the industry opens for everyone to learn from each other and that making errors is a part of being a human. In the unmanned aviation industry, however, the reported incidents are not available to the public (a lack of transparency), the NCAA does not have an overview over all incidents related to the use of UAVs (and they do not have ambitions to do so according to Eirik Svare in NCAA (Martinsen, 2017)) and most reported incidents are not analysed. This may indicate that the NCAA currently is not trying to create a good reporting culture within the unmanned aviation industry. Based on the statements in this paragraph, there may in fact not be any reasons for why one should report UAV related incidents and accidents other than that it is a regulation that states so.

Although, according to Johnson (Johnson, 2003) and Under and Gerede (Under & Gerede, 2021), incident reporting may be time consuming, expensive and employees may associate it with fear, this mostly applies when a proper reporting culture is not present. Incidents and accidents "… provide an untapped source of data" (Johnson, 2003). Having a proper reporting culture, reporting incidents and analysing the reported incidents may therefore be valuable to both the operating companies and to the NCAA (and all other CAAs), and should be considered by the NCAA to be created. According to James Reason in 2000, the recommended type of reporting culture is the one that the manned aviation industry practices today (Reason, 2000): the "just culture".

As addressed in subchapter 2.2.3, the NCAA received 148 incident reports in 2006 and 7424 reports in 2017 associated with manned aviation. The NCAA stated that this may be due to easier ways of reporting, an improved reporting culture or clearer demands for what should be reported (Luftfartstilsynet, n.d.-a). By making clearer demands for what should be reported in the unmanned industry, as discussed earlier in this subchapter, and by creating a proper reporting culture (e.g., the "just culture"), the safety in the unmanned aviation may be improved significantly. This can be due to more incidents being reported, more incidents being analysed, proper risk reduction measures and rules and regulations being implemented and improved transparency in the industry so people can learn from each other.

Reporting of all incidents in the unmanned aviation industry may be unrealistic due to time constraints and expenses. Although, some reporting and analyses (both qualitative and quantitative) of incidents may contribute to identifying appropriate risk reduction measures and making a proper set of rules and regulations. In other words, this may assist in increasing safety.

Should the process of incident reporting in the unmanned aviation industry be revised? Based on the results of the analyses in this thesis, the literature reviews and the discussion in this subchapter: if there is an aim is to lower the frequency and outcomes of UAV incidents and accidents, and to contribute to transparency in the industry, then yes it should. However, if the aim is to save expenses and time, and not have a focus on increasing safety, then it should not.

5.3 Recommend updated rules and regulations for the use of UAVs

The third objective of the thesis addresses recommending updated rules and regulations for the use of UAVs. **The associated research question** is stated as the following: "Do the current rules and regulations regarding the use of UAVs have a sufficient concern for safety, or should they be reassessed?". This subchapter presents a discussion of attempting to answer this question.

During analyses of the identified data in this thesis risk reduction measures were identified that may assist in decreasing both the frequency of incidents and accidents and the consequences should they happen. These measures were mainly identified using bow-tie analyses (see Figure 4-18 and Figure 4-22), and by identifying common denominators in the causes and consequences of incidents and accidents from the identified data (see appendix A) and from the preliminary risk assessment (see appendix B). The most important ones, according to the author of this thesis, were addressed in subchapter 5.1. The following paragraphs include discussions of some of these risk reduction measures that may assist in risk reduction, and that have the potential of becoming implemented as a rule or regulation for the use of UAVs. In addition, a paragraph regarding regulations of incident reporting (based on the discussion in subchapter 5.2) is included.

Figure 4-7 shows a distribution of the number of losses of link occurrences (loss of communication with the UAV) in the identified data of this thesis. By having a failsafe (a system that ensures that the UAV does an intended action automatically if a given requirement is met, e.g., making the UAV land if a loss of link occurs) a number of these occurrences potentially could have been prevented. Most UAVs on the marked today have the required hardware and software to implement a failsafe, which also is easily done by the operator. By looking at the event tree analysis and the bow tie analysis (Figure 4-17 and Figure 4-18) for loss of link, there are few barriers other than having a failsafe set. Therefore, this one risk reduction measure is important. Setting up a failsafe on a UAV is simple in most cases, there are no downsides to having one set, and they may contribute to preventing different types of unwanted events.

In the identified incidents and accidents in appendix A there are several occurrences where UAVs have performed unintended movements during autonomous flights, and at the same time the UAV operator has been unable to control the UAV manually due to it having enabled an autonomous flight mode. This has at some occasions lead to the UAV having a fly-away and crashing. To prevent this from happening it may be effective to have an easily accessible button on the remote UAV controller to switch from autonomous flight to manual flight. Some may already have this, but may have not used it due to a lack of competence.

There have been several incidents and accidents caused by incompetence of the UAV operator, by looking at the scenarios in appendix A. There have been occurrences where the UAV operator accidently toggled the emergency engine shut-off during flight, UAV crashes into objects due to the UAV operator not paying attention to the orientation of the UAV and so on. One can also argue that a number of the "external cause" occurrences also are due to UAV operator incompetence. When weather or electromagnetic interference were the main cause of an occurrence, the UAV operator may be the one who has failed to gain knowledge about the operating specifications of the UAV or about the operating area (see the fault trees in subchapters 4.12.1 and 4.13.1 for examples on how external causes sometimes may be due to human errors). To educate a UAV operator may be both costly and time consuming, but some education may contribute to decreasing the frequency of incidents and accidents. Examples of this may be having to pass a practical exam to operate UAVs (in higher risk categories, e.g., the specific UAV category) and/or more thorough written exams than the ones that exist today. Another risk reduction measure that may somewhat replace the need of extensive education and competence, is the use of checklists before an operation.

As discussed earlier in this subchapter, there are several of the identified incidents and accidents (see appendix A) that have occurred due to interference, weather challenges, loose propellors and motors, crashes into trees and so on. By being prepared, several of these incidents and accidents may have been prevented. Preparation may include gaining knowledge about the operation area (regarding interference, obstacles etc.), inspecting the UAS for tear, damage or defects, or even if the operator should wear sunglasses or not. These preparations, and more, may be written down as a checklist which the operator should go through and perform before every operation. Using checklists may assist in helping the UAV operator to remember important factors before an operation is carried out. As emerged from the identified incidents and accidents, several of the occurrences may have been prevented if checklists were used. The checklists may, for instance, be made by EASA or the given country's Civil Aviation Authority to assure high standards and quality. Making sure that checklists are being used by UAV operators, however, may not be easy to control. Many may skip using them to save time. Random check-ups of companies by the Civil Aviation Authority may be a solution to this.

Today, most UAVs have multiple sensors on board. These may include several types of cameras, but also distance sensors. These distance sensors are commonly used for obstacle avoidance system, where the UAV automatically detects obstacles and prevents itself from crashing into these obstacles. In the identified incidents and accidents, it is possible to see that there have been multiple occurrences where there has been a fly-away during autonomous flight resulting in the UAV crashing into obstacles. This may indicate that the UAVs either did not have an obstacle avoidance system or that the obstacle avoidance system was turned off. Based on that most UAVs have this kind of system, and knowledge of the author of this thesis, there is reason to believe that the obstacle avoidance system was turned off during autonomous flight. Therefore, the recommended risk reduction measure is to make sure that the software used to conduct the autonomous flight does not turn off the UAV's obstacles avoidance system. This may, based on the identified incidents and accidents, prevent UAV crashes due to fly-aways and poorly planned flights (where the flight altitude is set to lower than the altitude of obstacles in the operation area) during autonomous UAV operations.

Unmanned aircrafts must in all situations give way to manned aircrafts, therefore it is crucial to have risk measures implemented. Based on the analyses of the identified incidents and accidents (e.g., Figure 4-21 and Figure 4-22) there are multiple measures the UAV operator can take to give way to the manned aircraft, but not vice versa. There were identified 6 incidents with close passage between unmanned- and manned aircrafts, where, by viewing the given scenarios (in appendix A), it is noticeable that the manned aircrafts may have never even noticed the unmanned aircraft. Even though in some scenarios the unmanned aircraft operators had sent out a NOtice To AirMen (NOTAM) before the operation, which is a message with information about the operation (location, altitude of operation etc.), the manned aircrafts still entered the operation area of the UAV operation. In all the scenarios, the unmanned aircrafts ended up giving way. As a collision between a manned- and unmanned aircraft may result in critical outcomes (see the event tree analysis in subchapter 4.13.2, Figure 4-21), it is believed that identifying risk reduction measures for the manned aircraft to notice and maybe give way to the unmanned aircraft may be crucial on some occasions where the unmanned aircraft operator may not notice the manned aircraft. Therefore, a risk reduction measure may be to equip all UAVs with transponders (radio transmitters that send out a code of, for instance, their location) or other hardware that makes UAVs show up on the radar (or a similar instrument) of manned aircrafts. This way, it is possible for manned aircraft operators to have control over where unmanned aircrafts are located, and not solely the other way around. Additionally, by equipping UAVs with such a hardware, UAV operators will not have to spend time sending out a NOTAM and manned aircraft operators will not have to check for NOTAMs before their flight.

In multiple of the identified incidents and accidents (appendix A) the main cause was UAS error (see Figure 4-1), meaning some kind of error on the unmanned aircraft system. Without knowing exactly what did not work as intended, it is always crucial to have performed regular maintenance on the UAS. Some of the occurrences stated that the UAV failed due to a loose propeller, a loose motor and so on. If the maintenance plan according to the manufacturer of the UAS was followed, the given incidents and accidents may have been prevented. In the PRA (appendix B), it is noticeable that several of the identified unwanted events have risk reduction measures that includes regular maintenance. In the fault tree analyses (subchapters 4.12.1 and 4.13.1) it can also be seen that a lack of maintenance may be the basic cause of several other main causes of unwanted events. Maintenance may include tightening of screws, change of propellors, change of rubber gaskets and so on. Thus, based on the analyses and the identified unwanted events in the thesis, it is discovered that regular maintenance on unmanned aircraft systems is important and may contribute to preventing incidents and accidents.

As stated, and discussed in subchapter 5.2, the demands for when to report a UAV related incident may not be clear enough. The NCAA also has stated the increase in incident reports in the manned aviation industry may be due to clearer demands of what should be reported

(Luftfartstilsynet, n.d.-a). Therefore, it is believed that the regulation regarding what incidents to report should be reassessed and reformulated to be clearer and to include more incidents. This may, based on the literature review of this thesis (subchapters 2.2.2, 2.2.3 and 2.2.4), the results (chapter 4) and the discussion (chapter 5), assist in contributing to transparency in the industry which may lead to a decrease in frequency of incidents and accidents and the consequences should they happen. In addition, the NCAA (and other CAAs) may benefit of an increase in incident reporting for the reason of that the reports may assist in making clearer and more applicable risk reduction measures (Johnson, 2003). Reporting of <u>all</u> incidents may be unrealistic due to time constraints and expenses, as stated in subchapter 5.2, therefore the following regulation regarding incident reporting in the unmanned aviation industry is proposed: *all UAV related incidents where someone died or were serious injured, or if the incident could have resulted in this, are mandatory to report. Also, all incidents that had the potential of scoring a 3, 4 or 5 in the consequence table (e.g.,* Table 2-1*) must also be reported. In addition, all scenarios with close passage between unmanned- and manned aircraft must be reported.* "Close passage" meaning a distance shorter than, for instance, 500 meters. Furthermore, examples of incidents that are mandatory to be reported may be addressed by either EASA or each country's Civil Aviation Authority to make it clearer for the operators to understand which incidents that must be reported.

"Do the current rules and regulations regarding the use of UAVs have a sufficient concern for safety, or should they be reassessed"? The current set of rules and regulations regarding UAV operations include several important rules and regulations and risk reducing measures as addressed in subchapter 2.1.2. Subchapter 2.1.2 also addresses that the current rules and regulations (that apply in countries in the EU and countries with the European Economic Area) facilitates that one can exceed some rules and regulations by implementing other ones and having them approved by the given country's Civil Aviation Authority. However, based on the results of the analyses in this thesis, the literature reviews and the discussion in this subchapter it is suggested that some rules and regulations are too important to be exceeded. Therefore, out of the discussed risk reduction measures (and the discussed regulation regarding incident reporting), the following ones are proposed to become a rule or regulation that always should apply:

- All UAVs must have a failsafe set.

- All UAS' must have an easily accessible button to switch from autonomous flight to manual flight, during autonomous flights.
- All UAVs must have a transponder. This may not be realistic right now or anytime soon, but should be considered to be implemented as a regulation.
- All UAV operators who operate in higher risk categories (e.g., the specific UAV category) must pass a practical UAV exam.
- All UAV operators must have, and use, checklists.
- Reporting of the following incidents: *all UAV related incidents where someone died or were serious injured, or if the incident could have resulted in this, are mandatory to report. Also, all incidents that had the potential of scoring a 3, 4 or 5 in the consequence table (e.g.,* Table 2-1*) must also be reported. In addition, all scenarios with close passage between unmanned- and manned aircraft must be reported.*

5.4 Analysis methods' limitations and self-criticism of the research

The analyses conducted in this thesis, as with most other analyse methods, do have their limitations. The results from these analyses may therefore not be entirely accurate of how the reality indeed is. They rather show examples or patterns of how the results may look. The following paragraphs discuss some of these limitations in addition to self-criticism of the research.

Both the preliminary risk assessment (appendix B) and the table of identified incidents and accidents (appendix A) includes potential consequences of the unwanted events which addresses the worst-case scenario. Because they address the worst-case scenario, some of these potential consequences may be viewed as unrealistic and they may never happen. Addressing such outcomes may be viewed as a weakness of the analysis methods because one might spend an unnecessary amount of time and expenses on preparing for scenarios that may never happen. However, preparing for a worst-case scenario may at the same time be viewed as a strength of the analysis methods due to that you prepare for the worst, meaning one are prepared with risk reduction measures for any given scenario to happen. Yet, the key may be to find the 'golden mean' of preparing for the worst-case scenario without spending too much time nor expenses. This is where the ALARP principle comes into play (see subchapter 2.3.4).

As seen in Table 3-3 and Table 3-4, there are a number of companies that have participated with data for this thesis, and some that chose not to. The companies that chose to participate with data about UAV incidents and accidents for this thesis may be the ones that have not encountered any major or critical occurrences, and those that have encountered these may have chosen to not participate with their data. This may also be the case the other way around. Should one of these scenarios be the case, the results of the identified data may not be accurate of how UAV incidents happen and what the consequences are.

The analysis methods used to analyse data in this thesis, and the data itself, do include limitations. Some more crucial than others. Therefore, the results that have emerged in this thesis may be viewed as pointers rather than unblemished results of how UAV related incidents and accidents happen and degenerates. By conducting other analysis methods, by decomposing the causes and consequences more thorough, by collecting more data and so on, the results may become more accurate. These suggested steps of potential research on this topic are elaborated more in subchapter 6.2.

6 Conclusions and recommendations for future research

This chapter presents conclusions based on the results and discussions of the objectives with the associated research questions of the thesis. In addition, recommendations for possible future research on the same topic are given.

6.1 Conclusions

Through literature reviews, data collecting, data processing and discussions of the results, there has been identified findings that may assist in answering the given research questions of thesis. A conclusion on, whether or not the research aim has been reached is included. The following bullet points address conclusions of the findings related to each of the research questions, in chronological order.

- Most UAV incidents and accidents happen due to either a human error, often in the form of fatigue or lack of knowledge or experience, or errors on the unmanned aircraft system. It was also found, through the use of extensive analyses, that a number of the UAS errors may be due to human errors in the form of lack of maintenance or operating a UAV in conditions it was not suited for. This may, therefore, be an indication that UAV incidents and accidents often may be prevented by the UAV operator being competent and does not suffer from fatigue. It has also been found that the outcomes of the identified UAV incidents and accidents have not yet been critical, however many of them had the potential of being so. Risk reduction measures to avoid incidents and accidents have also been identified, and there have been found several measures that may assist in preventing unwanted events from happening and those that can lower the consequences should they happen.
- There are indications that the regulation of what incidents to report is not clear enough. Some companies have experienced a frequency of up to 100 times more incidents and accidents than others, which may indicate that some companies do not report the incidents that they should (or vice versa). It has also been found that most of the incidents that are reported to the NCAA are not analysed in any way, which means that there may not be any point for the companies to report any incidents at all. What is more, it has been found that analysing incidents may contribute to coming up with appropriate risk reduction measures and proper rules and regulations. Based on that, there has been identified several risk reduction measures that currently are not included

in rules or regulations. By analysing the identified incidents and accidents, this may indicate that the process of incident reporting in the unmanned aviation industry should be revised. Perhaps the "just culture" from the manned aviation industry should be adopted as this has proven to assist in increased transparency.

- The current set of rules and regulations regarding UAV operations include several important rules and regulations and risk reducing measures. However, there has been identified several other risk reduction measures that may assist in decreasing the frequency and severity of consequence of unwanted events in the unmanned aviation industry. Some of these are easy to implement, following the ALARP principle. It can be concluded that the current set of rules and regulations do have a good concern for safety, still it can be improved by adding or revising some rules or regulations. This includes both risk reduction measures in addition to which incidents should be reported.

As this thesis aims to "contribute to transparency of unwanted events in the unmanned aviation industry", one cannot state that the aim of the thesis is met (or not) without sharing the results of the thesis with the industry, and then observe if the transparency is increased (or not). However, based on the results of the literature reviews, the analyses, the discussions and the conclusions, there is reason to believe that transparency may contribute to increasing safety. Both in the unmanned aviation industry and in general. If the transparency in the unmanned aviation industry will be increased due to the results of this thesis, is, however, currently unknown. It may though be stated that the content of this thesis contributes to transparency.

6.2 Recommendations for future research

Due to limitations of this thesis, there are aspects of the topic that could be interesting to conduct further research on. The following points include recommendations (or suggestions) for future research on the given topic:

- Conduct analyses of the safety regarding potential upcoming UAV related services. For instance, Amazon's plan on package delivery by UAVs.
- Conduct analyses and identification of risk reduction measures of UAV incidents related to sabotage. For instance, when UAVs are flown close to/over airports and interrupts manned aircraft traffic, causing dangerous situations and large economic losses. E.g., the Gatwick Airport UAV incident in 2018 (Shackle, 2020) where hundreds of manned aircraft flights were cancelled for hours.

- Decompose causes of UAV incidents and accidents more than in human-, UAS- and external errors to analyse further exactly what causes these incidents and accidents to happen, and identify even more appropriate risk reduction measures.
- Identify and analyse UAV incidents and accidents from countries that have other rules and regulations than Norway. E.g., the U.S. Do stricter rules and regulations result in a higher or lower frequency of incidents and accidents?

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Appendices

Table 7-1 Information about the appendices

Appendix	Appendix name	Pages
A	The table of collected incident and accident data	94-105
B	Preliminary risk assessment	106-109

Appendix A – The table of collected incident and accident data

This appendix presents the table of the collected incident and accident data. The explanations of the columns are as follows:

- "**Incident/Accident ID**" represents a unique, random ID for every incident and accident.
- "**Date**" represents when the incident/accident occurred. Format: Day.Month.Year.
- "**Type of company**" refers to if the company that had the incident/accident occur was a company that only perform UAV related operations or a company that did UAV related operations as a smaller part of their other main work (drone company and other company respectively).
- "**Type of occurrence**" represents if the given occurrence is an incident or an accident (see subchapter 2.2.2 for the difference between the two).
- "**Type of UAV**" represents which type of drone that was used for the given incident/accident. VTOL (Vertical Take-Off and Landing), multirotor (drones that provide lift by having vertically mounted motors) and fixed wing (a wing that provides lift instead of vertical mounted motors)
- "**Weight class**" represents which weight class the UAV used for the given incident/accident is in. See Table A 1. Given that some companies operate unique UAVs that few other companies operate, this weight class system was chosen to be used. This was done in order to ensure censorship.

Weight kg	Class 1-5
<0,25	1
0,25-1,0	2
1,0-2,5	3
2,5-5	4
>5	5

Table A 1 The UAV weight categories.

The reasonings for the categories are as follows:

1. 250g (C0-marked) regulation (Luftfartstilsynet, n.d.-d).
2. Common UAVs. Often used by "other companies" for both professional and non-professional operations.
3. Common UAVs, at a higher weight class. More damage should they fail. Often used by "other companies" for both professional and non-professional operations.
4. Less common UAVs. Used by both "drone companies" and "other companies". Often quite similar UAVs as category 2 and 3, but with capacity to lift heavier payload (e.g., better cameras).
5. Uncommon UAVs. Mostly used by "drone companies" for professional operations.

- "**Flight hours since last inspection**" represents the amount of flight hours since the UAV for the given incident/accident was inspected.

- “**Weather**” represents the weather conditions during the given incident/accident.
- “**Cause**” represents the assumed cause of why the given incident/accident happened. See subchapter 2.3.2 for explanations of each cause.
- “**Cause and consequences**” represents a short summary of the incident/accident with emphasis on the cause and consequences.
- “**Severity of consequence**” represents the severity of the consequences on a scale from 1-5, based on the consequence table (see Table 2-1).
- “**Potential consequences**” represents potential consequences that could have been the outcome of the incident/accident, in a worst-case scenario.
- “**Potential severity of consequence**” represents the potential severity of consequences on a scale from 1-5, based on the consequence table (see Table 2-1).

The incidents and accidents are not elaborated more than they are, due to censuring. See the table of the identified incidents and accidents starting from the following page. Zoom in to see the table clearer.

Incidentaccident ID	Date DD.MM.YYYY	Type of company Drone/Other	Type of occurence Incident/Accident	Type of UAV Multirotor/Fixed wing/VTOL	Weight class of UAV 1-5	Flight hours since last inspection	Weather Explained	Cause Human/External/UAS	Cause and consequences Explained	Severity of consequence 1-5	Potential consequences Explained	Potential severity of consequence 1-5
1	05.03.2018	Drone company	Accident	Multirotor	5	N/D	N/D	UAS error	Loss of link to UAV resulting in a fly-away. UAV crash into object. Damages to UAV only.	3	The UAV could have caused significant damage to the object, itself and the reputation of the operating company. The object could in a worst case scenario have been a person, and the UAV could have caused significant injuries or even death.	5
2	20.09.2021	Drone company	Accident	Multirotor	5	N/D	N/D	Human error	Pilot was unaware of nearby trees. UAV crash into tree. Damages to UAV only.	2	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
3	04.09.2021	Drone company	Accident	Multirotor	2	N/D	N/D	Human error	Pilot was unaware of nearby powerlines. UAV touched powerlines during flight. Damages to UAV only.	1	The UAV could have caused significant damage to the powerlines, itself and the reputation of the operating company. Reparations of the powerlines could have been costly.	4
4	06.05.2021	Drone company	Accident	Multirotor	2	N/D	N/D	Human error	Accidental emergency engine shut-off during flight by controller input (mode 2: left stick "south-west" and right stick "south-east"). Drone fell and crashed into the sea. Damages to UAV only.	2	The UAV could have caused significant damage to the environment (if pollution), itself and the reputation of the operating company. In a worst case scenario there could have been people located underneath the UAV, and the UAV could have caused significant injuries or even death.	5
5	24.03.2021	Drone company	Incident	Multirotor	5	N/D	N/D	UAS error	Landing gear retracted during engine test on ground after all engines' RPM increased by themselves. "Self adaptive landing gear"-function was not turned off. No damages.	1	The UAV could have caused significant damage to itself.	3
6	30.05.2019	Drone company	Incident	Multirotor	2	N/D	N/D	External error	Manned aircraft headed for the operation area of the UAV. UAV was descended. Manned aircraft did not fly in accordance with regulations. No damages.	1	The UAV and the manned aircraft could have had a mid-air collision. This could in a worst case scenario have ended in the manned aircraft crashing into the ground causing lives to be lost.	5
7	11.02.2018	Drone company	Incident	Multirotor	5	N/D	N/D	Human error	UAV displayed wrong battery voltage. UAV firmware was not updated. No damages	1	The UAV could have suddently ran out of power during flight without pilot knowing. In a worst case scenario, the UAV could have fell and hit people or buildings causing major injuries, death or damages.	5
8	17.06.2018	Drone company	Incident	N/D	N/D	N/D	N/D	External error	Third person flew a UAV next to operator's UAV. Third person did not comply with rules and regulations for UAVs. Near miss between the UAVs. No damages.	1	The UAVs could have had a mid-air collision and caused significant damages to both aircrafts.	3
9	18.04.2017	Drone company	Incident	N/D	N/D	N/D	N/D	Human error	UAV flown in altitude hold mode, and drifted into nearby bushes without pilot noticing. Crash, but no damages.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
10	11.08.2017	Drone company	Incident	N/D	N/D	N/D	N/D	Human error	UAV crashed into tree. Pilot flew FPV (first person view), and spotter did not aware pilot of trees before crash. No damages.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
11	15.02.2017	Drone company	Incident	Multirotor	2	N/D	N/D	UAS error	UAV reported faulty sensors during flight. Pilot ignored this due to that the UAV still was flyable. No damages.	1	The UAV could have had electrical issues, which could have suddently caused a loss of power during flight. In a worst case scenario, the UAV could have fell and hit a person or a building causing major injuries, death or damages.	5
12	01.11.2016	Drone company	Incident	N/D	N/D	N/D	N/D	UAS error	UAV descended by itself. Increased throttle input by pilot did not stop the UAV from descending. Poor GPS signals. UAV landed. No damages.	1	In a worst case scenario there could have been people or buildings close to or underneath the UAV. This could have been hit by the UAV, which would have caused major injuries or damages.	4
13	01.06.2016	Drone company	Accident	N/D	N/D	N/D	N/D	UAS error	Sudden loss of motor power during take-off. Damages to UAV only.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
14	14.05.2016	Drone company	Incident	N/D	N/D	N/D	N/D	UAS error	Sudden loss of GPS. UAV switched to altitude hold mode automatically without warning. Landed safely. No damages.	1	Nothing more significant than what happened.	1
15	10.07.2020	Other company	Accident	Multirotor	2	N/D	6 m/s wind. No precipitation.	UAS error	Loss of link resulting in a fly-away and crash into a mountain wall. UAV was never found.	2	The UAV could have caused significant damage to the reputation of the operating company. The object could in a worst case scenario have been a person, and the UAV could have caused significant injuries or even death.	5
16	01.07.2019	Other company	Accident	Multirotor	5	N/D	No wind. No precipitation.	UAS error	Loss of link resulting in a fly-away and crash into a mountain wall. Damages to UAV only.	2	The UAV could have caused significant damages to itself and the reputation of the operating company. The object could in a worst case scenario have been a person, and the UAV could have caused significant injuries or even death.	5
17	N/D	Other company	Incident	Multirotor	2	N/D	N/D	Human error	Pilot was unaware of nearby trees. UAV crash into tree. No damages.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3

18	N/D	Other company	Incident	Multirotor	2	N/D	N/D	Human error	Pilot was unaware of nearby trees. UAV crash into tree. No damages.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
19	07.04.2014	Other company	Incident	N/D	N/D	N/D	N/D	Human error	Pilot was unaware of nearby trees. UAV crash into tree. No damages.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
20	24.01.2016	Other company	Incident	N/D	N/D	N/D	N/D	External error	UAV was landing autonomously, but was off almost 100m from intended landing spot. This may have been due to icing on sensors. Landed in trees. No damages.	1	The UAV could have caused significant damages to itself and the reputation of the operating company. The trees could in a worst case scenario have been a person, and the UAV could have caused significant injuries.	4
21	04.05.2016	Other company	Accident	N/D	N/D	N/D	N/D	Human error	Autonomous flight was planned poorly. Altitude input in flight plan was lower than altitude of terrain. UAV crashed into ground. Damages to UAV only.	2	The UAV could have caused significant damages to itself and the reputation of the operating company. In a worst case scenario there could have been a person where the UAV crashed, and the UAV could have caused significant injuries or even death.	5
22	17.02.2017	Other company	Accident	Fixed wing	2	N/D	N/D	UAS error	Loss of link resulting in a fly-away. UAV crashed in a residential area. Damages to UAV only.	3	The UAV could have caused major damages to buildings, itself and the reputation of the operating company. There could in a worst case scenario have been a person where the UAV crashed, and the UAV could have caused significant injuries or even death.	5
23	02.06.2017	Other company	Accident	Multirotor	3	N/D	N/D	UAS error	Loss of link immediately after take-off resulting in a fly-away and crash into a wall. Damages to UAV only.	1	The UAV could have caused significant damages to itself and the reputation of the operating company. There could in a worst case scenario have been a person where the UAV crashed, and the UAV could have caused significant injuries.	4
24	02.01.2018	Other company	Accident	Multirotor	3	N/D	N/D	UAS error	Autonomous flight (Software: Pix4D). Loss of link after take-off. UAV drifts and lands upside down. Damages to UAV only.	1	The UAV could have caused significant damages to itself and the reputation of the operating company. There could in a worst case scenario have been a person where the UAV crashed, and the UAV could have caused significant injuries.	4
25	08.05.2018	Other company	Accident	Multirotor	3	N/D	N/D	Human error	UAV crashed into object during autonomous flight. Pilot observed wrong altitude of object and input wrong altitude into software. UAV fell 120 ft. Damages to UAV only.	2	The UAV could have caused major damages to the object, itself and the reputation of the operating company. There could in a worst case scenario have been a person where the UAV crashed, and the UAV could have caused significant injuries or even death.	5
26	20.06.2018	Other company	Incident	Multirotor	3	N/D	N/D	External error	Manned aircraft flew into the operation area of the UAV. Control tower of closest airport was notified, but misunderstanding of flight altitudes lead to the incident (control tower thought UAV operator flew X ft above mean sea level (AMSL), when in reality UAV operator flew X ft above ground level (AGL)). UAV was descended. No damages.	1	The UAV and the manned aircraft could have had a mid-air collision. This could in a worst case scenario have ended in the manned aircraft crashing into the ground causing lives to be lost.	5
27	04.08.2018	Other company	Accident	Multirotor	3	N/D	N/D	Human error	UAV crashed into tree during autonomous flight (Software: Pix4D). Mistaken height of tree by pilot. UAV fell and crashed into ground. Damages to UAV only.	2	The UAV could have caused significant damages to itself and the reputation of the operating company. There could in a worst case scenario have been a person where the UAV crashed, and the UAV could have caused significant injuries.	4
28	14.09.2018	Other company	Accident	Multirotor	3	N/D	N/D	UAS error	Loss of link during autonomous flight. Fly-away into a mountain wall at low height. Damages to UAV only.	1	The UAV could have caused major damages to itself and the reputation of the operating company. There could in a worst case scenario have been a person where the UAV crashed, and the UAV could have caused significant injuries or even death.	5
29	04.11.2018	Other company	Accident	Multirotor	2	N/D	N/D	Human error	Pilot was unaware of nearby trees. UAV crash into tree. Damage to UAV only.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
30	07.11.2018	Other company	Accident	Multirotor	3	N/D	N/D	Human error	Autonomous flight (Software: Pix4D) was planned poorly. Altitude input in flight plan was lower than altitude of terrain. UAV crashed into ground. Damages to UAV only.	2	The UAV could have caused significant damages to itself and the reputation of the operating company. In a worst case scenario there could have been a person where the UAV crashed, and the UAV could have caused significant injuries.	4

31	01.01.2019	Other company	Accident	Multirotor	3	N/D	N/D	Human error	Autonomous flight was planned poorly. Altitude input in flight plan was lower than altitude of terrain. UAV crashed into tree. Damages to UAV only.	1	The UAV could have caused significant damages to itself and the reputation of the operating company. In a worst case scenario there could have been a person where the UAV crashed, and the UAV could have caused significant injuries.	4
32	31.01.2019	Other company	Accident	Multirotor	3	N/D	N/D	UAS error	Loss of link after take-off resulting in a fly-away and crash into a wall. Damages to UAV only.	2	The UAV could have caused major damages to itself and the reputation of the operating company. There could in a worst case scenario have been a person where the UAV crashed, and the UAV could have caused significant injuries or even death.	5
33	28.02.2019	Other company	Accident	Multirotor	2	N/D	Clear sky.	Human error	Loss of visual line of sight (VLOS) to UAV due to sun in pilot's eyes. UAV crashed into object and fell. Damages to UAV only.	1	The UAV could have caused major damages to itself and the reputation of the operating company. There could in a worst case scenario have been a person underneath where the UAV crashed, and the UAV could have caused significant injuries or even death.	5
34	22.05.2019	Other company	Accident	Multirotor	5	N/D	N/D	UAS error	UAV suddenly driftet towards the wall of a building while in GPS mode. UAV crashed into the wall. Damages to UAV only.	3	The UAV could have caused significant damages to itself and the reputation of the operating company. In a worst case scenario there could have been a person where the UAV crashed, and the UAV could have caused significant injuries.	4
35	19.09.2019	Other company	Accident	Multirotor	N/D	N/D	N/D	UAS error	UAV suddenly fell during a flight and crashed into the roof of a building. This resulted in a fire that was put out relatively quick. Damages to UAV and roof of building.	2	The UAV could have caused major damages to itself, the building and the reputation of the operating company. There could have been a major delay in the project. There could in a worst case scenario have been a person where the UAV crashed, and the UAV could have caused significant injuries or even death.	5
36	19.04.2021	Other company	Accident	Multirotor	3	N/D	N/D	UAS error	UAV suddenly fell during a flight and crashed into the ground. After inspection done by manufacturer the cause was believed to be a battery fault. Damages to UAV only.	2	The UAV could have caused major damages to itself and the reputation of the operating company. There could in a worst case scenario have been a person where the UAV crashed, and the UAV could have caused significant injuries or even death.	5
37	18.08.2021	Other company	Accident	Multirotor	2	N/D	N/D	Human error	UAV hit bushes and crashed into ground while being flown manually. Damages to UAV only.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
38	03.04.2021	Other company	Accident	Multirotor	3	N/D	N/D	Human error	UAV hit object and crashed into ground while being flown manually. Damages to UAV only.	1	The UAV could have caused major damages to itself, the object and the reputation of the operating company. There could in a worst case scenario have been a person where the UAV crashed, and the UAV could have caused significant injuries or even death.	5
39	31.03.2021	Other company	Accident	Multirotor	1	N/D	N/D	Human error	While flying inside a tunnel in altitude hold mode, the UAV suddently crashed into the tunnel wall. This may have been due to a change in lightning which caused the UAV sensors to attempt to move the drone. Damages to UAV only.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
40	25.03.2021	Other company	Accident	Fixed wing	3	N/D	N/D	Human error	UAV was attempted to be landed with tailwind. UAV crashed into ground. Damages to UAV only.	2	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
41	13.02.2021	Other company	Accident	Multirotor	1	N/D	N/D	UAS error	Loss of link of UAV immediately after take-off. Resulted in a crash into ground. Damages to UAV only.	1	The UAV could have caused major damages to itself and the reputation of the operating company. There could in a worst case scenario have been a person where the UAV crashed, and the UAV could have caused significant injuries.	4
42	20.11.2020	Other company	Incident	Multirotor	3	N/D	N/D	UAS error	Loss of link during autonomous flight (software: Pix4D). UAV engaged failsafe and landed autonomously when reached low battery warning. No damages.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
43	22.09.2020	Other company	Accident	Multirotor	3	N/D	N/D	UAS error	Loss of link during autonomous flight. UAV finished mission and hovered over landing spot until empty battery. The UAV then crashed. Damages to UAV only.	1	The UAV could have caused significant damages to itself and the reputation of the operating company. There could in a worst case scenario have been a person close to where the UAV crashed, and the UAV could have caused significant injuries.	4
44	14.08.2020	Other company	Incident	Multirotor	3	N/D	N/D	UAS error	UAV suddenly did not respond to autonomous flight plan during flight. Manual mode was toggled and UAV landed. No damages.	1	Nothing more significant than what happened.	1

45	25.05.2020	Other company	Accident	Fixed wing	3	N/D	N/D	Human error	UAV was attempted to be landed with tailwind. UAV crashed into object. Damages to UAV only.	2	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
46	14.05.2020	Other company	Incident	Multirotor	3	N/D	N/D	UAS error	Loss of GPS signal during low altitude, manual flight close to glass objects. No damages.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
47	11.05.2020	Other company	Incident	Multirotor	3	N/D	N/D	UAS error	UAV battery became hot during flight. Battery meltet stuck to the UAV. No major damages.	1	The battery could have failed completely during flight which could have caused the UAV to fall. This could have resulted in significant damage to the UAV, to the reputation of the operating company and to a person or building should they have been located underneath the UAV when it fell.	5
48	10.02.2020	Other company	Accident	Multirotor	5	N/D	N/D	External error	Loss of GPS signal or compass caused the UAV to drift. May have been caused by a nearby high voltage facility. The UAV was landed during this drifting and touched a building wall while landing. Some parts of the UAV flew everywhere and almost hit a third person. Damages to UAV only.	1	The UAV could have caused significant damages to itself and the reputation of the operating company. The parts could in a worst case scenario have hit a person in the eyes or other critical places and caused major injuries.	4
49	23.10.2019	Other company	Incident	Multirotor	3	N/D	N/D	Human error	UAV almost hit by moving object during operation due to pilot looking at camera screen (First Person View, FPV). No damages.	1	The UAV could have caused major damages to itself, the object and the reputation of the operating company. The UAV could in a worst case scenario have fell and could have hit a person where the UAV crashed, which could have caused significant injuries or even death.	5
50	23.10.2019	Other company	Incident	Multirotor	3	N/D	N/D	Human error	Neck strap accidentally moved the right controller stick which caused the UAV to fly fast close to ground level. The pilot regained controlled fast. No damages.	1	The UAV could have hit the pilot which could have caused significant injuries ot the pilot, damage to the UAV and damaged reputation of the operating company.	4
51	07.10.2019	Other company	Accident	Fixed wing	3	N/D	N/D	Human error	UAV was attempted to be landed with tailwind. UAV crashed into ground. Damages to UAV only.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
52	25.05.2019	Other company	Accident	Fixed wing	3	N/D	N/D	Human error	Pilot miscalculated altitude of the UAV which caused a crash landing into ground. Damages to UAV only.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
53	23.04.2019	Other company	Accident	Multirotor	5	N/D	N/D	External error	Strong wind during landing caused UAV to overturn. Damages to UAV only.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
54	23.04.2019	Other company	Incident	Multirotor	5	N/D	N/D	External error	Third person suddently appeared close to operation area during flight. No damages.	1	Should something unexpected have happened with the UAV during the flight, in a worst cause scenrio it could have fell down and hit the third person causing major injuries or death.	5
55	29.03.2019	Other company	Accident	Multirotor	3	N/D	N/D	UAS error	UAV suddently banked, fell and crashed into ground from 10 ft AGL. Damages to UAV only.	1	The UAV could have caused significant damages to itself and the reputation of the operating company. There could in a worst case scenario have been a person underneath where the UAV crashed, and the UAV could have caused significant injuries.	4
56	08.06.2018	Other company	Incident	Multirotor	3	N/D	N/D	Human error	Loss of VLOS to drone due to sun in pilot's eyes. Return to home failsafe was engaged and worked. No damages.	1	The UAV could in a worst case scenario have hit somehing or someone before the pilot was able to engage failsafe. This could have caused significant injuries or damage to objects, people or the reputation of the operating company.	4
57	02.06.2017	Other company	Accident	Multirotor	3	N/D	N/D	UAS error	Loss of link immediately after take-off. Resulted in a fly-away and crash into a house wall. Damages to UAV only.	1	The UAV could have caused significant damages to itself and the reputation of the operating company. There could in a worst case scenario have been a person where the UAV crashed, and the UAV could have caused significant injuries.	4
58	04.08.2016	Other company	Accident	Multirotor	3	N/D	N/D	Human error	Autonomous flight (Software: Pix4D) was planned poorly. Altitude input in flight plan was lower than altitude of terrain. UAV crashed into tree and then into ground. Damages to UAV only.	2	The UAV could have caused significant damages to itself and the reputation of the operating company. In a worst case scenario there could have been a person where the UAV crashed, and the UAV could have caused significant injuries.	4
59	26.06.2021	Other company	Incident	Multirotor	3	N/D	Clear sky. No wind.	External error	Several manned aircrafts flew through operation area during UAV operation. Notice to Airmen (NOTAM) was sent by UAV operators, but ignored by manned aircraft pilots. No close calls due UAV pilot being attentive and descending UAV. No damages.	1	The UAV and the manned aircraft could have had a mid-air collision. This could in a worst case scenario have ended in the manned aircraft crashing into the ground causing lives to be lost.	5
60	09.09.2021	Other company	Incident	Multirotor	3	N/D	Clear sky. No wind.	External error	Manned aircraft flew into the operation area of the UAV at several occasions. No NOTAM was sent out. The UAV operator gave way, and delayed his operation. No close calls nor damages.	1	The UAV and the manned aircraft could have had a mid-air collision. This could in a worst case scenario have ended in the manned aircraft crashing into the ground causing lives to be lost.	5

61	24.01.2016	Drone company	Accident	Multirotor	5	1	Cloudy. -6 C, no wind.	External error	Icing occured during flight, causing one motor to fail. This resulted in a hard emergency landing. Damages to UAV only.	1	The UAV could have caused significant damages to itself and the reputation of the operating company. There could in a worst case scenario have been a person where the UAV landed , and the UAV could have caused significant injuries.	4
62	30.04.2016	Drone company	Accident	Multirotor	2	8	Partly cloudy, 8 C, no wind.	External error	Loss of link to UAV due to interference by nearby radio tower. UAV autonomically activated RTH which resulted in a crash into a tree. Damages to UAV only.	1	The UAV could have caused significant damages to itself and the reputation of the operating company. There could in a worst case scenario have been a person where the UAV landed , and the UAV could have caused	4
63	15.06.2019	Drone company	Accident	Multirotor	5	1,33	Partly cloudy, 14 C, 8 m/s wind.	External error	Strong wind during take-off caused UAV to flip and crash into ground. Damages to UAV only.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
64	12.09.2020	Drone company	Incident	Multirotor	5	25	Partly cloudy, 13 C, 2 m/s wind.	UAS error	Loss of link to UAV during flight. Return to home failsafe activated. UAV flew unctrolled over road with low traffic. Regained control after estimated 1 minute. No damages.	1	Nothing more significant than what happened.	1
65	02.06.2021	Drone company	Accident	Multirotor	5	N/D	Clear sky, 12 C, 5 m/s wind.	Human error	During take-off the UAV hit an object, causing it to fall and break completely. Damages to UAV only.	3	The object the UAV hit could have been a person, which could have caused significant damage to the UAV, the reputation of the operating company and injuries to the person.	3
66	20.10.2021	Drone company	Accident	Multirotor	5	N/D	N/D	Human error	During landing of the UAV the pilot grabbed the UAV in the air, and accidently touched one of the propellers. Damages to the UAV and the pilot's hand. Need for medical treatment.	2	The UAV could have injured the person more than what it did.	4
67	14.02.2016	Drone company	Accident	Multirotor	2	N/D	N/D	Human error	Pilot lost focus during flight indoor and the UAV crashed into a wall. Damages to UAV only.	1	The UAV could in a worst case scenario have hit a person. This could have caused significant injuries to the person and to the reputation of the operating company.	4
68	09.07.2017	Drone company	Accident	Multirotor	2	N/D	Clear sky, 15 C, no wind.	Human error	Pilot accidently turned the UAV the wrong way, causing the pilot to misunderstand the orientation of the UAV. This resulted in the UAV hitting a tree and was then landed. Damages to the UAV only.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
69	20.09.2017	Drone company	Incident	Multirotor	3	N/D	Clear sky, -7 C, 7 m/s wind.	UAS error	Loss of control of right controller stick (pitch and roll movement). UAV was landed manually by pilot. No damages.	1	In a worst case scenario the pilot could have not been able to control the UAV at all with only the left controller stick. This could have caused the UAV to crash into an object or a person, causing significant damage or injuries.	4
70	10.08.2017	Drone company	Accident	Fixed wing	3	N/D	Clear sky, 12 C, 2 m/s wind.	Human error	Pilot accidently pulled pitch (right controller stick forwards/backwards) forward too hard during landing, causing the UAV to crash into ground. Damages to UAV only.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
71	28.09.2017	Drone company	Accident	Fixed wing	3	N/D	Clear sky, 4 C, 2 m/s wind.	Human error	Pilot accidently pulled pitch forward instead of pitch backwards during landing, causing the UAV to crash into ground. Damages to UAV only.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
72	17.11.2017	Drone company	Incident	Fixed wing	3	N/D	Clear sky, -15 C, no wind.	UAS error	Loss of link of UAV during flight. UAV automatically engaged failsafe and landed where it was located at time of control loss. Landed estimated 200 meters from take-off. No damages.	1	In a worst case scenario there could have been people or buildings close to or underneath the UAV. This could have been hit by the UAV, which would have caused significant injuries or damages.	4
73	05.06.2017	Drone company	Accident	Multirotor	3	N/D	Partly cloudy, 8 C, 2 m/s wind.	Human error	Pilot miscalculated speed and heading of UAV, and crashed into a tree. Damages to UAV only.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
74	23.08.2018	Drone company	Accident	Multirotor	3	N/D	Some rain, 12 C, no wind.	Human error	Pilot was training on flying UAV in altitude mode (no GPS) and lost control of UAV. UAV hit an object. Damages to UAV only.	2	The UAV could have caused significant damage to itself and the reputation of the operating company. In a worst case scenario the object could have been a person, which could have resulted in injuries.	4
75	24.09.2019	Drone company	Incident	Fixed wing	3	N/D	Clear sky, 4 C, 1 m/s wind.	UAS error	During autonomous flight the computer that sent information to the UAV ran out of power. UAV continued flight and computer was reconnected. No damages.	1	In a worst case scenario the UAV could have had a fly-away which could have resulted in the UAV hitting an object or a person. This could have caused major damages or injuries.	4

76	16.03.2018	Drone company	Incident	Fixed wing	3	N/D	N/D	External error	A helicopter suddently appeared at same altitude as UAV while operating with UAV. The distance between the two was estimated to be 200 meters, both heading towards each other. The UAV pilot descended the UAV instantly. No damages.	1	The UAV and a manned aircraft could have had a mid-air collision. This could have ended in the manned aircraft crashing into the ground causing lives to be lost.	5
77	01.07.2020	Drone company	Incident	N/D	N/D	N/D	N/D	UAS error	During autonomous flight the software used for programming the flight (Pix4D) shut down. The UAV continued to fly autonomously. Pilot engaged return to home function, which worked. No damages.	1	Nothing more significant than what happened.	1
78	13.03.2021	Drone company	Incident	Multirotor	5	N/D	Clear sky, -5 C, 5 m/s wind.	Human error	Unusual sound from UAV was heard during flight. The UAV was landed and it was noticed that a propeller was not fastened correctly. No damages.	1	In a worst case scenario the propeller could have fell off during flight, which could have caused the UAV to fall. This could have resulted in the UAV hitting a person or object, causing significant damage, injuries or death.	5
79	20.04.2021	Drone company	Incident	Multirotor	5	N/D	Clear sky, 12 C, 8 m/s.	UAS error	Loss of link to UAV immediately after take-off during manual flight. UAV flew fast in one direction close to ground before it stopped when pilot toggeled off GPS mode. No damages.	1	The UAV could have caused significant damages to itself and the reputation of the operating company. There could in a worst case scenario have been a person where the UAV flew, and the UAV could have caused	4
80	04.08.2021	Drone company	Incident	Multirotor	1	N/D	Clear sky, 10 C, 5 m/s wind.	UAS error	Pilot switched to autonomous flight (software: Litchi) during operation, but because of the wind the UAV did not manage to fly the intended route back to the pilot. Pilot was unable to switch back to manual flight. The wind then decreased and the UAV flew back to take-off point. No damages.	1	The UAV could have had a fly-away if the wind strength did not decrease. This could in a worst case scenario have resulted in the UAV hitting a person or an object, causing significant damage, injuries or death.	5
81	23.09.2021	Drone company	Accident	Fixed wing	3	N/D	Clear sky, 12 C, 4 m/s wind.	Human error	Pilot lost control of UAV during flight, resulting in the UAV having a fly-away out of sight of the pilot. The UAV almost hit a car and a personell before it crashed into ground. No damages.	1	The UAV could have caused significant damages to itself and the reputation of the operating company. The UAV could in a worst case scenario have hit a person or an object, causing significant damage, injuries or death.	5
82	18.02.2021	Drone company	Accident	Multirotor	2	N/D	N/D	UAS error	Sudden loss of power during flight. UAV fell and crashed into ground. After investigation it was noticed that one of the cables from the battery was ripped. Damages to UAV only.	1	The UAV could have caused significant damages to itself and the reputation of the operating company. The UAV could in a worst case scenario have hit a person or an object, causing significant damage, injuries or death.	5
83	05.07.2021	Drone company	Incident	VTOL	5	N/D	N/D	Human error	The UAV tilted to one side during flight. Landed quickly after realising the issue. May have been due to insufficient compass calibration in prior to flight. No damages.	1	Nothing more significant than what happened.	1
84	23.09.2021	Drone company	Accident	VTOL	5	N/D	N/D	Human error	The UAV crashed not long after take-off. Turned out the aileron cables of the right and left wing were reversed. Manual input caused the crash. Damages to UAV only.	1	The UAV could have caused significant damages to itself and the reputation of the operating company. The UAV could in a worst case scenario have hit a person or an object, causing significant damage, injuries or death.	5
85	18.11.2021	Drone company	Incident	VTOL	5	N/D	N/D	Human error	Personnel flew a UAV closer than intended to another UAV flown by the same company. No damages.	1	The UAVs could have had a mid-air collision and caused significant damages to both aircrafts.	3
86	13.07.2021	Drone company	Accident	VTOL	5	N/D	N/D	UAS error	Loss of link during autonomous flight. Not possible to initiate manual control. Failsafe caused the UAV to land after a given amount of time, at a safely placed landing spot. Hard landing. Damages to UAV only.	2	In a worst case scenario there could have been people where the UAV landed. The UAV could have caused injuries to the people.	3
87	15.07.2021	Drone company	Incident	VTOL	5	N/D	N/D	UAS error	The UAV suddently engaged failsafe (land where it is) during an autonomous flight. No damages.	1	In a worst case scenario there could have been people where the UAV landed. The UAV could have caused injuries to the people.	3
88	30.07.2021	Drone company	Accident	VTOL	5	N/D	N/D	Human error	The UAV suddently started descending quickly during autonomous flight and landed hard. After inspection of the UAV it turned a motor was not corrently fastened and may have lost power mid-air. Damages to UAV only.	1	In a worst case scenario there could have been people where the UAV landed. The UAV could have caused injuries to the people.	3
89	10.08.2021	Drone company	Accident	VTOL	5	N/D	N/D	UAS error	UAV battery started smoking during landing. Damages to battery and UAV only.	2	The battery could have failed completely during flight which could have caused the UAV to fall. This could have resulted in significant damage to the UAV, to the reputation of the operating company and to a person or building should they have been located underneath the UAV when it fell.	5
90	10.09.2021	Drone company	Incident	VTOL	5	N/D	N/D	UAS error	The UAV suddently engaged failsafe (land where it is) during an autonomous flight. No damages.	1	In a worst case scenario there could have been people where the UAV landed. The UAV could have caused injuries to the people.	3

91	29.09.2021	Drone company	Accident	VTOL	5	N/D	N/D	UAS error	The UAV started acting up during autonomous flight. Land command was therefore engaged, but the UAV started descending while flying forward. Resulted in a crash in a tree. Damages to UAV only.	2	The UAV could have caused significant damages to itself and the reputation of the operating company. The UAV could in a worst case scenario have hit a person or an object, causing significant damage, injuries or death.	5
92	13.10.2021	Drone company	Incident	VTOL	5	N/D	N/D	UAS error	Loss of link to UAV during autonomous flight. The UAV engaged failsafe mode (land at given GPS point) after a given amount of time. Landed safely. No damages.	1	Nothing more significant than what happened.	1
93	19.11.2021	Drone company	Incident	VTOL	5	N/D	N/D	UAS error	Loss of link of UAV during autonomous flight. The UAV engaged failsafe mode (land at given GPS spot). Landed safely. No damages.	1	Nothing more significant than what happened.	1
94	26.11.2021	Drone company	Incident	VTOL	5	N/D	N/D	External error	Severe icing during autonomous flight caused the UAV to not being able to ascend. The UAV engaged failsafe (land at given GPS point). Landed safely. No damages.	1	The icing could in a worst case scenario have caused the UAV to fail completely and fall. This could have resulted in the UAV hitting a person or an object, causing significant damage, injuries or death.	5
95	28.12.2021	Drone company	Incident	VTOL	5	N/D	N/D	UAS error	UAV battery level depleted fast during flight, resulting in the motors stopping and the UAV engaging failsafe (land at given GPS point). Damages to batteries and UAV only.	1	In a worst case scenario there could have been people where the UAV landed. The UAV could have caused injuries to the people.	3
96	31.12.2021	Drone company	Incident	VTOL	5	N/D	N/D	Human error	The UAV's heading during autonomous flight was way off. After a while, the pilot engaged failsafe (land at a given GPS point). May have been due to insufficient compass calibration in prior to flight. No damages.	1	In a worst case scenario there could have been people where the UAV landed. The UAV could have caused injuries to the people.	3
97	28.01.2022	Drone company	Accident	VTOL	5	N/D	N/D	UAS error	Loss of link during autonomous flight which resulted in a fly-away. UAV crashed into a tree. Damages to UAV only.	2	The UAV could have caused significant damage to itself and the reputation of the operating company. The tree could in a worst case scenario have been a person, and the UAV could have caused significant injuries or even death.	5
98	11.03.2022	Drone company	Accident	VTOL	5	N/D	N/D	UAS error	Loss of link during autonomous flight which resulted in a fly-away. UAV crashed into a mountain side. Damages to UAV only.	1	The UAV could have caused significant damage to itself and the reputation of the operating company. The tree could in a worst case scenario have been a person, and the UAV could have caused significant injuries or even death.	5
99	02.03.2022	Drone company	Incident	Multirotor	3	N/D	N/D	UAS error	Sudden loss of camera feed during flight, in VLOS. UAV was landed safely immediately after noticing. No damages.	1	Nothing more significant than what happened.	1
100	03.02.2022	Drone company	Accident	Multirotor	3	N/D	N/D	UAS error	Loss of link during manual flight over ocean. UAV engaged failsafe (land at current location), resulting in a crash into the ocean. Loss of UAV.	3	In a worst case scenario the UAV could have ended up landing on a boat with people, injuring the people, the UAV and the boat.	4
101	03.02.2022	Drone company	Incident	Multirotor	3	N/D	Cloudy, 5 m/s wind.	UAS error	UAV compass errors during manual flight after take-off. Heading of UAV compass was incorrect. UAV was quickly landed. No damages.	1	The UAV could have become hard to control due to the compass error, making the UAV crash. In a worst case scenario the UAV could have hit a person, causing injuries.	4
102	02.02.2022	Drone company	Incident	Fixed wing	5	N/D	Cloudy.	UAS error	Loss of link during flight. The UAV engaged failsafe (return to launch) and control was regained. No damages.	1	Nothing more significant than what happened.	1
103	02.02.2022	Drone company	Accident	Multirotor	3	N/D	Clear sky, 3 C, 7 m/s wind.	Human error	Pilot attempted to land the UAV in a grass field. Before the UAV touched the ground a leg of the UAV got caught in some grass, causing the UAV to flip and crash. Damages to UAV only.	1	The UAV could have caused significant damage to itselff. In a worst case scenario, parts of the UAV could have been thrown from the UAV, hit personnel and caused significant injuries.	4
104	28.01.2022	Drone company	Accident	Fixed wing	5	N/D	N/D	UAS error	Loss of link of UAV during autonomous flight. Control was regained quickly with another type of link. No damages.	1	Nothing more significant than what happened.	1
105	08.12.2021	Drone company	Incident	N/D	5	N/D	Cloudy, 10 m/s wind.	UAS error	UAV suddently started ascending uncontrollably during flight. Stopped ascending after 5 seconds, and pilot regained control. Turned out to be IMU error. No damages.	1	The UAV could have continued ascend until loss of battery power, causing it to fall from great height. In a worst case scenario there could have been people where the UAV would crash, causing significant injuries or death.	5
106	29.10.2021	Drone company	Incident	Multirotor	5	N/D	Clear sky.	UAS error	Loss of link to UAV during flight. UAV automatically engaged failsafe (return to launch). No damages.	1	Nothing more significant than what happened.	1
107	25.10.2021	Drone company	Incident	Multirotor	5	N/D	N/D	UAS error	UAV suddently started ascending and turning uncontrollably during manual flight. Pilot engaged return to home (RTH) and the UAV was landed safely. No damages.	1	Nothing more significant than what happened.	1
108	25.10.2021	Drone company	Incident	Multirotor	5	N/D	N/D	UAS error	UAV suddently reported errors to all sensors during flight. UAV was landed. No damages.	1	UAV could have suffered electrical errors which could have resulted in a loss of power. This could have caused the UAV to fall. In a worst case scenario there could have been people where the UAV would crash, causing significant injuries or death.	5
109	18.10.2021	Drone company	Accident	Multirotor	5	N/D	Cloudy, 7 C, 11 m/s wind.	UAS error	Loss of motor power on one motor during flight. Due to the UAV having more than 4 motors, it was still controllable. Resulted in a hard landing. Damages to UAV only.	1	When one motor loss power, multiple could have lost power. This could have caused the UAV to fall and in worst case hit a person. Could have resulted in injuries or death.	5

110	30.09.2021	Drone company	Accident	Multirotor	5	N/D	Cloudy, 5 m/s wind.	Human error	Poor landing by pilot, and the UAV fell over. Damages to UAV only.	1	The UAV could have caused significant damages to itself and the reputation of the operating company. In a worst case scenario, parts of the UAV could have been thrown from the UAV, hit personnel and caused significant injuries.	4
111	27.08.2021	Drone company	Accident	Multirotor	5	N/D	Clear sky. No wind.	UAS error	Loss of link during manual flight. UAV suddenly started drifting to one side towards a wall without the pilot being able to counteract this drift with opposite controller input. UAV crashed into wall. Damages to UAV only.	3	The UAV could have caused significant damage to itself and the reputation of the operating company. The wall could in a worst case scenario have been a person, and the UAV could have caused significant injuries.	4
112	19.08.2021	Drone company	Incident	Multirotor	5	N/D	N/D	Human error	The UAV almost crashed during take-off due to payload was misplaced by operator. The UAV was back-heavy. UAV landed safely. No damages.	1	The UAV could have crash landed and caused significant damages to itself and the reputation of the operating company. In a worst case scenario, parts of the UAV could have been thrown from the UAV, hit personnel and caused significant injuries.	4
113	08.07.2021	Drone company	Incident	Multirotor	3	N/D	N/D	Human error	UAV reported vibration during flight. UAV was landed and it was noticed that a motor was not securely fastened. No damages.	1	In a worst case scenario the motor could have failed completely causing the UAV to fall. If people were underneath the UAV at the time, they could have been hit and injured hard or be killed.	5
114	22.06.2021	Drone company	Incident	Multirotor	3	N/D	N/D	External error	During operations with two UAVs both UAVs experienced GPS and compass errors. Both UAVs were landed safely. No damages.	1	Nothing more significant than what happened.	1
115	08.06.2021	Drone company	Incident	Multirotor	3	N/D	N/D	Human error	During a flight the pilot accidently turned off the radio transmitter. The UAV engaged failsafe (hover). Transmitter was turned back on and UAV landed safely. No damages.	1	In a worst case scenario the UAV could have ran out of battery power, and fell down. This could have caused significant damage to the UAV and to the reputation of the operating company.	3
116	23.05.2021	Drone company	Incident	Multirotor	3	N/D	Clear sky. No wind.	UAS error	Loss of link during manual flight. UAV engaged failsafe (hover) while pilot repositioned to regain link. UAV was landed safely. No damages.	1	If the pilot did not manage to regain link, the UAV could have descended by itself causing damage to the UAV.	3
117	19.05.2021	Drone company	Incident	Multirotor	5	N/D	N/D	Human error	Loss of link during manual flight. The pilot flew the UAV behind a small hill and lost link instantly. Pilot repositioned and regained link. UAV was landed safely. No damages.	1	If the pilot did not manage to regain link, the UAV could have descended by itself causing damage to the UAV	3
118	16.05.2021	Drone company	Accident	Multirotor	5	N/D	Clear sky. No wind.	UAS error	Loss of link during flight over the ocean. UAV engaged failsafe (hover) while pilot attempted to regain link. Link was not regained and the UAV crashed into the sea after a while. Damages to UAV only.	2	In a worst case scenario the UAV could have ended up landing on a boat with people, injuring the people, the UAV and the boat.	4
119	05.05.2021	Drone company	Incident	Multirotor	5	N/D	Cloudy, 8 C, 15 m/s wind.	UAS error	Loss of link during manual flight. UAV started descending slowly. It eventually stopped and hovered. Autonomous flight was engaged and UAV worked fine. No damages.	1	The UAV could have ended up descending until it crashed into ground. Could have caused damages to the UAV.	3
120	26.04.2021	Drone company	Incident	Multirotor	3	N/D	Rainy (within UAV limits), no wind.	UAS error	Loss of link during flight. The UAV engaged failsafe (hover) while pilot attempted to regain link. Link was regained and UAV landed safely. No damages.	1	If the pilot was not able to regain link, the UAV could have ran out of power and landed by itself. This could have caused damage to the UAV as it would maybe not land well.	3
121	24.04.2021	Drone company	Accident	Multirotor	3	N/D	N/D	UAS error	Loss of link during flight. The UAV engaged failsafe (return to launch). While the UAV was landing automatically it descended faster than intended. It crash landed and the motors first stopped when one of the motor cables were cut by a propeller. Damages to UAV only.	2	The UAV could have caused significant damages to itself and the reputation of the operating company. In a worst case scenario, parts of the UAV could have been thrown from the UAV, hit personnel and caused significant injuries.	4
122	15.04.2021	Drone company	Incident	Multirotor	5	N/D	N/D	UAS error	Loss of link during manual flight. The UAV engaged failsafe (return to launch) and link was regained after a few minutes. The UAV was landed safely. No damages.	1	Nothing more significant than what happened.	1
123	08.04.2021	Drone company	Incident	Multirotor	5	N/D	N/D	UAS error	Loss of link during autonomous flight. The UAV engaged failsafe (return to launch) and link was regained when UAV came closer to launch. No damages.	1	Nothing more significant than what happened.	1
124	25.03.2021	Drone company	Incident	Multirotor	3	N/D	N/D	UAS error	During flight the estimated flight time suddenly dropped from 27 to 7 minutes. The UAV was quickly landed. It was assumed to be a battery error due to the battery health being 59 %. Battery was discarded.	1	If not noticed by the pilot, the UAV could have run out of battery power during flight causing the UAV to being have to be landed where not intended. Could have caused damage to the UAV.	3
125	19.03.2021	Drone company	Accident	Multirotor	5	N/D	N/D	UAS error	During an autonomous flight (software: Litchi) the UAV suddenly descended and landed when it shouldn't have. After inspecting flight plan it was noticed that a waypoint of the flight plan was set to a negative altitude, instead of the intended positive. This was apparently not human error, but a software error. No damages.	1	In a worst case scenario, there could have been people located where the UAV landed. This could have caused a bad reputation of the operating company and injuries to the people.	4
126	17.02.2021	Drone company	Accident	Multirotor	5	N/D	Partly cloudy.	Human error	During an autonomous flight the UAV suddenly disarmed all motors, when the intention was to return to launch, land and then disarm motors. This was programmed wrong by operator. Damages to UAV only.	2	In a worst case scenario, there could have been people located where the UAV crashed. This could have caused a bad reputation of the operating company, significant damages to the UAV and critical injuries or death to the people.	5

127	20.01.2021	Drone company	Accident	Multirotor	3	N/D	Clear sky, no wind.	UAS error	Loss of link during an autonomous flight. The UAV started descending, and eventually descending into a tree. Damages to UAV only.	1	In a worst case scenario, there could have been people located where the UAV crashed. This could have caused a bad reputation of the operating company, significant damages to the UAV and critical injuries to the people.	4
128	08.01.2021	Drone company	Incident	Multirotor	3	N/D	N/D	Human error	During a manual flight it was suddently noticed that the home point was continuously changing to where the UAV was located. This could have resulted in the UAV landing straight down if the failsafe (return to home point) was engaged. No damages.	1	If the return to home failsafe was engaged, in a worst case scenario there could have been people located underneath where the UAV was landing. Could have caused injuries to the people and a bad reputation to the operating company.	4
129	18.12.2021	Drone company	Accident	Multirotor	5	N/D	Clear sky, no wind.	UAS error	One propeller fell off during flight. UAV was landed safely. Damages to UAV only.	1	In a worst case scenario the UAV could have fell. If people were underneath the UAV at the time, they could have been hit and injured hard or be killed.	5
130	12.11.2020	Drone company	Incident	Multirotor	5	N/D	Cloudy, some wind.	Human error	Loss of radio transmitter link during autonomous flight. The link between UAV and ground control station (GCS) was not lost. Pilot positioned himself in a place where there was no line of sight between him and the UAV.	1	Nothing more significant than what happened.	1
131	22.10.2020	Drone company	Incident	N/D	N/D	N/D	Partly cloudy, 5 m/s wind.	Human error	The pilot did not change failsafe from "return to launch" to "return to current transmitter position" before flight from ship. This was noticed after the flight was performed. No damages.	1	The UAV could have ended up landing in the ocean if it were to engage failsafe. This could have caused damages to the UAV, and in worst case have hit a boat with people causing injuries to the people, damage to the boat and a bad reputation for the operation company.	4
132	11.10.2020	Drone company	Accident	Multirotor	3	N/D	Partly cloudy, 12 C, rainy and no wind.	UAS error	During operation in rainy conditions, it was concluded to land the UAV and wait until rain stopped. Return to launch was engaged, but during the landing all motors stopped and the UAV fell into the ocean.	2	Nothing more significant than what happened.	2
133	24.08.2020	Drone company	Accident	Multirotor	4	N/D	Partly cloudy.	Human error	Loss of propeller right after take-off. UAV crashed into ground from 6 ft height. Most likely a human error, either lack of maintenance or operator fastened propellers incorrectly. Damages to UAV only.	2	In a worst case scenario, parts of the UAV could have been thrown from the UAV, hit personnel and caused significant injuries.	4
134	21.08.2020	Drone company	Accident	Multirotor	3	N/D	N/D	Human error	The pilot landed the UAV while maneuvering the UAV horizontally. Resulted in the UAV touching the ground with two out of the four legs first, making it flip upside down. Damages to UAV only.	1	In a worst case scenario, parts of the UAV could have been thrown from the UAV, hit personnel and caused significant injuries.	4
135	17.07.2020	Drone company	Incident	Multirotor	3	N/D	Clear sky, no wind.	External error	Loss of link to UAV when a military vessel passed underneath the UAV during an operation. UAV engaged failsafe (return to launch) and landed safely. No damages.	1	Nothing more significant than what happened.	1
136	19.05.2020	Drone company	Accident	Multirotor	5	N/D	Clear sky.	Human error	The UAV flipped upside down during take-off due to that two propellers were mounted on the wrong motors. Damages to UAV only.	1	In a worst case scenario, parts of the UAV could have been thrown from the UAV, hit personnel and caused significant injuries.	4
137	05.05.2020	Drone company	Accident	Multirotor	3	N/D	Clear sky, no wind.	Human error	Loss of link during flight. Return to home was initiated. Due to the return to home function being set to that the UAV should return to current transmitter location and not to launch point, and that the pilot was standing under a tree, the UAV crashed into the tree. Damages to UAV only.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
138	16.01.2020	Drone company	Incident	Multirotor	5	N/D	Cloudy, some wind.	UAS error	Loss of one motor during flight. Due to the UAV having more than 4 motors, the UAV was still controllable and was anded safely. Damages to UAV only.	1	When one motor lost power, multiple could have lost power. This could have caused the UAV to fall and in worst case hit a person. Could have resulted in injuries or death.	5
139	13.09.2019	Drone company	Accident	Fixed wing	5	N/D	Partly cloudy, 14 C, 4 m/s wind.	UAS error	During a manual flight the pilot lost sight of the UAV, resulting in a loss of link to the UAV. The UAV then engaged failsafe (return to launch), and appeared over the pilot after a while. However, the UAV did not land at launch and had a fly-away and crashed into ground near a road with high traffic density. Damages to UAV only.	2	The UAV could have caused significant damage to the reputation of the operating company. There could in a worst case scenario have been located people where the UAV crashed, and the UAV could have caused significant injuries or even death. Could also have caused cars to collide which also could have killed people.	5
140	16.09.2019	Drone company	Accident	Fixed wing	5	N/D	Clear sky, 14 C, 6 m/s wind.	UAS error	Loss of link to UAV during autonomous flight. The UAV had a fly-away over a main road and crashed in a forrest. Damages to UAV only.	2	The UAV could have caused significant damage to the reputation of the operating company. There could in a worst case scenario have been located people where the UAV crashed, and the UAV could have caused significant injuries or even death. Could also have caused cars to collide which also could have killed people.	5
141	03.02.2020	Drone company	Accident	Fixed wing	5	N/D	Clear sky, -3 C, 2 m/s wind.	Human error	Loss of camera feed during manual flight. The pilot focused on troubleshooting the camera feed instead of focusing on flying the UAV. This resulted in the UAV crashing into ground. Damages to UAV only.	2	The UAV could have caused significant damage to the reputation of the operating company. There could in a worst case scenario have been located people where the UAV crashed, and the UAV could have caused significant injuries or even death.	5

142	25.07.2017	Drone company	Accident	Multirotor	5	N/D	N/D	External error	Loss of link during flight caused the UAV to have a fly-away and land hard. Damages to UAV only.	2	The UAV could have caused significant damage to the reputation of the operating company. There could in a worst case scenario have been located people where the UAV crashed, and the UAV could have caused significant injuries.	4
143	11.10.2017	Drone company	Accident	Fixed wing	5	N/D	N/D	UAS error	UAV suddently entered a flat spin (concidered unrecoverable by operator) during an autonomous flight. Resulted in the UAV crashing into ground. Damages to UAV only.	3	The UAV could have caused significant damage to the reputation of the operating company. There could in a worst case scenario have been located people where the UAV crashed, and the UAV could have caused significant injuries.	4
144	06.04.2017	Drone company	Accident	Multirotor	5	N/D	Partly cloudy, 3 m/s wind.	UAS error	The UAV suddently started drifting during flight. The pilot attempted to counteract this drift, but without being able to. Resulted in the UAV countinuing to drift and crashing into ground. Damages to UAV only.	3	The UAV could have caused significant damage to the reputation of the operating company. There could in a worst case scenario have been located people where the UAV crashed, and the UAV could have caused significant injuries.	4
145	14.01.2021	Drone company	Accident	Fixed wing	5	N/D	Clear sky, -10 C, 1 m/s wind.	UAS error	Loss of link during a flight resulting in a fly-away and crash into ground. Damages to UAV only.	2	The UAV could have caused significant damage to the reputation of the operating company. There could in a worst case scenario have been located people where the UAV crashed, and the UAV could have caused significant injuries or death.	5
146	01.07.2016	Other company	Accident	Multirotor	5	N/D	Clear sky.	UAS error	Loss of motor power during flight. UAV fell approximately 400 feet and crashed into ground 50 meters from road with high traffic. Damages to UAV only.	2	The UAV could have caused significant damage to the reputation of the operating company. There could in a worst case scenario have been located people where the UAV crashed, and the UAV could have caused significant injuries or death.	5
147	03.04.2017	Other company	Accident	Multirotor	5	N/D	Clear sky.	UAS error	1 out of 8 motors fell off the UAV during flight. UAV was landed safely. Damages to UAV only.	1	Nothing more significant than what happened.	1
148	10.05.2018	Other company	Accident	Multirotor	3	N/D	Clear sky.	UAS error	UAV suddently fell and crashed into ground from about 30 feet height. Cause was assumed to be a worn out propeller. Damages to UAV only.	1	The UAV could have caused significant damage to the reputation of the operating company. There could in a worst case scenario have been located people where the UAV crashed, and the UAV could have caused significant injuries or death.	5
149	01.06.2019	Other company	Incident	Multirotor	3	N/D	Clear sky.	External error	Manned aircraft and UAV had a near miss. UAV was flown legally, and UAV activity was reported. No damages.	1	The UAV and the manned aircraft could have had a mid-air collision. This could in a worst case scenario have ended in the manned aircraft crashing into the ground causing lives to be lost.	5
150	02.08.2019	Other company	Accident	Multirotor	3	N/D	Clear sky.	Human error	Pilot was unaware of nearby trees. UAV crash into tree. Damages to UAV only.	1	The UAV could have caused significant damage to itself and the reputation of the operating company.	3
151	11.07.2019	Other company	Accident	Multirotor	3	N/D	Clear sky.	UAS error	UAV suddently started spinning and falling towards ground. Crashed into ground from about 200 feet height. Damages to UAV only.	2	The UAV could have caused significant damage to the reputation of the operating company. There could in a worst case scenario have been located people where the UAV crashed, and the UAV could have caused significant injuries or death.	5
152	19.09.2019	Other company	Incident	Multirotor	3	N/D	Clear sky.	External error	Manned aircraft flew past UAV during operation at just under 400 feet height. No damages.	1	The UAV and the manned aircraft could have had a mid-air collision. This could in a worst case scenario have ended in the manned aircraft crashing into the ground causing lives to be lost.	5
153	05.04.2019	Other company	Incident	Multirotor	3	N/D	N/D	UAS error	One propeller fell off during landing. UAV was landed safely. No damages.	1	In a worst case scenario the propeller could have fell off during flight at great height, which could have caused the UAV to fall. This could have resulted in the UAV hitting a person or object, causing significant damage, injuries or death.	5
154	24.05.2019	Other company	Incident	Multirotor	3	N/D	Clear sky.	External error	Loss of GPS during flight. UAV was landed safely. Cause was assumed to be GPS jamming by a passing semi truck. No damages.	1	Nothing more significant than what happened.	1

Appendix B – The preliminary risk assessment

This appendix presents the preliminary risk assessment conducted for this thesis. See subchapter 2.4.4 for theory on this type of assessment.

Risk ID	Type of hazard What kind of hazard is it?	Unwanted event What could go wrong?	Consequences What can be the worst potential outcome?	Potential causes for the unwanted event How may the unwanted event occur? (May be several causes)	Frequency What is the estimated likelihood of the unwanted event happening? (1-5)	Severity of consequence How significant can the impact be? (1-5)	Risk index Calculation (Frequency * severity of consequence)	Corrective and preventive measures (frequency- and consequence reducing) What may help mitigate the hazard?	New frequency What is the estimated likelihood of the unwanted event happening, after measures? (1-5)	New severity of consequence How significant can the impact be, after measures? (1-5)	New risk index Calculation (New frequency * New severity of consequence)
1	External hazards	Snow and ice accumulation on UAV (that is vulnerable to this) during flight	The UAV may have to be landed on an unfavorable spot or in a worst case scenario it may fall and hit people, buildings or other structures because of changed flying properties, too much weight added or blocked sensors. May cause significant damages, injuries or even death.	* Low temperatures * Polar low *Precipitation * High humidity	2	5	10	* Regular service and routine check-ups. Checklists before operation start. * Use and read weather forcasts before operation start. * Prevent operating in weather that the UAV is not suitable for. * De-icing equipment or solution on the UAV.	1	5	5
2		The wind strength increases considerably during the operation (to a higher wind strength than what the UAV is rated to withstand)	The UAV pilot may have to cancel the operation and land. In a worst case scenario the UAV may either fall or get carried away by the wind, away from the pilot and may result in it hitting people or buildings. May cause significant damages, injuries or even death.	* Polar low * Changing weather * Flying high above take-off spot	4	5	20	* Prevent operating in weather that the UAV is not suitable for. * Use and read weather forcasts before operation start. * Use a UAV that is big and powerful enough to handle strong wind strength if strong wind strength is forecasted. * Be aware of that the wind strength may vary in different heights and around corner etc.	2	5	10
3		Precipitation starts during operation with UAV (that is vulnerable to this).	The pilot may have to cancel the operation and land the UAV. In a worst case scenario the UAV may fall and injure people or damage buildings. May cause significant damages, injuries or even death.	* Polar low * Changing weather	4	5	20	* Prevent operating in weather that the UAV is not suitable for. * Use and read weather forcasts before operation start. * Equip the drone with cladding so that it can withstand precipitation. * Sufficient amount of traning and experience.	2	5	10
4		Lower temperatures than what the UAV is suited for occur during operation	The UAV electronics may not work as they should, without giving the pilot a warning. The UAV may crash into people, building or fall. May cause significant damages, injuries or even death.	* Polar low * Winter * Propellers creates wind chill effect	4	5	20	* Prevent operating in weather that the UAV is not suitable for. * Use and read weather forcasts before operation start. * Equip the UAV with cladding so that it can withstand low temperatures. * Heat the drone's electronics before starting the operation.	2	5	10

5		Disruption of pilot's vision during flight	The pilot may lose control of the UAV which may result in a collision or crash with catastrofic outcomes. May cause significant damages, injuries or even death.	* The sun * Fog * Darkness	3	5	15	* Have the correct equipment ready before operation start. E.g sunglasses. * Use and read weather forcasts before operation start. * If darkness or weather fenomena disrupts the pilot, postpone the operation.	1	5	5
6		UAV collide with bird	May result in injuring or killing the bird. May also cause the UAV to fall, which may result in a person being hit and injured (or killed). UAV may be damaged.	* Injured bird * Fatigue * Disruption of pilot's vision * Lack of training or knowledge	2	5	10	* Make sure the pilot is in good health, has enough sleep, has eaten enough etc. * First aid- kits and experience * Have the correct equipment ready before operation start. E.g sunglasses. * UAV equipped with parachute if operating over populated areas.	1	5	5
7		The UAV and a manned aircraft crash into each other	The manned aircraft can in a worst case scenario fall which may result in several lives lost. May also result in a weakened reputation of the UAV company, in addition to big economic losses.	* Lack of training or knowledge * Fatigue * Hardware/software failures * One or the other does not fly according to rules and regulations	1	5	5	* Sufficient amount of training, knowledge, sleep etc. * Make sure the pilot is in good health, has enough sleep, has eaten enough etc. * Software on UAV to detect other aircrafts nearby. * Regular service and routine check-ups. Checklists before operation start.	1	5	5
8		Third person intentionally uses a jammer close to UAV operator	The pilot may lose link to UAV which may result in a fly-away. This can in a worst case scenario lead to the UAV falling and injuring or killing a person, cause significant damage to the UAV and weaken the reputation of the company.	* The third person may have been insulted by the operating company. * Third person's health issues.	1	5	5	* Ensure good communication with third persons. * Have failsafe (e.g return to launch) programmed in case loss of link. * First aid- kits and experience	1	2	2
9		Manned aircraft heading towards UAV operation area	The UAV and the manned aircraft may have had a mid-air collision. This may in a worst case scenario end in the manned aircraft crashing into the ground causing lives to be lost.	* Manned aircraft operator ignores warning from UAV operator * UAV operator lack of knowledge of UAV rules and regulations, and flies UAV close to an airport * Manned aircraft performs an emergency landing * Manned aircraft operator loses control of aircraft	1	5	5	* UAV operater has radio equipment so that he is able to contact and warn the operator of the incoming manned aircraft. * UAV operator or visual observer pays attention of incoming aircrafts, so that the UAV operator can descend or land the UAV if such a case. * UAV operator has a emergency engine shut-off button so that the UAV can be descended quickly.	1	5	5

10	**Pilot related hazards**	Pilot does not fly according to UAV rules and regulations	This may hurt the reputation of the operating company. In a worst case scenario it may result in a crash with big economic costs and bad injuries to people.	* Lack of training or knowledge * Fatigue * Stress	3	5	15	* Sufficient amount of training and experience. * Have other well experienced personnel ready to take over control of UAV. * Make sure the pilot is in good health, has enough sleep, has eaten enough etc.	2	5	10
11		Bad mental health / Fatigue	May cause the operation to be delayed. In a worst case scenario the pilot may crash the UAV and injure people, the UAV and reputation of the company.	* Not enough sleep * Food poisoning * Stress * Not enough food	3	5	15	* Have other well experienced personnel ready to take over control of UAV. * Make sure the pilot has enough sleep, has eaten enough etc. * Make sure the work environment is good. This can help the pilot in being honest about his situation, and may prevent him from flying if he knows he shouldn't.	2	4	8
12		The pilot slips or falls during operation	May cause bad injury to the pilot himself. In addition, the UAV can crash or fall and cause big economic losses and significant injuries (or death) to people.	* Oil spill * Fatigue * Icing * Other lose objects	2	5	10	* Make sure the pilot is in good health, has enough sleep, has eaten enough etc. * Make sure the place where the pilot stands is clear of lose objects and oil spill etc. * De-icing equipment or solution on the floor where the pilot stands.	2	4	8
13		Miscommunication between UAV pilot and company/second pilot	May cause the pilot to fly the UAV places where he shouldn't or are not allowed to. May also cause third person to appear in the operation area, when they are not supposed to. May cause delays in the operation or in worst case crash and injuries to people and impaired reputation.	* Language barrier * Bad call quality on radio * Fatigue * Lack of knowledge or training	4	4	16	* Make sure important information is in written form when possible, not just oral. * Training and experience in communicating during operations. * Have failsafes set in case something unexpected happens.	2	5	10
14		Pilot mounts the wrong propellors on the wrong motors	May cause the UAV to not be able to take-off. May cause the UAV to flip when trying to take-off, causing damages to it and may cause parts of the UAV to break and hit and injure people.	* Lack of knowledge or training * Fatigue * Stress	2	4	8	* Regular service and routine check-ups. Checklists before operation start. * Make sure the pilot is in good health, has enough sleep, has eaten enough etc. * Sufficient amount of training and experience. * Sufficient amount of time to carry out the operation, so that stress is eliminated.	1	4	4

15	**UAS related hazards**	Sensor failure	May cause the UAV to not detect obstacles. This may make it harder to fly. May in worst case make the UAV crash and cause significant damage to the UAV, injuries to people and a weakened reputation.	* Icing * Electronic shortenings * Lack of maintenance * Precipitation	4	5	20	* Regular service and routine check-ups. Checklists before operation start. * First aid- kits and experience. * Prevent operating in weather that the UAV is not suitable for. * Equip the drone with cladding so that it can withstand precipitation.	2	4	8
16		The landing gear of the UAV falls off during flight of fails to deploy before landing.	The UAV may have to be landed without the landing gir, which may cause significant damage to the UAV.	* Electronic shortenings * Icing * Lack of maintenance	2	3	6	* Regular service and routine check-ups. Checklists before operation start. * Prevent operating in weather that the UAV is not suitable for. * Equip the drone with cladding so that it can withstand precipitation. * Bring a spare UAV to finish the operation with, in case the original UAV breaks (redundancy).	1	4	4
17		Loss of link to UAV during autonomous flight	The UAV may have a fly-away which may result in it hitting someone or something. This may cause major damages to buildings, the UAV itself and the reputation of the operating company. In a worst case scenario a person is hit and may be injured significantly or even killed.	* Link transmitter or receiver fault * Interference, and the UAV operator fails to investigate the operation area * Snow or ice accumulation interrupts link * The software used to fly autnonomous is faulty	2	5	10	* UAV operator gains knowledge about the operation area before the operation. About elevation, intereference etc. * Update all softwares before the operation * Regular maintenance, service and routine check-ups. Checklists before operation start. * Only operate in weather according to the specifications of the UAV.	1	5	5