AALBORG UNIVERSITY
STUDENT REPORT

Use of drones for firefighting operations

Master Thesis Report

MSc. Risk and Safety Management

10/01/2019

Aalborg University, Esbjerg, Denmark

Student:

Vlad Tiberiu Radu

Supervisors:

Anders Schmidt Kristensen

Saqib Mehmood

AALBORG UNIVERSITY
DENMARK

Abstract

Theme:

Master Thesis Report

Title:

Use of drones for firefighting Operations

Group:

RISK4-11

Student:

Vlad Tiberiu Radu

Supervisors:

Anders Schmidt Kristensen

Saqib Mehmood

Project period:

01/09/2018 – 10/01/2019

Content page numbers:

54

Total page numbers:

89

Date of completion:

10/01/2019

Uploaded materials:

Report file (.pdf)

After many years of being tools used by military, drones have become very popular among commercial uses and public safety. One of the area of application where drones could have a big impact is firefighting. The report studies how drones could become an asset for Falck Fire Services by studying different aspects that influence the implementation of this technology.

Research is built with the help of qualitative semi-structured interviews that are conducted either face-to-face or via email with several decision makers within Falck Fire Services. In this way it is highlighted experts' opinion within firefighting sector on the current stage of implementation of drones, benefits, possible usage, limitations and future prospects. In addition, it was found necessary to analyze the current stage of legislative developments within several countries within the EU and to identify if there are any drones that are capable of meeting the requirements for firefighting purposes.

The report ends with a schematic analysis of the potential usage of drones in different stages of the emergency management cycle, followed by a Bow-Tie model that identifies causes, consequences and barriers for the risk of the drone crashing. This report offers insights in drone technology, legislation on drones, firefighting activities and risks. It encourages future research within the scope of safely introducing drones into firefighting activities or other area of application.

AALBORG UNIVERSITY
DENMARK

Preface

This Master Thesis report “Use of drones for firefighting operations” report is concerned with the subject of drones and their possible uses by a fire protection organization for enhancing the way firefighters conduct their operations. It was developed by Vlad Tiberiu Radu in the project period of 01/09/2018 – 10/01/2019 and counts for 30 ECTS. The subject is analysed by making use of different knowledge gained throughout the courses of the Master’s programme of Risk and Safety Management at Aalborg Univeristy Esbjerg, campus Esbjerg. This thesis report is aimed towards students and professionals, who are interested in drones and its application in the firefighting sector, as well as the current status of legislation in different countries within European Union.

The report is structured based on the Aalborg University guidelines, following the Problem Based Learning method of gaining knowledge. Figures and tables are numbered with two indices. The first one represents the number of the chapter, while the second one represents the number of the figure in that chapter. For example, Figure 6.1 is regarded as the first picture in the sixth chapter. Throughout this Master Thesis report it is used the IEEE (The Institute of Electrical and Electronics Engineers) reference style. Reference to the appendix is done by brackets such as “(Appendix 2)”. Blank pages and spaces throughout the report are intentionally left so.

I would like to acknowledge the participation of several decision-makers from Falck within Denmark, Romania, Slovakia and United Kingdom, which helped with building the analysis by offering interviews, information, recommendations and other tips: Morten Poulsen-Hansen, Søren Vincent Brydholm, Florentin Radu, Jan Jeno and Paul Frankland. For the same purpose I would like to thank Stelorian Voicu and Ovidiu Romer from OMV Petrom SA. I would also like to thank my supervisors who participated with comments and recommendations: Anders Schmidt Kristensen, Saqib Mehmood.

Aalborg University Esbjerg, 10.01.2019

Vlad Tiberiu Radu

Bachelor in Management

vradu17@student.aau.dk

radu.vlad.t@gmail.com

Acronyms

UAV - Unmanned Aerial Vehicle

UAS - Unmanned Aerial Systems

RPAS - Remotely Piloted Aircraft System

CAA - The Civil Aviation Authority

ICAO - The International Civil Aviation Organization

FAA - Federal Aviation Administration

EASA - European Aviation Safety Agency

EU - European Union

DEMA - Danish Emergency Management Agency

ISO - International Organization for Standardization

EENA - European Emergency Number Association

VTOL - Vertical Take Off and Landing

BVLOS - Beyond Visual Line of Sight

GDPR - General Data Protection Regulation

Table of Contents

Table of Tables

Table of Figures

1 Introduction

Nowadays, in this fast-paced continuously evolving era, the development of technology feels like it is accelerating, having serious implications. Ray Kurzweil explains that in the 21st century will experience 20000 years of progress instead of 100, arguing that the acceleration of technology can be measured in its "returns" such as speed, efficiency, price-performance which grow exponentially [1]. The term "technology" and its abbreviation "tech" are used more and more, becoming an everyday used word by a large number of people all over the world. The word originates from two Greek words "tekhne", which refers to any type of skill and "logia" or the English "logy", which refers to a subject of study or interest, as the English Dictionary explains. Today, technology embodies a multitude of means, processes and ideas, in addition to tools and machines, that can help global society in various ways, such as living an easier life, easy access to information, easier transportation, greater life expectancy because of medical innovations and so on. One technology that can add value to businesses and society is drone technology.

In order to define the term "drone", which has many other names (UAV, UAS, RPAS, etc.), it is interesting to see what terms do the major organizations in the industry (Manufacturers, Public Organizations, National Aviation Agencies) are using, and how the definitions of those terms differ. An UAV (unmanned aerial vehicle) is an autonomous aircraft or an aircraft piloted by remote control used for recreational and professional civilian applications, being the most recurrent term on the internet. Some professionals consider that an UAV must have autonomous flight capabilities. UAS (unmanned aerial systems) is used by CAA (The Civil Aviation Authority) in United Kingdom who defines them as "the entire operating equipment including the aircraft, the control station from where the aircraft is operated and the wireless data link", covering in the definition not only the aircraft and the operator, but also the system that connects both. This terminology is also adopted by FAA (Federal Aviation Administration) in USA and EASA (European Aviation Safety Agency). ICAO (The International Civil Aviation Organization) utilize the term RPAS (remotely piloted aircraft system) providing a quite similar definition to the previous one: "A remotely piloted aircraft, its associated remote pilot station(s), the required command and control links (C2) and any other components as specified in the type". Lastly, drone is the most common used term, defined by the English Dictionary as “an aircraft without a pilot that is controlled by someone on the ground” [2].

In regards to the comfort of the reader, the term drone is mostly used throughout the report.

Nowadays, drones can be used in a large number of fields, depending on what type of payload, sensors and cameras they are equipped with. The application of drones ranges from journalism, geographic mapping, wild-life monitoring, precision agriculture, shipping or delivery, to activities oriented more towards the safety of people such as search and rescue missions, structural safety inspections, airplane inspections, healthcare, law enforcement, disaster management and firefighting operations [3].

With so many areas of application also comes a number of successful stories, where the use of drones made a real difference. One of these stories comes from Australia where Jai Sheridan, a lifeguard supervisor who was testing a new drone (Little Ripper), equipped with an AI based system able to detect sharks in real-time, got alerted that there were two men caught in turbulent waves. The drone released a “rescue pod” that inflates in the water, minimizing the duration of the life-saving operation to 70 seconds [4].

Another successful story comes from New York City Fire Department (FDNY) which used a drone for the first time in a fire emergency in March 2017. The drone equipped with infrared and HD cameras was tethered in the ground, being able to broadcast live footage to the Incident Commander and the decision-makers in the operation center for the whole duration of the operation. The result was a better coordination of the team due to having the right information throughout the entire operation [5].

1.1 Originating idea (need for a project)

The drone market in the US is subjected to a rapid growth, where the value of drone activity raised from 40 million dollars in 2012 to 1 billion dollars in 2017 and is expected that by 2026, commercial drones will impact the country's GDP (gross domestic product) with up to 46 billion dollars. In Denmark, The Ministry of Higher Education and Science, allocated 27.5 million DKK to the development of drone technology, as part of the 23 initiatives from Denmark's first drone strategy, aiming at exploiting the potential of this technology [6]. Figure 1.1 illustrates five factors that contribute to the growth of drone market.

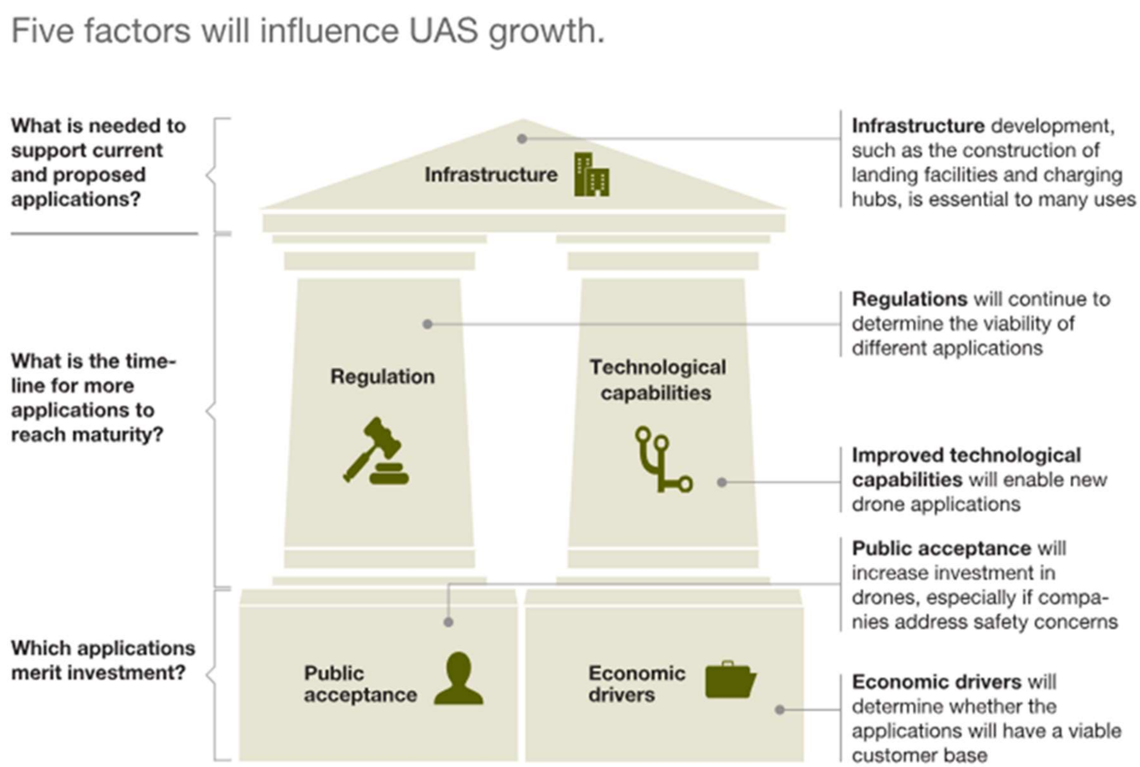

Figure 1.1 – Drone Industry Growth Factors [7]

Nowadays, the usage of drone for fire emergency situations around the world becomes a key element for reducing of response time, increase safety for people, assets and rescuers, improve effectiveness on repression operations and bring savings on intervention costs. In Europe the usage of drones in emergency and fire departments is still at the beginning, but it is supposed to grow fastly in the coming years.

On a European level, at the moment, there are 10 million Euros at stake for drone products and services. By 2035, it is expected that drone market will reach 10 billion Euros, whereas in 2050 the value is expected to exceed 15 billion Euros. 5 out of the 10 billion Euros, expected by 2035, are forecasted to be generated by civil missions for governmental or commercial businesses. The report from [8] also mentions that the most discussed areas of application of drones are related to inspecting industrial infrastructure, patrolling of pipelines and transferring live video-feed from emergency sites to firefighters and police forces. Figure 1.2 shows the key figures from the aforementioned report.

Figure 1.2 – Key figures in European drone market [8]

Not only the facts above, but also the interest that my teachers showed for drone technology contributed to the decision of analyzing drones. After having a Skype discussion with a decision-maker that works for Falck in Denmark, the conclusion was that there is a need of looking at how drones could impact the activity of firefighting, what benefits it can bring and what would possibly be the most relevant situations where drones can be used to accelerate firefighting, save lives, ease the way that the fire is attacked or improve firefighters' safety. This subject can be analyzed by using knowledge gained from several courses throughout the Risk and Safety Management MSc. What piqued my interest is the challenge of using critical thinking by analyzing benefits of using drones for firefighting operations and trying to balance them with the analysis of the inherent risks and barriers that come along with this area of application.

1.2 Scope

The scope of this master thesis is to analyze the possibilities of using drones in the firefighting area of application, by investigating: whether this technology is already implemented in fire protection organizations, what type of operations would be enhanced by drone capability, what are the risks and limitations, how capable are drone manufacturers to offer sustainable solutions and what are the legislative requirements.

1.3 Initiating stating problem

How can drones bring benefits to emergency management and particularly in fire emergencies?

To develop a more focused problem formulation, in order to facilitate the limitation of the present initiating stating problem, the analysis is built on the following steps:

- Describe the problem by identifying and ranking different stakeholders related to the scope and the initiating stating problem
- Describe what an emergency is and different phases in an emergency
- Identify a relevant organization that is acting in the field of fire emergencies and describe the type of services that they perform
- Analyze the problem by doing a thorough literature review on the state of the art
- Conclude with key research objectives for the present thesis

1.4 Methodology

1.4.1 Theoretical background

On one hand, the present thesis project makes use of theory. On the other hand, a part of the theory presented is based on empirical data. A literature review was performed in order to identify what is already known about drone use in the emergency sector. After analyzing different articles and conference papers which were related to the use of drones in disaster management, the focus shifted towards firefighting area of application. The literature review helped the author make a general impression about the state of the art which further helped with adapting the initial stating problem in a more focused problem formulation that tries to solve identified gaps in the literature. The literature review was done in a narrative way as it offers the author the freedom of not following a standard structure, which led to the variability of the boundaries and to a filtering process that included mostly the impact of the conclusions and the key results. The challenge here was to find relevant articles on the topic as there is not much scientific background, maybe due to the specific area of application.

1.4.2 Research Strategy and Design

Qualitative research strategy

Qualitative research aims at describing the world "from the inside out", by analyzing views of the people involved. This research uses qualitative strategy because it facilitates gathering data in an exploratory way. Moreover, it has a solid orientation to everyday events and knowledge and focuses on analyzing the diversity of perspectives of the participants in the study. It enables the researcher to use a spectrum of methods for the purpose of trying to answer to the research question. The data collection process is characterized by openness in the sense that questions are formulated to allow the participants to express their opinions on the selected topic. The qualitative research was also chosen as it creates data in the form of written data (text), or visual data (photos, figures) [10]. It was found as being the appropriate way to identify and describe ways in which firefighters can benefit from drone capability, what are the existing limitations and risks. A quantitative analysis would have been difficult to be performed due to limitations in finding numerical data on the subject.

Interviews

A qualitative research interview can be defined as a form of discussion where the interviewer obtains information/subjective views, from the interviewees, about a specific area. There are mainly three ways of conducting interviews: structured, semi-structured and unstructured [11]. For this thesis, semi-structured interviews were chosen as they allow the participants to talk in freedom and include examples based on personal experiences or stories. The questions posed were open-ended followed by additional probing questions where necessary and were used as a guideline for the interviewing process. The interviewees were able to see the questions before as they are displayed in Appendix 6. There were conducted two face to face interviews and three email interviews. The face-to-face interviews were tape-recorded and transcribed (see Appendix 1, Appendix 2) as this allows for a precise recalling of the discussion and the data to be reused. The interviewees did not respond to the answers in the order they were stated and the discussion went a bit more freely getting a narrative mark. The transcription is free of pauses and onomatopoeias, while the linguistic mistakes are minimized to a degree where the transcript still matches the recording. The email interviews were conducted based on the same set of questions which where posed via email. The participants answered to each question in the original email and sent back the answers. One of the participants also offered extra details on the topic. While the face-to-face interviews are very rich in information and also provide examples and stories, the email interviews tend to produce clear, specific answers as the use of probing questions is limited. The selection process of the interviewees was based on a mixture of convenient and snowball sampling method. In this way, the researcher starts contacting a person or a small group of people, that are relevant to the research topic and then these respondents facilitate creating contacts with other people [10]. Three of the interviewees are decision makers for Falck Fire Services in different countries, while the other two are decision makers for companies that benefit from fire protection services.

Collection of data

As mentioned above, some of the data gathering process consisted of semi-structured interviews. Other data gathering methods included regular internet searches in the Google search engine, or browsing different databases provided by Aalborg University Library such as Scopus or IEEE Xplore. Google scholar and SceinceDirect were also used to find relevant information that was used throughout the report.

2 Problem description

This chapter follows the first three steps in trying to narrow the initiating stating problem by making it more clear and focused. After identifying and mapping of stakeholders, and describing emergency management in theory, as well as emergency management in Denmark, it is important to identify a company that acts in the field of fire protection in order to understand how would a company perceive the introduction of drones in their fire emergency activities. Moreover, it is important to find out if this technology is already used or if there are any ongoing projects or future plans for adopting it.

2.1 Stakeholder identification

To understand how drone technology can be beneficial for firefighting operations, it is critical to establish the context by identifying relevant stakeholders that are of influence towards the industry within Europe. Stakeholders are individuals or organizations that are invested or interested in a product or company [12]. Figure 2.1 shows the identification of a limited group of stakeholders that are of influence for the scope of the project.

Figure 2.1 - Relevant stakeholders within the scope of the project (own illustration)

After the stakeholders were identified, they were used to construct a Power/Interest Matrix by adapting the theory from [13] on stakeholders. The matrix represented in Figure 2.2 is built on two axes where one represents the level of interest, while the other one the influence or power; it consists of four squares describing how stakeholders that belong to each square must be treated: "keep satisfied", "minimal effort". "keep informed", "key subjects". To further categorize the stakeholders considered to be involved in the process of using drones for firefighting activities, they were split in three categories: supportive, neutral, resistant.

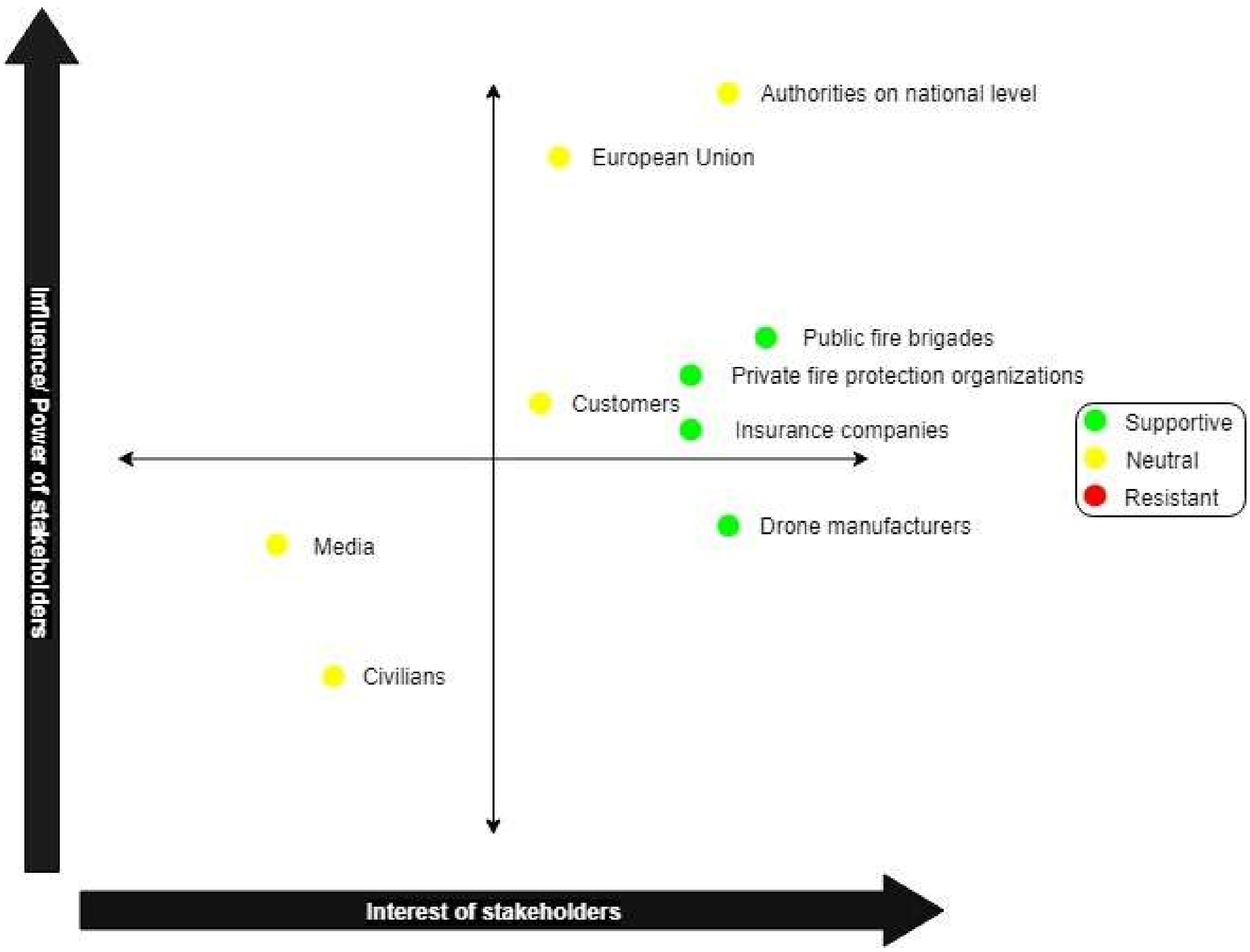

Figure 2.2 – Power (Influence)/Interest Matrix (own illustration)

The figure shows that EU, authorities on national level, insurance companies, public fire brigades and private fire protection companies are all considered to be key subjects as they have high power and a high level of interest. Customers are also placed in the same square but more on the left side, as they can influence the adoption of drone technology by supporting or constraining contractors, but they might not have such a high interest in it. EU and authorities are placed above the others as they are the ones that have the highest power by creating legislation. However, the fire brigades have a higher interest as they are the final users, while the insurance companies could seize a business opportunity. Civilians and media are placed in the “minimal effort” square as they can’t influence that much this area of drone application.

Public fire brigades, private fire protection organizations, insurance companies and drone manufacturers are all considered to be supportive as all these parties can benefit from drone implementation. The main benefit of all the stakeholders mentioned above is that it helps them increase their businesses by developing their portfolio of products and services. Moreover, the public and private fire brigades benefit from additional equipment that enhances their operations which can result in saved lives, reduction of damage or monetary loss.

European Union (EU) and the national authorities of different countries within the EU are considered to be neutral as they are not promoting or denoting firefighting drones. As their main job is to be transparent and create legislative frameworks and regulations for this purpose. If the regulations are created with respect to emergency responders, then they can be considered as being supportive. Media and civilians are considered to be neutral, but these two stakeholders can be part of all three categories as their attitude and behavior are different and can change easily. For example, a person that is resistant thinking that his/her privacy is endangered by seeing a drone in the sky, might change this behavior to a supportive one when learning that the drone is there to save lives.

2.2 Emergency Management

As firefighting operations are usually associated with the occurrence of an emergency, it is necessary to find out what an emergency is and what is the discipline associated with it. An emergency can be defined as an unplanned event which can result in individual deaths or injuries, structural or environmental damage and financial losses.

Emergency management is the discipline that creates frameworks for organizing and managing the resources and responsibilities when dealing with risks related to hazards that can make individuals vulnerable. The emergency management consists of four phases that are being repeated: mitigation, preparedness, response and recovery displayed in Figure 2.3. Mitigation is the phase where risks are being mitigated until the cost of reducing one more risk is higher than the benefits that it produces. In preparedness phase, equipment and procedures are being devised to face emergencies better by either responding better to them or mitigating their impact. In the response phase, the equipment and procedures developed in the previous phase are put into action. Finally, the recovery phase, begins after the recently occurring danger to human life has been reduced. The immediate objective of the recovery phase is to restore the affected area to normality as soon as possible, even in some cases it can last decades. (knowledge gained during the emergency management course on 3rd semester)

Figure 2.3 – The Emergency Management Cycle (own illustration)

Emergency management in Denmark

In Denmark, all governmental institutions are authorized to act upon the phases of the emergency management cycle. The main role of the national government is to train, advise and coordinate the activities of emergency responders by establishing general policies. At a national level, the Ministry of Defense is responsible for the coordination of civil preparedness planning and for implementation of measures, but DEMA (Danish Emergency Management Agency) is responsible for a big part of the daily emergency management coordination under the jurisdiction of the aforementioned ministry.

The Danish law of preparedness, beredskabsloven (BRSL) states that (own translation):

"§ 1, Subsection 1, The job of the emergency services to prevent, limit and alleviate damage to persons, property and the environment in the event of accidents and disasters, including terrorist and war operations, or imminent danger.

Subsection. 2. Rescue preparedness includes state rescue preparedness, which includes state regional rescue preparedness, and municipal rescue preparedness."

The Danish fire and rescue service is designed as a three-level system as follows [14]:

1) The municipal fire and rescue service

At this level, the municipality decides whether they opt for a municipal fire and rescue service, contract a private company, which is usually Falck, or choose to work with a voluntary fire brigade. The local council decides how many firefighters and vehicles are needed based on a risk assessment. The first team must depart with a five-minute readiness; this response is managed by the municipal onsite commander.

2) The municipal and national support sites

Aalborg, Aarhus, Esbjerg, Fredensborg, Fredericia, Greve, Odense, Kalundborg, and Nykøbing Falster as well as the five national fire and rescue centers can support the municipal fire and rescue services being able to arrive at the scene of an accident within 1 hour. The equipment used by the volunteers, part-time or full-time employees of the municipality is supplied by DEMA.

3) The national fire and rescue service

Thisted, Herning, Allinge, Næstved and Haderslev are the five fire and rescue centers that can assist the ones described previously, in case of complex, large-scale accidents, that demand a big amount of equipment and personnel. These centers can deploy up to 1200 conscripts, non-commissioned officers and volunteers. with five-minute readiness and reach the site of the accident within 2 hours.

2.3 Company description

To further establish the context, it is relevant to describe the activities of one of the fire protection organizations that also acts as a stakeholder for the present thesis, Falck and understand its business model as well as the adjacent services that it provides, to whom and where. The company finds four key resources for their business model: people (dedicated, well-trained, professional employees), equipment (high quality equipment that supports effective problem solving), brand and reputation (promote trustworthiness competency and competitiveness) and partnerships. The company offers four categories of services: ambulance, healthcare, assistance and portfolio business that aim at creating income by providing efficient operations worldwide to governments, businesses and insurance companies, high quality services for clients, local responsibility by engaging local communities in healthcare and emergency issues and the objective of generating shareholder value. The report is further describing each category of service [15].

- Ambulance

Falck is the world leader in ambulance and patient transport services, operating more than 2500 ambulances in 21 countries; 16672 rescue officers, nurses and doctors respond to emergencies by assisting people who are ill and injured at the incident site or take them to a medical clinic or hospital. Customer segment ranges from governments to insurance companies, hospitals and individuals, but governments cover a big part of this segment.

- Healthcare

In Scandinavia, Falck offers health programs for more than 3 million individuals assisted by more than 3000 healthcare professionals ranging from physiotherapists to psychologists who aim at reducing the number of accidents at the workplace and loss of working capacity, resulting in reducing cost of sickness-related absence. Moreover, staffing services such as providing employees to hospitals, medical clinics etc. and citizen services such as providing operations of General Practitioner clinics both in Denmark and Sweden are also part of the healthcare branch.

- Assistance

Provides assistance to people, organizations and institutions in multiple ways such as first-aid equipment, maintenance, roadside assistance and public firefighting, the latter two standing as the largest service lines. Roadside assistance contracts are present mostly in the four Scandinavian countries: Denmark, Norway, Finland and Sweden, but it doesn't matter where in Europe the subscribers need assistance. Public firefighting is present in Denmark in approximately two-thirds of the 98 municipalities offering services that range from preparedness or prevention (train individuals, institutions and organizations in extinguishing small fires) to response by putting out fires and respond to fire alarms, under the certification of ISO 9001. The year 2017 brought many innovation projects that aimed at optimizing processes and the ways that public resources are being used.

- Portfolio businesses

Portfolio business refers to the three smaller businesses where Falck offers services: Global Assistance, Industrial Firefighting and Safety Services. Industrial Firefighting covers companies operating in high-risk industries (petrochemical plants, nuclear power plants, steel plants) and airports that are outsourcing their fire safety, offering protection against fire, training, consulting and security related to fire in 18 countries where 66 fire brigades operate. The other small business offers safety services to high risk industries such as oil and gas and maritime.

Falck Fire Services

Falck Fire Services is present in 19 countries, where it operates under certifications such as ISO 9001, 14001 and OHSAS 18001, to guarantee reliable quality level and brigade management. In Denmark, it operates as Public Fire Service where 300 full-time and 2800 part-time employees are divided in 148 fire brigades. In the remaining 18 countries it operates as Industrial Fire Services, providing high fire safety for clients that perform activities in high-risk industries such as: oil, gas, petrochemical, nuclear power, steel, automotive, airports and others. The division offers complex services to its clients focused around fire prevention and maintenance services, while the response capabilities include hazmat, extrication and rescue related activities such as rescue at heights [15].

In order to familiarize the reader with the type of services provided by Falck Fire Services for petrochemical plants it is presented below a table of these services and related activities:

Service Field	Type of Services	Activities
Emergency Response	Firefighting	Receipt of emergency alarms Dispatch of emergency response resources Incident command Fire extinguish Search, rescue and evacuation
Prevention	Stationary Fire Protection systems Surveillance/Safety Management Training of customer Fire incident investigation Emergency plans	Regular control of stationary fire protection systems Hot work permission issue Risk assessment before start of Hot Work Monitoring of Hot Work Basic training of customer, first response and drills Conduct Fire incident investigation Design of emergency plans
Maintenance	Maintenance of firefighting equipment Fire protection systems maintenance	Maintenance of vehicles, firefighting, rescue, Hazmat and other equipment Maintenance of Fire Protection Systems e.g. fire hydrants, fire extinguishers, sprinkler system, fire detection systems, foam systems Calibration of portable gas and other detectors

Table 2.1 - Type of services provided by Falck for petrochemical plants

3 Problem analysis

The problem of trying to introduce drones in the activity of firefighters so that it provides real benefits is going to be analyzed through the use of the existing literature on the subject. In this way, previous theory and studies guide the development of the research objectives for the present study, which tries to solve gaps in the literature and to summarize knowledge gained throughout the thesis period.

3.1 Literature review

Search methodology

The main purpose of the literature review is to gather knowledge of the current implementation of drones into activities of firefighters. For this purpose, several sources were identified through the use of databases that Aalborg University Library provides access to, such as: Scopus and IEEE Xplore. The search field in these databases utilizes the Boolean operators "AND" and "OR" for conducting searches and the asterisk symbol for truncating specific words. There were several combinations of words in order to find relevant sources, but the main keywords used were: drone, UAV, UAS, RPAS, firefighting, fire, firefighter(s), emergency. By combining some of these different words it was identified a gap in the literature. For example, searching in Scopus for "drone" AND "firefighting" produces 12 results (6 articles, 6 conference papers, 1 book chapter and 1 article in press), but only 3 open access options.

Literature presentation

On a normal working day, firefighters have to perform different activities from maintenance to conducting pre-incident planning or even cleaning and organizing. When an emergency occurs, firefighters need to make critical decisions which are dependent on a number of factors such as the capabilities of the existing resources, the context of the emergency and the way the emergency is being comprehended based on the available information. Therefore, having live information about an incident (casualties, spread of fire etc.) is a critical factor for enhancing the quality of the decision making process. [16] undertook a study to explain how willing are individuals to assimilate innovation attributes. For this purpose, they interviewed 21 firefighters distributed in seven fire departments all over Germany. When firefighters were asked about drones, all of them agreed that compared to traditional means of intelligence, drones offer an informational advantage. 57% of them emphasized that drones also provide a time advantage, but pointed out how limited in range of application drones can be; 81% mentioned robustness and simplicity as key compatibility factors, while around half of this percentage argued that operational complexity can be a drawback, as well as the high training required effort [16].This study of user acceptance for emerging technologies opens up possibilities to study more in depth how preparedness and emergency responses can be improved with novel equipment (drones).

In 2015, EENA (European Emergency Number Association) organized a Working Group consisting of 125 members from 39 countries that aimed at understanding how drones can be used by the emergency services, SAR (Search and Rescue) and First Responders. Later in the same year, an operation document [17] was released containing information about: how emergency services could use drones and what types of drones would be suitable, legislation at that time, technical considerations (onboard equipment and technology, technical requirements from the emergency services), operational use, safety and privacy. The document generated a set of recommendations for authorities on a national and European level, for emergency services and lastly for drone manufacturers. In April 2016, EENA made a partnership with DJI and chose four Pilot sites, out of 41 emergency services organizations who showed interest, where they used drones and equipment provided by DJI for real case scenarios. One of the sites was Greater Copenhagen Fire Department in Denmark, who had at that point around 1000 employees spread in 12 stations. An important point to mention here, is that they were already using DJI Inspire drone since 2014 with three different payloads: Z3 zoom camera, a FLIR XT Thermal camera and the ZT zenmuse camera [18].

There were 60 callouts during the 6 months' project period, most of them due to fire and missing persons. One of these 60 callouts was due to a fire at a waste storage area belonging to an industrial titanium milling company. Optical and thermal cameras equipped on the drone guided firefighters in hitting the seat of the fire while they were at a safe place. The project resulted in a set of best practices: the need for an industry standard for first responders to use blue lights, operate at night and BVLOS (Behind Visual Line Of Sight), development of drones that are able to fly in bad weather conditions, integrated broadcast capabilities, operations with both thermal and optical cameras attached on the drone, drop capabilities, hardware and software improvements and having a team with at least two drone operators that can replace each other in case of fatigue or other factors. Software solutions included the development of DroneSAR, an app for search and rescue, and DJI HotShot, a simple UI (user interface) for thermal camera use [18].

In 2017, the initially established working group reached more than 180 members, following in 2018 the launch of DES (Drone Efficacy Study) which consisted of 50 trials of SAR with and without drones provided by different manufacturers. The tests showed a 77% success rate of locating missing persons with drones in contrast with an 85% success rate without drone use, but drone-enabled SAR provided a three-minute faster response than the traditional operation [19].

Another study on how drones can improve the activity of firefighters during emergency response is developed by Khan and Nestaedter [20], resulting in assumptions on how to design drone systems in conjunction with people's trust, privacy and safety. The authors conducted semi-structured interviews with 7 firefighters with an average working experience of 26.5 years and 12 lay people who previously called 9-1-1 for medical, fire and police related emergencies. The interviews were structured in two phases: the first one was focused on the experience that the lay people calling 9-1-1 had, followed by questioning all participants about what should a drone capture, what benefits can it offer, concerns and challenges that can arise; the second phase was focused on comprehending how participants would react to drone-like video footage of emergencies. The researchers showed participants 7 video clips that showed four types of emergencies: fire, hazardous material, injury in apartment and road accident, followed by asking different questions to lay people and firefighters. Lay people were asked questions about:

- how would they feel about seeing a drone if they or a family member, neighbor or stranger would have been involved in the accident
- privacy and safety issues
- movement and control
- when should the drone stop capturing the scene
- what do they think about the drone recording also audio data

The firefighters were asked about the type of information they could gather and how would that information be useful, safety and privacy concerns. Both participants were also asked in which scenario drones fitted the best and where should they be located.

Regarding fire emergencies, it appears that the 12 lay persons considered that drones would be useful by offering live footage to call centers and first responders or locating nearby fire hydrants. They felt an increased trust in the response teams as they knew that more reinforcements are going to come so their actual risk perception has changed. The firefighters saw benefits in the way that they would position their devices to contain explosions, create rescue strategies, park their vehicles, set up a safe working area, locate fire hydrants, but the key advantage was the ability to have a view from the top [20].

Khan and Nestaedter [20] concluded that emergency drones have a high acceptance level by lay persons, especially if they are designed in such a way so that people can visually differentiate them from the recreational or commercial ones. Some suggested design patterns, lights or prominent bright colors. The same topic is also discussed in the book "The Future of Drone Use" where authors emphasize not only on color or design patterns, but also on license plates or RFID tags for identification, in order to better solve liability issues [21]. This would also help with privacy concerns as people tend to be more lenient if they understand that the drone flying around is trying to help in an emergency situation, not to surveil public. From a safety point of view, the biggest concerns were that drones could be hacked and crashed intentionally or hinder the natural bird habitat. There is also a concern if the video footage of an accident ends up in court for analyzing the decision of firefighters, as those decisions are made under pressure and are very sensitive. There are some good conclusions that can be drawn from this study, but it also has its limitations. To be critical, it is important to point out that the study involved only twelve lay persons and seven firefighters, so, the opinions of these can be similar by coincidence. It is bold to generalize conclusions with such a small sample, but it opens ways for more in depth research. Moreover, the interviewed people were having the same nationality (Canadian), so, the factor of cultural influences does not exist [20].

Another relevant source [6:32] indicates that drones can be used in case of disasters or crises by collecting data or access places that are hard to reach. It can also provide information on the size and development of large fires, the release of toxic particles and the direction of local winds or trace the presence and dispersal of radioactivity even in case of accidents with nuclear power plants. The authors remark that drones equipped with cameras can detect weak spots, erosion, pipelines leaking gas or water, in different types of inspection or maintenance activities including inspection of high objects.

Drones as a support for disaster management has been also investigated in [22], where the author proposes a model to differentiate between the three chronological phases of a disaster: before, during and after the disaster. The pre-disaster activities would include prevention or early detection. The activities performed during managing the disaster could be supported by real-time monitoring and obtaining information for better decisions, while the post-disaster activities consist of quicker damage assessment and recovery. This model is similar to a model which was learned during the Systems Engineering Course in the first semester. Figure 3.1 and Figure 3.2 illustrate both models, one below the other one, in order to emphasize the similarities. Amongst other disasters, the author mentions the spread of hazardous materials, which can be managed by drones in all 3 phases, from identifying the spread of liquids or gaseous materials to assisting the intervention and lastly recovery [22]. The level of detail that the author offers is unfortunately very low, making it difficult to draw any conclusions, but inspires to a more thorough analysis in the present report.

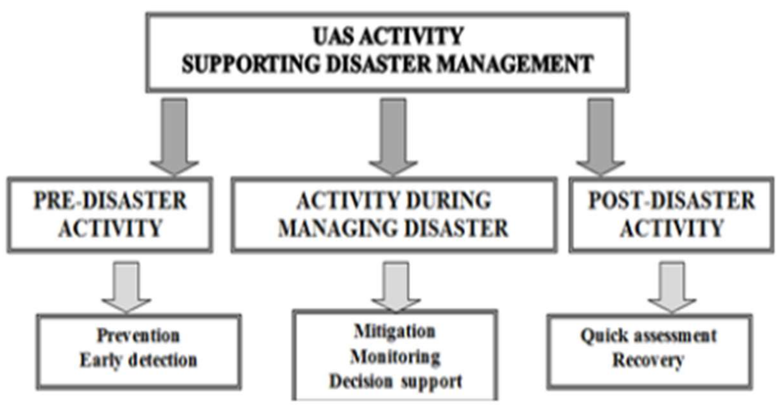

Figure 3.1 - Drone activity in time scale of disaster eruption [22]

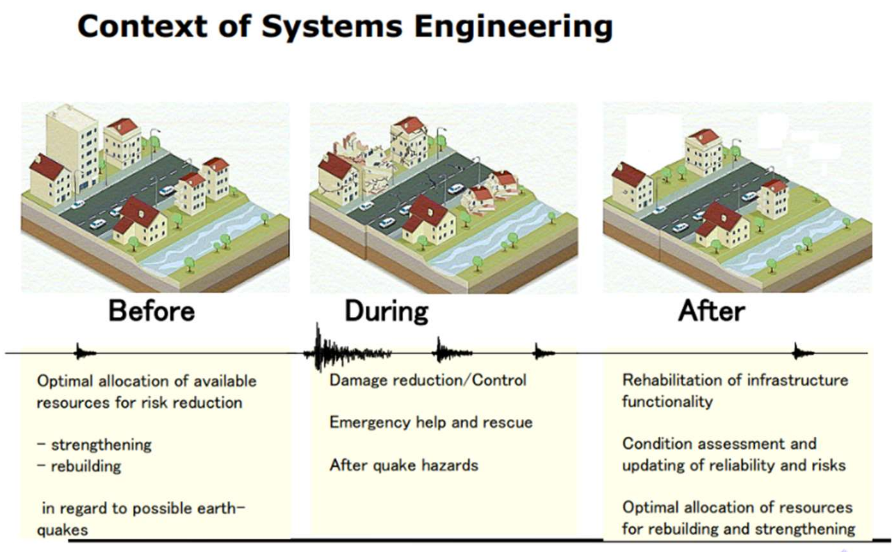

Figure 3.2 – Phases of a disaster (lecture slides)

Project AirShield [23] proposed the use of miniature drones equipped with lightweight sensors for collecting data used by compentent authorities or decision-makers in predicting and preventing emergency situations. A delegation of AirShield team tested a swarm of miniature drones to measure oxygen, carbon dioxide and hydrogene sulfide in atmosphere. The test took place in Rotterdam International Safety Center (RISC), owned by Falck, where they simulated real fire scenarios. The results of the test were positive, in the sense that the drones were able to send real-time measurements on the system's graphic interface. Moreover, drones were not affected by smoke or heat. This project is highly relevant for fire brigades that operate in high risk industries such as nuclear power plants or petrochemical plants, which is the case for Falck Industrial Fire Services.

Some researchers [24] proposed a methodological framework to assess operational behavior of drones for SAR. Their model is a combination of 6 interconnected "needs": UAV specifications, social system, mission context, accident scenarios, simulation and decision making. They conclude in their work in progress paper, that there is a need to define risk assessment methodologies for specific context or missions, that can be used by teams in order to avoid or minimize contrast effects to the expected ones.

As the literature demonstrates, drones are seen as a real benefit for search and rescue missions, firefighting or other emergency-related situations. There are also ongoing projects and future work on the subject which is expected to materialize more and more. However, almost none of the literature reviewed expressed concerns about the risks that come along with the use of drones for such purposes. Moreover, there is not much mentioned about liability issues or legislative barriers that would hinder the ability of emergency responders to have drones in their equipemnt repertoire. The following paragraphs discuss three papers that deal with some of the issues mentioned before.

A framework for modelling risks involved by drone operations is described in [25] as a consequence of insufficient consitency of existing models. The risk analysis is structured around a Barrier Bow Tie Model (BBTM) which is considered relevant to be used for developing safety cases for any drone operation. In order to show how the BBTM model works, the authors use a study case based on a study from NASA related to current aircraft certification processes and airworthiness standards, where engine failure stands as the hazardous event. The paper is very comprehensive and results in a set of control barriers that can be the basis of risk assessments in any drone operation. It is also supposed to help legislators build regulations in accordance with technical and operational factors.

Another framework for modelling risks related to professional drone use is proposed by reference [26], where the authors criticize the current method of analyzing safety of operations requested by Dutch government in order to allow businesses to operate drones. They consider that a STPA (Systemathic Theoretic Process Analysis) is much more efficient than the current Risk Matrices, as it also focuses on the interaction of components besides failure modes. However, the method lacks in identifying mitigation measures.

Researchers at University of Sao Paulo in Brazil [27] have a different approach when analyzing risk of introducing drones into non-Segregate Airspace. The methods proposed are a qualitative Risk Assessment Matrix and a quantitative FTA (Fault Tree Analysis). Four FTA are conducted having as the undesired event “mid-air collision” and “ground collision” both based either on the commanc and control (C2) link failure or on jamming attack (hacking into wireless networks). The results show that there is a need for developing navigation system equipped with artificial intellingence, that are not dependent upon radio waves. The authors also point out that authorities must develop actions that enhance the cybersecurity of drones’ communication systems.

References [25], [26], [27] offer good methods of analyzing risks related to professional drone use and provide good control measures, but none of those take into account the risk perception factor.

As studies show that lay persons and experts have different opinions on how risky technologies are, risk communication plays a major role in developing legislation and communicating safety aspects.

4 Problem formulation

For the study research of the present thesis, the author looks at Falck Fire Services and how it can benefit from drone support. As it was identified that a big part of the activities of firefighters at Falck Fire Services are of a preventive and maintenance nature, it is interesting to look into how drones could be used not only in emergencies, but also in these stages of preparedness and mitigation of the emergency management cycle. For this purpose, the initiating problem statement is narrowed down to the following research question:

How can drones become an asset that improves the activity of Falck Fire Services and what are the limitations?

The following list contains key objectives for answering the above question:

- Conduct interviews to find out the perspective of managers at Falck Fire Services;
- Conduct interviews to find out the perspective of a customer that would benefit from the implementation of drones in Falck Fire Services;
- Identify benefits, possible usage and limitations;
- Analyze how a drone can be used within the emergency management cycle by Falck Fire Services
- Identify how a drone itself can become a risk;
- Categorize drones and identify if there are drone manufacturers that produce drones exclusive for this area of application;
- Analyze how the legislation impacts the use of drones in a few countries (Denmark, Romania, Slovakia, UK) where Falck Fire Services is present;

4.1 Delimitation and limitations

Delimitations are those choices made by the author which describe the boundaries that are set for the study. One delimitation is the fact that the report does not include a detailed description of how a drone works and other technical aspects that a drone system consists of, but opens up to possibilities of future work related on the subject. The author limits the study to a qualitative one by analyzing how drones can be used only in firefighting operations with the help of semi-structured interviews, while discarding other possible areas of use by emergency responders e.g. ambulance, road assistance, police. Another set boundary is the choice of the author to only briefly identify risks that drone pose and not go into detail with it as this itself can become the research basis of an entire thesis.

Limitations are those shortcomings or influences that cannot be controlled by the author and limit the methodology and conclusions. One limitation appeared when an interview was proposed to an incident commander of the Greater Copenhagen Fire Brigade, who was not available due to high workload. The knowledge which would have been gained from this interview, it is assumed to have had contributed significantly different to the outcomes of the present study as it is known that Greater Copenhagen Fire Brigade is already using drones since 2014 [28]. This is one of the reasons the analysis looks more at industrial firefighting. Another limitation is the number of interviews conducted as it was expected to reach the number of six.

5 Integration of drones in Falck Fire Services

5.1 Analysis of interview results

As it was stated already in the methodology there were conducted five semi-structured interviews both face-to-face and via email. The purpose was to understand how implementation of drone technology into firefighting activities is perceived by a few key managers of Falck Industrial Fire Services and a company that they work with, in ensuring fire protection. The questions were mainly addressing benefits that drone could provide for their activity, possible risks, liability issues and legislative requirements, but also future prospects, as it is shown in Appendix 6. The interview data was analyzed so that it can be grouped in different themes. Therefore, most of the relevant information was selected and grouped in two main themes that are discussed below. For the simplicity of writing the interviewed people will be referred to as “I1” corresponding to the participant in Appendix 1, “I2” corresponding to the participant in Appendix 2 and so on until I5 in Appendix 5.

5.1.1 Benefits, possible usage and risks

In order to learn what the possible usage and benefits of drones are, the participants were asked at first if they or their company has any previous experience with using drones. None of the participants had real experience with using a drone at a company level, but some of them considered the idea of implementing drone technology in their activity and were able to share different short stories related to this scope. For example, I2 shared the experience he had at an exhibition in Dubai where it was proposed to use drones for the repression of fire in tall buildings:

“For those kind of buildings if the fire starts at a high floor there are systems for fire repression only inside, but if the fire starts outside, and outside for construction the material used is not concrete or steel but prefabricated panels of plastic sandwiches then there are no possibilities of killing the fire, if the fire starts above 13-14 floor (where a normal platform could reach) then there are no means to kill the fire. And one company was presenting a system with using more drones, maybe 5 drones having a hose attached with nozzles and operative cameras. The systems go up 60-70 meters, the operator starts the fire and in 10 minutes the fire can be liquidated.” – I2

Another story that is also relevant for how drones could be used by firefighters was told by I1. It consisted of a project that was proposed by researchers at SDU (University of Southern Denmark), where drones could be equipped with different sensors or cameras that would help inspect fences and a software that would analyze where there are any nonconformities and send the information to the ground station. The most important part is that the software is supposed to do the assessment, so there is no need for a person to waste time by looking at the recording and analyze it.

I1 explained that mainly drones would be beneficial for Falck in the prevention phase, for "*inspection, monitoring, surveillance of constructions and installations, fences, damage, leaks*". He pointed out that a lot of money in refineries is spent on people that have to perform oil pipe inspections structural resilience inspections or situations where they have to climb on scaffoldings in order to perform flare stock inspections. He emphasizes that these preventive works can be managed easier with a drone equipped with multiple sensors (sniffing sensors, radioactivity sensors), optical cameras, thermal cameras that can detect different faults in industrial buildings and in the systems that run them.

"But is the view that we've have had on that part of it and as I said to you previously that our experience in Falck and at least in Industrial Fire Services it is kind of limited but our primarily focus hasn't been on support to emergency response but it will be to have a broader view and using it for inspections and detections of releases whatever it is." - I1

As retained from the discussion held with I2 a very important aspect for the drone to have a real contribution to the improvement of an emergency and fire operation is represented by the type of drone used, its payload and the flying performances. According to his saying a drone must have at least these types of sensors... *"thermal imaging, cameras optical, cameras high resolution, acoustic sensors, GPS to always know where the drone is, sniffer, gas free, laser scanner heats and maybe they are some more. And if we want to go into which would be our requirements for a drone or which are also the external requirements and you can see here what we've put in: transport, drones must be easy to transport, preserve drone, drones must be able to operate on a rain cold"," At least 30 minutes shall be operating range, be able to be controlled on a range of 3 km, liability comprehensive insurance."*

The same area of application, inspection, is also debated by I2. More specifically, he talks about using drones for inspection of fire hydrant networks in petrochemical refineries, as this is a time consuming activity for the firefighters "*for checking this hydrant network we use firefighters that travel around refinery 3-3,5hours"*. Using drones would improve the quality of inspection by reducing the time to an estimate of 30 minutes and by having the certainty that it is done professionally without skipping any phases of the process, as this sometimes happens due to bad weather conditions and can result in financial losses: "*For instance, now is cold outside, and running the bicycle is difficult and make the person skip some aspects, while using drones, with electronic system you have 100% scan of all items, so eliminate human error and increase safety and finally have financial benefits.*" I2 emphasized that in this type of scenario, a memory SD card that stores all the information can be more reliable than live video feed where technical errors might occur due to data overload. He also mentions another possible usage related to inspection of fuel tanks, corrosion on pipes and building temperature.

The other three participants considered a possible usage of drones in emergency response to incidents, where it can provide visual access to low visibility areas, monitor gas emissions or hazardous chemicals. The key benefits considered by I3, I4, I5 are related to the increased efficiency in the emergency interventions, enhancing at the same time, the safety of firefighters or other personnel involved in the emergency. I5 thought that drones can be used in training and exercising which can provide competitive advantage for the company that implements it first.

When asked about risks associated with drone use in firefighting operations, the participants appeared to be aware of the fact that the drone itself can become a risk factor. Although, none of them discussed this subject in depth, which means that the balance between risks and benefits tips in the favor of benefits. However, some of the participants considered the fact that the drone can produce an accident or can be hacked and turned into a destructive tool instead of a productive one. For example, I2 argues that "As from the risks to take into account using drones we must consider possibility of hacking the drone by other people", "this is also one of the risks that for the moment drone is not use too much in the public sector but more in military sector".

5.1.2 Factors that hinder implementation

Even if the potential of drones to become a reliable tool for firefighting operations is perceived as being very high, the implementation process appears to be quite slowly. This happens due to multiple factors and limitations. One of these factors is the cost. It is well-known that a drone that is designed to aid in specific emergency operations can become much costlier than a drone bought for recreational use. This happens due to high production costs to design drone components to be weather resistant, fire resistant, maintenance cost, insurance or high-cost payloads and sensors that must be equipped on the drone. Therefore, the cost of implementing drone technology can be high and might not necessarily be a top priority for the management if they are not justified. Moreover, Falck has to convince the beneficiaries of their services that this can add value to the quality of their activity. I1 explains that: "*You need to be sure that all your costs will be paid, your investments are paid and that all your operational costs are paid, and that the benefits that would be achieved by having a drone it cans easy be defended by having these costs.*"

When it comes to liability issues the opinions are different. I3 and I4 consider that the drone operator should be liable in case drone produces an accident, while I5 argues that a root cause analysis should determine what caused the accident and who should be called accountable for it. I2 argues that there is still no answer for this liability issue, but sees it from two perspectives: if an autonomous drone is used then the producer should be liable; if the drone is remotely operated, then the operator should be responsible.

Another factor that limits the implementation of drones into firefighting related activities is legislation. I3, I4 and I5 don't offer any insights in the theme of legislation, while I2 argues that both in Romania and Slovakia the legislation is not existent.

"*We do not have legislation today. This is other big topic. Generally internal on one territory of a company it is possible to use but for example the use inside refinery for checking tanks that often height is over 10-15 meters this is falling under aviation rules.*"

On a side note, the drone operators might be a limitation themselves. It might be difficult to find already licensed or specialized drone pilots which means that there is a lot of training required with the existing personnel. Especially if the personnel perceive the use of this technology as an extra task or extra responsibility, it is required a lot of communication to solve this issue.

5.1.3 Summary

For a simpler overview, Table 5.1 summarizes the information presented as well as extra findings of the author. The benefits, usage and limitations are involving both RPAS and autonomous drones.

Benefits	Usage	Limitations
- reduction of personnel - can eliminate human error in inspections - increased safety during prevention processes - increased safety during emergency response - incident coordination support for the emergency response team - post incident investigation and reporting - optimized data gathering processes - time saving during inspections - financial benefits by reducing facilities downtime and production interruptions - see through smoke - visual access to low visibility areas	In prevention, by inspecting: - water hydrant network - oil pipelines - gas emissions - structural integrity of buildings - flare stacks - fuel tanks In response (repression): - involved directly in fighting the fire - data gathering through video feed, thermal imaging, visual spectrum camera, other type of sensors In recovery: - post incident data gathering through video feed, chemical sensors and other type of sensors	- legislation - liability issues - GDPR - costs - personnel perception - public acceptance - sensitive data - location (airports, defense facilities) - training of personnel - cybersecurity

Table 5.1 – Key findings from the interviews

5.2 Schematic analysis

In order to analyze how drones could be used by Falck Fire Services to secure fire protection for possible clients, data gathered from the interviews as well as from other sources during the thesis period, is structured in a schematic picture as it is shown in **Error! Reference source not found.**.

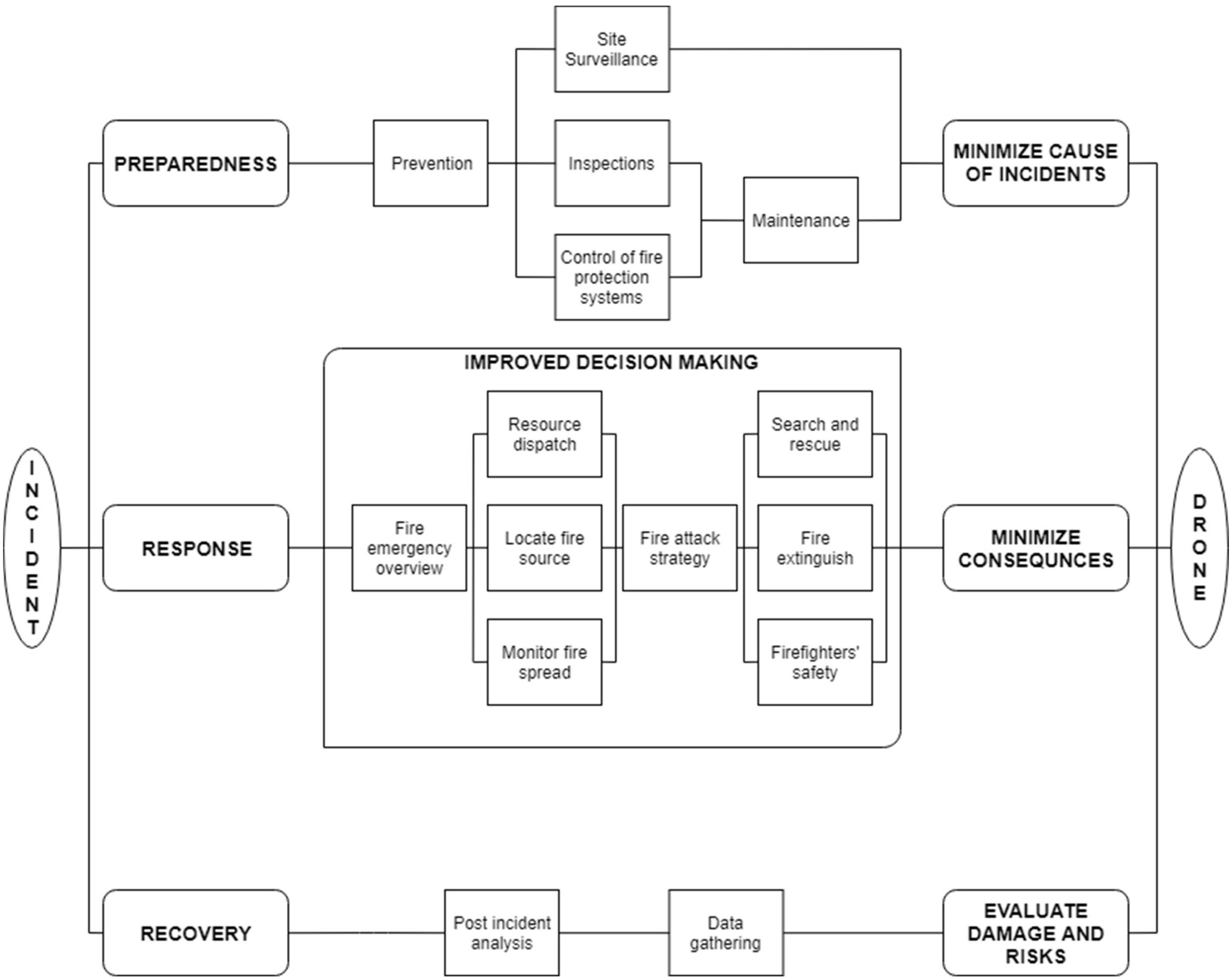

Figure 5.1- Drone use in different stages of the emergency management cycle (own illustration)

The figure shows how the three stages of the occurrence of an incident or emergency are impacted by the use of drones.

Preparedness stage consists of preventative activities that are undertook before the incident happens. In this respect, a drone can help minimize the causes of incidents, by facilitating the way inspections of e.g. flare stacks (see Table 5.1) and controls of fire protection systems e.g water hydrant network are done, by ensuring that they are faster and complete. If nonconformities with the normal standard of operation are found, then, maintenance or service teams are sent to the exact location to fix them.

The response phase respresents all the activities that are undertook during the occurrence of an incident or emergency. As the incident is considered to be the occurrence of a fire, the drone is used to offer the incident commander the ability to have a better overview of the situation and enhance the decision making process of developing a fire attack strategy. It can help with locating the fire source and monitoring the spread and development of fire (thermal camera and optical camera). By gathering data about the incident, the incident commander can decide upon the number and type of resources that have to be dispatched and how to position them in order to safely fight the fire. Then they can proceed with fighting the fire (here a drone could possibly be involved directly in fighting the fire) or search and rescue other workers trapped in the incident.

In the recovery phase, which takes places after the incident has happened, the drone can help evaluate the level of damage by mapping the affected area or searching for potential hazardous chemicals that could have been spreading during the incident. In this way, the post incident analysis is developed in a faster and safer manner.

5.3 Drone risk identification

From the analysis of the interviews, one conclusion that can be drawn is that there is a need to look at how the drone itself can become a possible risk if used in any of the three phases of emergency management cycle (preparedness, response and recovery). For this purpose, a Bow-Tie model is constructed to serve as a method to illustrate what are the factors that must be considered for safe operations and develop procedures and rules within the company, according to it.

The bow-tie model is a graphical risk analysis tool that identifies, prevents, controls and mitigates the causes and consequences of an hazardous event by forming a logical relationship between them. It can be considered to be a combination of the thinking of a fault tree that analyzes causes and an event tree that analyzes consequences, but the bow-tie model focuses more on identifying barriers for both sides. It serves more as a qualitative risk analysis method, while Fault Tree Analysis and Event Tree Analysis allow for quantification of probabilities. It is a strong method to illustrate a brief risk picture as it is simple to understand, focuses on barriers and does not require a high level of expertise, but lacks in complexity [29].

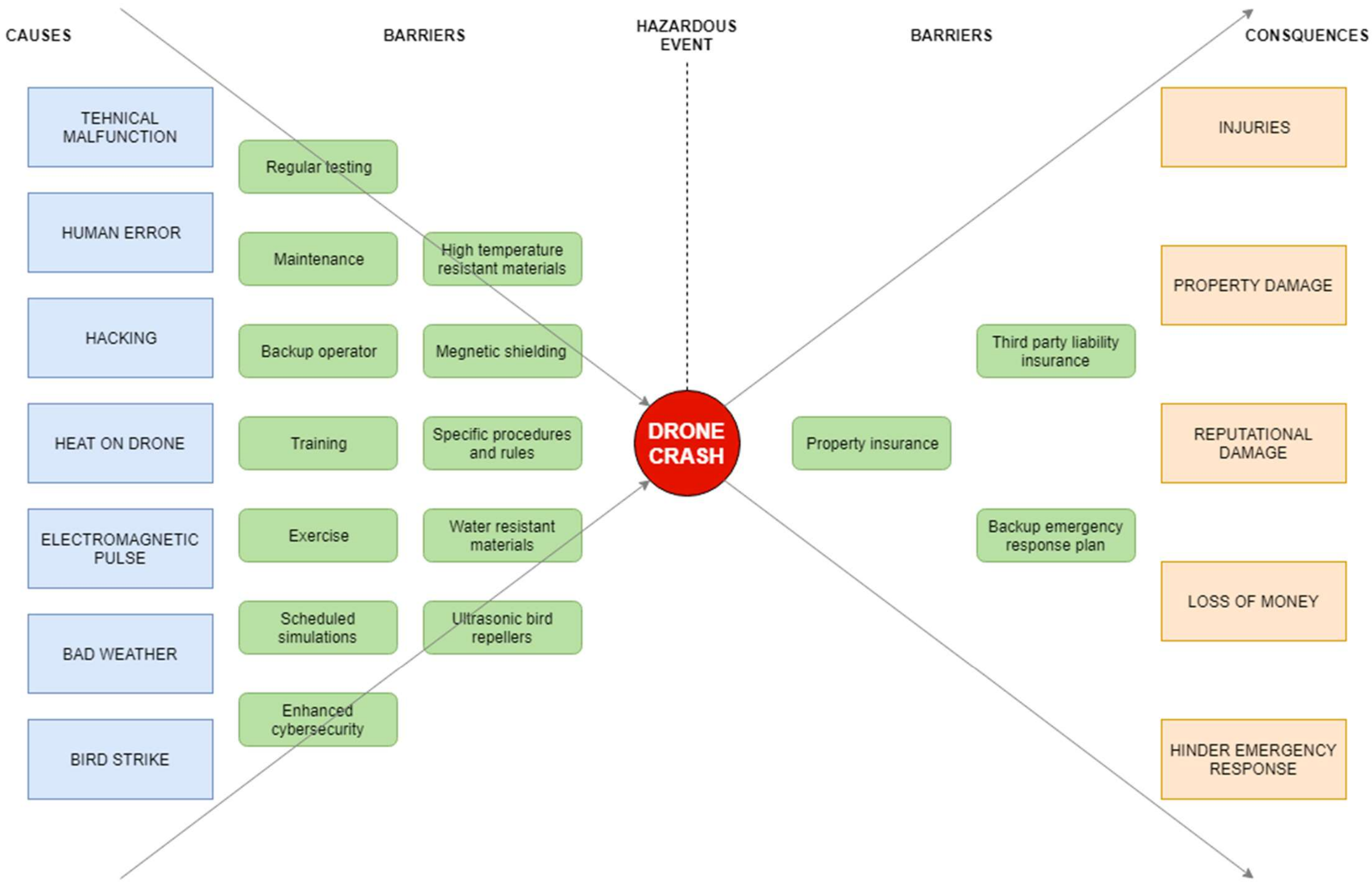

Figure 5.2 – Bow-Tie Model for Drone Crash as a hazardous event (own illustration)

In this model there are identified several causes and controlling barriers for a possible drone crash, while operating it during all three phases of the emergency management. These are explained below:

- Technical malfunction – it can occur in any component of the drone due to manufacturing defects or due to inappropriate/extensive usage without regular maintenance and check-ups;
- Human error – it can occur due to the following factors:
  - Fatigue – the drone operator can experience it during the operation; can be controlled by using a backup operator that can take control of the drone in any given moment;
  - Intentionally
  - Inappropriate use of equipment (flying more than the capability of the battery, flying out of range); can be mitigated with regular training, exercise and scheduled simulations of a real-life scenario;
- Hacking – jamming attack to the wireless communication network that can be minimized by enhancing cybersecurity to a certain degree;
- Heat on drone – it can occur in emergency response while flying the drone above or around an area that is ablaze; this cause can be mitigated by operating a drone that is built to withstand high temperatures and by following pre developed procedures on how close the drone can get to the fire;
- Electromagnetic pulse – it can occur in operations e.g. in power plants, where it can cause damage to the drone or interfere with its signal leading to a drone crash; this can be minimized by adding magnetic shielding to the drone;
- Bad weather – the drone can be affected by high speed winds or lighting strikes during storms; it can be equipped with water resistant materials bur requires special pre developed procedures on flying drones during bad weather conditions;
- Bird strike – this is a well-known cause for the majority of airplane incidents, but happened also with drones that were attacked by e.g. eagles [30]; can be controlled by equipping the drone with ultrasonic bird repeller systems;

The consequences of a drone crash along with the controlling barriers are discussed below:

- Injuries – can be the consequence of a drone crashing and hitting a worker;
- Reputational damage – the company might be discussed negatively in the media, which can also lead to loss of money due to inability to win future contracts;
- Loss of money – can occur due to high damage to assets or structures provoked by the drone crash or due to reputational damage; can be controlled by property insurance and third party liability insurance for the property damage consequence
- Hinder emergency response – if the drone is an integrated part of the emergency response plan, losing it during an emergency might disrupt the planned development of actions; having an alternate emergency response plan is a barrier to prevent unpredicted escalations;

6 Drone Technology for Firefighting Operations

This chapter starts with a categorization of drones depending on different factors: weight, level of autonomy, power source and design. It is followed by an identification of commonly used drones in firefighting missions, as well as previously proposed drone designs that would be suitable for this type of application. Furthermore, it is also important to analyze what type of payloads are suitable for different stages in firefighting operations. The aim of the chapter is to draw conclusions on how advanced the drone technology is and how prepared the drone manufacturers are to offer capable drones to clients in the fire emergency area of application.

6.1 Type of drones

6.1.1 Basic classification of drones

At a basic level, drones can be classified in: fixed wing, multirotor and hybrid. The fixed wing drones need more space to be launched as their wings need forward airspeed to generate lift. The multirotor drones use rotary wings to create lift and don't need much space to be launched as they are usually able to perform VTOL (Vertical Take Off and Landing) and they can also hover vertically, but have limited range, flight time and thus payload capacity. The hybrid drones encompass features of both fixed-wing and multirotor, for example, rotors to perform VTOL and wings to hover longer distances. [16:24]

Multirotor drones can be further categorized depending on the number of propellers that are used in order to generate lift [31]:

- Bicopter – 2 propellers;
- Tricopter – 3 propellers;
- Quadcopter – 4 propellers;
- Hexacopter – 6 propellers;
- Octocopter – 8 propellers;

Another way to categorize multirotor drones is depending on the type of frame as it can be seen in the Figure 6.1.

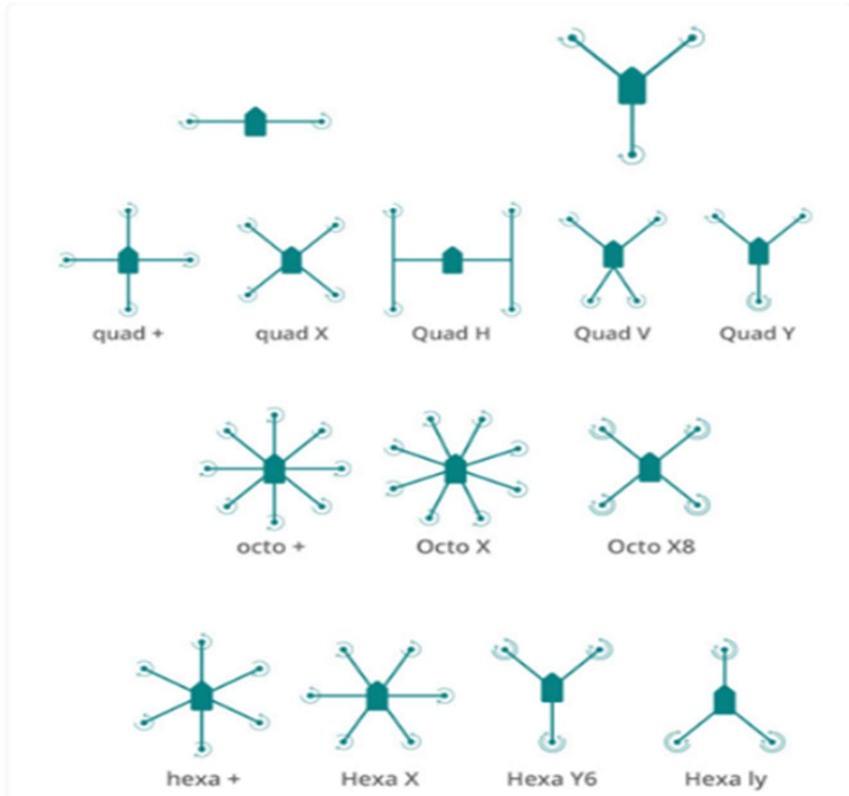

Figure 6.1 - Possible solution to frame construction [31]

The same paper [31] explains that double propellers which rotate in opposite directions can be mounted in each of the aforementioned frame types, which leads to higher drone strength and more lift capability. With an increased size in the diameter of the wings, the speed becomes lower, which helps reduce the volatility of the drone. For the bicopter, quadcopter, hexacopter and quadcopter, half of the rotor blades rotate Clockwise, while the other half rotates Counter Clock Wise.

6.1.2 Drone classification by weight

As there is currently no international recognized drone category system, drones are classified based on weight differently across countries and literature. For example, CASA (Civil Aviation Safety Authority) in Australia classifies drones based on their weight into [32]:

- micro: gross weight equal or less than 100g;
- very small: gross weight between 100g and 2kg;
- small: gross weight between 2kg and 25kg;
- medium: gross weight of at least 25 kg and less than or equal to 150 kg;

- large: gross weight bigger than 150 kg;

They also use this weight system to assess the operational risk when they need to authorize drone operations.

Another categorization of drones based on their weight can be found in [33] as displayed in Figure 6.2:

Class	Type	Weight range
Class I(a)	Nano drones	W≤200 g
Class I(b)	Micro drones	200 g < W≤2 kg
Class I(c)	Mini drones	2 kg < W≤20 kg
Class I(d)	Small drones	20 kg < W≤ 150 kg
Class II	Tactical drones	150 kg < W≤600 kg
Class III	MALE/HALE/Strike drones	W > 600 kg

Figure 6.2 – Drone categorization by weight [33]

It can be seen that the two sources provide a different weight range for the same type of drones, namely the small drones. According to Danish legislation [34] small drones are categorized into the following categories:

- Category 1A: less than 1.5 kg;
- Category 1B: between 1.5 and 7 kg;
- Category 2: between 7 and 25 kg;

6.1.3 Drone classification by level of autonomy

CASA [32] categorizes drone by level of autonomy only in two categories: RPAS and autonomous aircraft systems, but does not explain the different level of autonomous aircraft systems that exist.

Reference [35] points a distinction between four level of autonomy as follows:

- Level 1- Remotely Controlled System: system feedbacks and behavior depend on operator input;
- Level 2 - Automated System: reactions and behavior depend on preprogrammed functionality;

- Level 3 - Autonomous non-learning system: behavior depends upon preprogrammed functionality or upon a defined set of rules that command the behavior of the system
- Level 4 - Autonomous learning system with the ability to modify rules defining behaviors: the behavior is dependent upon a modifiable set of rules in order to meet goals;

Another way to categorize autonomy level can be found in [16:25] as follows:

- Human operated system: the operator is in full control of the system;
- Human delegated system: the system can perform various tasks on its own, which the operator can either activate or deactivate;
- Human supervised system: actions based on the data that has been detected can be initiated either by the operator or by the system itself;
- Fully autonomous system: the system converts the commands given by the operator in tasks, but the tasks can be modified by the operator;

6.1.4 Drones classification by power source

Drones can also be classified depending upon which type of energy source they are equipped with [16:27]. The most common drone energy sources are listed below:

- Battery cells: drones are usually equipped with lithium-polymer batteries (LiPos); this power source is used in small multirotor drones that have a limited operating time
- Fuel cells: the electrochemical device turns chemical fuel energy into electrical energy; it is environmentally friendly, but is rarely used (only in fixed-wing) due to its massive weight
- Airplane fuel: the fuel is kerosene which is used in large fixed-wing drones for military purposes
- Solar cells: implies that the drone has attached a solar cell that stores energy in the battery from the sun;
- Tethered: a cable tethers the drone to a power source in the ground; it can provide unlimited hours of flying in a limited area

6.2 Identification of firefighting drones

6.2.1 Prototypes

Prototype 1

At the 2018 3rd International Conference for Convergence in Technology [36] it was proposed a conceptual design of a "Fire brigadier Quadcopter" which can be used for finding people trapped in fire and rescue them in a safe manner. The concept describes a four rotor drone, build on an "X shape" chassis with 3 wing propellers or 4 wing propellers which is built to be a fireproof carrier as it can be seen in Figure 6.3.

Figure 6.3 - Concept of Fire brigadier Quadcopter [36]

The concept would use an USB web camera for direction control and live video feed, while the thermal camera aims at finding endangered people due to low body temperature compared to the ignited surroundings. The carrier would be used to transport different payloads such as fireproof blanket or fire extinguishers.

Prototype 2

This prototype describes a hexacopter able to carry payloads that are capable to extinguish fires in a ten square meter area. The drone was built from different components: flight and motor controllers, motors, transmitter and receiver (RC TGY-I6 [37]), battery and propellers, wireless transmitter and receiver linked to GPS, as well as a dispenser actioned by a servomotor to release payload.

The drone is controlled via DJI NAZA M-Lite flight controller [38] and weights 7 kg including 2 extinguisher bombs which weight 3 kg together. The developers also tested the drone in various experiments and concluded that the size of the propellers has to be 8inches because they offer better stability. The prototype is a low cost solution that proposes not only video feed capabilities, but also interaction with the fire. [39]

Figure 6.4 - Prototype of the conceptual design proposed as a firefighter drone designed by [39]

Prototype 3

The third prototype found is similar with the previous two in the sense that the purpose of the drone is to interact with the fire through a payload release mechanism: a robot which is made of two mechanical claws which open and close based on a trigger button on the drone's remote control via radio signal. The fire extinguishing ball contains Monoammonium Phosphate as the extinguishing agent and is made of a lightweight mixture: gypsum and rubber based bonding agent. The researcher went further and developed an "Automatic Electric Spring Operated Gun" that can launch the fire extinguishing ball up to 20 meters. This would allow the drone to fight fire in high-rise buildings where the access of the firefighters is remote due to the limited height of the firefighting truck platform. The quadcopter drone was put to tests which resulted into positive capability, as it was able to get close to the fire and control the fire in a small area. Because the current prototype can only carry one ball at a time, the author suggests a different design with a tray that can hold up to 4 balls. For a more detailed explanation of the used components see reference [40]. The prototype can be seen in Figure 6.5.

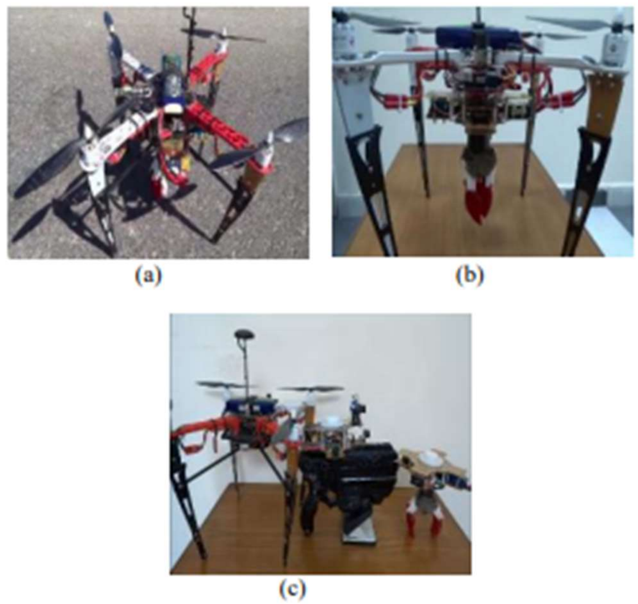

Figure 6.5 - Fire extinguishing system designed by [40]

Prototype 4

The prototype proposed by the reference [41] represents an innovative design incorporating a cage and a railing system attached on a quadcopter to hold the Fire Extinguishing ball as it can be seen in Figure 6.6. The idea behind the concept is similar to the previous prototype, a fire extinguishing ball that is going to be dropped at a certain location to put off fire. The researchers haven't performed any tests or experiments so the quadcopter was still at a concept stage.

Figure 6.6 - Quadcopter with cage and railing system designed by [41]

6.2.2 Drones used for real firefighting operations

Mid and West Wales Fire and Rescue Service have 17 pilots on call 24/7 that are able to use drones for responding to emergencies. The department owns drone support vehicles that carry drones and search dogs. The used drones are DJI Inspire 1 and Aeryon R60 Skyranger [42].

Italian National Fire Corps used drones in a very big number of flights during large scale disastrous events that occurred across Italy. The division owns a fleet consisting of four type of drones: DJI Mavic Pro, DJI Inspire 1 v2.0, Parrot Bebop2 and SenseFly Ebee. The drones were used in 5704 flights, approximately 1402 hours of flight time since 24-08-2016, during disasters such as: Central Italy Earthquake in 2016 or the recent Genoa Morandi Bridge Collapse in 2018. The division had 40 trained pilots and 7 opened bases in 2018, while in 2019 it is expected that 70 other pilots are going to be trained and 8 new other bases are going to be opened [43].

Los Angeles Fire Department also used drones for the first time to assist the repression of a wildfire which devastated 6 houses and burned 400 acres. The team deployed two DJI Matrice 100 which helped them to assess the perimeter of the burned area [44].

The fire service in western Zealand used drones for managing a fire at a hospital in Holbæk which started due to a tumble drier. The drone which is equipped with thermal and optical cameras is used once in a month and belongs to the volunteer section of the fire brigade [45]. The article does not mention what type of drone was used but according to the EENA/DJI Pilot Project Report [18] it is assumed that DJI Inspire was used. However, another article from 2015 [28] states that Copenhagen Fire Brigade have added drone support to their advanced gear stock which provides them a tactical overview at the scene of a catastrophic event. They used Hugin X1 UAV made by Danish company Sky-Watch, which is equipped with a chemical detection kit, to assist firefighters in putting off a fire at an exhibition center in Copenhagen.

The Greater Manchester Fire and Rescue Service (GMFRS) used an Aeryon SkyRanger drone during an emergency to gather information. It informed the operator that the firefighters were not working on a supported wall, who informed the team immediately avoiding harsh consequences. The drone was equipped with dual-use camera (standard and infrared) where the images can be live streamed to a tablet or stored on a digital card [46].

Another important breakthrough in the development of firefighting drones is the one made by the Latvian company Aerones [47]. The drone is equipped with water hose and a wire for electricity which ensures endless flight time. It was tested together with a fire and rescue team, the results proving that it was able to reach bigger heights than the firefighting truck ladders. The drone weights around 55 kilograms, is powered by 16 propellers and is expected to have the ability of reaching 300-meter height in 6 minutes.

Table 6.1 shows the specifications of the usually used drones in firefighting emergencies that would be relevant to be considered by Falck Industrial Fire Services. The data is retrieved from [48], [49], [50].

Model	SkyRanger R60	DJI Inspire 1	DJI Mavic PRO
Weight	2.4kg without payload	2.84kg without payload	734 g
Max Range	3km with standard base station 10km with directional antenna	-	7km
Speed	50 km/h	79 km/h	65 km/h
Payload capacity	0.7kg	0.65kg	-
Wind Tolerance	65kp/h sustained 90kp/h gusted	-	-
Max Flight Time	50 min	18 min	27 min
Operating temperatures	-30˚C to +50˚C	-10° to 40° C	0° to 40° C
Environmental tolerance	IP-53 rated components (not all)	-	-

Table 6.1 - Specification of used drones in firefighting emergencies

The payloads that these drones can support are discussed further. The DJI Mavic PRO features only one camera which can be used mainly for gathering visual data that does not involve fire directly. The DJI Inspire 1 can be equipped with different camera setups such as the Zenmuse Z30 which is a powerful integrated aerial camera, offering a 30x optical zoom and a 6x digital zoom, or a Zenmuse XT camera developed by FLIR which offers high-sensitivity thermal imaging with a 360 degree rotation capability [49]. The SkyRanger R60 also offers two camera possibilities: an electro-optical camera (Aeryon HDZoom 30) that promises view ranges of up to 5km with a 30x optical zoom and a 60x enhanced digital zoom; the other option is a daylight thermal imaging camera (Aeryon EO/IR Mk-II). Both are IP-53 certified, which means that they can be used in different weather conditions [48].

Figure 6.7 - Aeryon SkyRanger R60 (left) and DJI Mavic PRO (right) [48], [50]

Figure 6.8 - DJI Inspire 1 (left) and Zenmuse XT Thermal Camera (right) [49]

The three drone models described above use 4 propellers in order to generate lift, fly and hover. It can be argued that a drone built on a frame which allows more engines to run would provide longer flight times, a better stability (especially in case one of the engine fails), higher maximum speed, but lacks portability. After analyzing several types of drones in the market, it was decided that a DJI Matrice 600 PRO would perfectly suit any firefighting operation due to the fact that it is hexcopter that can provide longer flights at higher altitudes. Moreover, it offers the possibility of charging 6 batteries simultaneously in maximum 2 hours and can be equipped with multiple camera setups [51].

Figure 6.9 - DJI Matrice PRO 600 [51]

6.3 Summary

This chapter categorized drones depending on different variables such as weight, level of autonomy, power source and design. Afterwards, an identification of different prototypes of firefighting drones was performed along with an identification of commonly used drones in firefighting emergencies. It is observed that most of these drones are small, multirotor (mostly quadcopters), that use batteries as a power source and are remotely operated by a human. They can be equipped with zoom cameras or thermal cameras to serve the purpose of better managing fire emergencies. At the end of the chapter an hexacopter drone, namely DJI Matrice PRO 600 is proposed as a reliable tool for fire departments. Nevertheless, they have to take into consideration the financial factor as these drones can become very expensive, but the overall benefits seem to outlast costs. Overall, it appears that drone manufacturers are ready to offer sustainable solutions to match different data gathering needs for firefighting brigades, while the future promises drones that can interact with fire, acting as a real firefighter.

7 Drone legislation

Special attention when studying implementation of drones in fire emergency procedures must be paid to legislation on flying drones in designated country.

7.1 Legislation in Denmark

The applicable rules for flying drones falls under authority of The Minister for Transport, Building and Housing, specifically under *Consolidated Air Navigation Act no. 1149 of 13. October 2017* which provides at *Chapter 9,* called below "The Act", general rules for flying small drones.

Detailed rules are further developed in the legal documents *Order no. 1256 of 24 November 2017- Order on flights with drones in built-up areas and Order no. 1257 of 24 November 2017- Order on flights with drones outside built-up areas.*

For the purpose of this thesis the focus will be oriented to *Order no. 1256 of 24 November 2017- Order on flights with drones in built-up areas* called below "The Order" which will be presented further below in this chapter.

Main rules stipulated by The Act refer to [52]:

Definition

"§ 126 b. A drone shall mean an unmanned aircraft." "(2) A small drone shall mean an unmanned aircraft lying within the upper weight" This act does not provide specific weight limits for small drones, but these limits are treated in the *Order no. 1256 of 24 November 2017- Order on flights with drones in built-up areas,* called below "The Order" which will be presented further below in this chapter.

Operative flight rules:

"§ 126 c. Flights with small drones shall be operated in such a way that the lives and properties of other persons are not exposed to danger or other unnecessary inconvenience.*"*

This act stipulates that: "Flights with small drones shall exclusively be operated outside flight safety critical areas, safe-guarding critical areas and particular environmentally sensitive natural areas…" However special rules for flights over safety critical areas are provided by The Order.

7.1.1 Flights outside built-up areas

As a general rule, a small drone can fly outside built-up areas, operated by any remote pilot who has fulfilled previously the following conditions [53]:

- has obtained a Drone Awareness Accreditation issued by the Minister for Transport, Building and Housing or is a member of an accepted aircraft organization;
- the owner of the drone owns a third party liability insurance;
- the drone can be identified and the owner of the drone has been registered by the Danish Transport, Construction and Building Authority, or the flight is operated from an approved model aerodrome and its airspace;
- the remote pilot has attained the age of 16 if the construction or weight of the drone involves an increased flight safety risk;

7.1.2 Flights in built-up areas

For flying drones in built-up areas general rules are provided by The Act supplemented by detailed rules provided by The Order. It is to be mentioned that The Order [54] contains some provisions related to insurance from the Regulation (EC) 2004/785/EC of the European Parliament and of the Council of 21 April concerning requirements for air carriers and aircraft operators, and also from Treaty on the Functioning of the European Union.

Further below, there are presented main aspects stipulated in The Order that need to be followed when flying drones in built-up areas.

Thus, in the Chapter 1, The Order [54] present definitions of the main terms used in the document, terms that will be also used in other sections of this thesis:

- *Built-up areas* represent areas used for habitation, commercial or recreational activities, as well as crowded roads or parks frequented by many people.
- "*Drone* shall mean an unmanned aircraft, i.e. an aircraft without a pilot on board". Drones could be categorized into: 1) Fixed-wing and glider, 2) Helicopter and Multirotor, 3) Airship and Balloon, 4) Combined fixed-wing and rotor and 5) Special class.
- *Night flights* represent flights taking place between sunset and sunrise.
- *Remote pilot* is a person who operates the drones.

- *Professional purpose* means flights operated to fulfill specific tasks. Professional use of drones may be performed both by private traders and companies and also by public authorities, for surveillance of the environment, nature, infrastructure etc.
- *"Emergency management operation with drones* means the emergency management's performance of tasks with drones used in connection with emergency management operation, including e.g. in connection with fire, search or surveillance of floods.*"*

A very important rule provided by this order presented in Chapter 2 is that "§ 3. Flights with small drones in built-up areas may only be operated for professional purposes…"

Chapter 3 of The Order is presenting rules that must be observed for:

- *Registration and identification of drones*. A drone must be registered with an assigned number issued by Danish Transport, Construction and Housing Authority and must also be marked with name and phone number of the owner
- *Insurance*. "Drones other than micro drones shall be covered by a valid third party liability insurance with an insurance amount of 0.75 million SDR, cf. Article 7 of Regulation (EC) No 785/2004 of the European Parliament and of the Council of 21 April 2014".
  The SDR is an international reserve asset, created by the IMF in 1969 to supplement its member countries' official reserves. So far SDR 204.2 billion (equivalent at beginning of December 2018 to about US$282 billion) have been allocated to members.
- *License and minimum age of the remote pilot.* The drone flight for professional use can only be done by a remote pilot who attaint age of 18 and only after obtaining a license issued by Danish Transport, Construction and Housing Authority.

There are also provisions about flight and safety areas, special permissions needed for flight with increased safety risk and during night time, flight levels, distance and permission, obligations for air surveillance observation and rules and action to be taken after flight, etc.

A very important chapter of The Order in the context of this thesis, is represented by Chapter 8 called *Special provisions for drones used in connection with the emergency preparedness.*

In this chapter it is stipulated that for flying drones in connection with emergency management, current provisions of The Order may be deviated from, if the flight is performed based on a standard scenario approved by the Danish Transport, Construction and Housing Authority, Approved scenarios can be found on *www.droneregler.dk.* The use for different scenarios must be submitted for approval to Danish Transport, Construction and Housing Authority before the flight is initiated.

7.2 Legislation in Europe

Legislation regulating flying drones, especially smaller drones, was not coherent across Europe, each country, based in EU law having internal competence for all drones weighting below 150kg. Although based on European Aviation Safety Agency (EASA) opinion, issued at beginning of 2018, Members of European Parliament, adopted on 4 July 2018 new aviation safety rules that provide clear and consistent laws for the use of drones in the European airspace by issuing REGULATION (EU) 2018/1139 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL. In the Section VII of this document [55] general rules are provided in connection with:

- <u>Essential requirements for unmanned aircraft</u> concerning: product integrity, airworthiness aspects of product operation, organizations, pilot training, experience requirements – pilots, medical fitness – pilots, training organizations, flight preparation, flight operations, aircraft performance and operating limitations, instruments, data and equipment, continuing airworthiness and environmental compatibility of products.
- <u>Compliance of unmanned aircraft</u> concerning: certificate that "may be required for the design, production, maintenance and operation of unmanned aircraft and their engines, propellers, parts, non-installed equipment and equipment to control them remotely, as well as for the personnel, including remote pilots, and organizations involved in those activities"
- <u>Implementing acts regarding unmanned aircraft</u>. Based on general rules included in the above mentioned REGULATION, the European Commission could implement acts establishing detailed provisions that will be further released in the near future.

For the purpose of this thesis, there is the need to look further into the legislation on flying small drones for professional activities in several countries like: United Kingdom, Slovakia and

Romania.

7.3 Legislation in United Kingdom (UK)

The legislation on drones is under authority of Ministry of Aviation, Civil Aviation Authority (CAA) and Department for Transport (DfT). According to their mass, drones in UK are split in three different categories: 20 kg or less, called Small Unmanned Aircraft (SUA); >20 kg to 150 kg called Light Unmanned Aircraft and >150 kg. This last category has to comply with the same legislation as manned aircraft. Currently the general legislation provisions on flying drones in UK are provided by Air Navigation Order could be summarized as it follows [56]:

- To operate a drone it is needed to obtain a prior permission from CAA.
- The operation of a drone cannot be done without having a valid insurance.
- The drone must be operated in such manner that the remote pilot has the drone in his visual line of sight (VLOS) at all time.
- Drone must not fly above 122 m (400 feet) height irrespective of their mass.
- Minimum distance for flying a drone over a congested area is 150 m (492 feet) and 50 m (164 feet) away from any person, property, vessel, vehicle, or structure which is not under the control of the person in charge of the aircraft.
- Flying a drone closer than 1 km (0.6 miles) from the boundary of an airport is forbidden.
- Compliance of drone operators with Data Protection Act 2018 is required.

Fast growing use of drones in UK in all domains, from recreation activities to commercial and industrial as well as and public activities as police, fire and rescue services, made the Government take the decision of launching a public consultation between July to September 2018 that will be the base of future regulation in order to unlock policy and regulatory barriers, and to encourage innovation in drone technology to allow UK to become one of the world leaders in this field.

Compared with Denmark and UK where the use of drones and legislation is more advanced in order to support this development, in Slovakia and Romania there is a limited activity with drones and legislation is not specifically developed in this field. Yet, in both countries regulation about flying drones is provided by their national civil aviation authorities with the following particularities:

7.4 Legislation in Slovakia

In Slovakia, main rules for flying a drone are provided by the Civil Aviation Division consisting of [57]:

- Drones are allowed to fly only within the pilot's visual line of sight.
- Night flights are restricted.
- Drones must not fly below 50 m from any person, building, ship or vehicle, excluding the remote pilot and his operation facility.
- Drones must not fly in controlled airspace areas.
- Drones cannot be used for carrying luggage, mail or persons.

7.5 Legislation in Romania

In Romania, irrespective of their weight, drones are assimilated to civil aircraft and rules for flying are provided by the Aviation Code issued by Romanian Civil Aviation Authority (AACR). Main rules are presented below [58], [59]:

- Drones above 500 grams weight must be registered and get an identification Certificate from AACR. However, if the drone is already registered in other EU member state, registration is no longer needed.
- Each flight must be pre-approved by the Air Operation Center of national Defense Ministry.
- Using of drones for taking aerial photos, videos or mapping must receive a prior approval from Ministry of Defense.
- The use of drones in built-up areas is restricted unless a prior approval is obtained.
- Insurance is mandatory for drones with weight equal or over 20 kg.
- Flying drones near airports or area of aircraft operation is not allowed.
- Drones must fly only on daylight and good weather conditions.

8 Conclusion

As it can be observed going through the thesis, the subject of using drones in emergency situations and especially in firefighting activities it was generally accepted as being the next high technology tool to be implemented in this sector that could bring a lot of improvements with the final purpose of saving lives and money.

According to one of the participants to the interviews: "*Now drones seems science fiction but it can be done"," In my view this (using of drones) will have a big development in the firefighting, in the future"* (Appendix 2)

The overall opinion that came out of the interviews held with specialists of Falck in the firefighting services as well as with some of their client's representatives, was that the implementation of drones in this field could be done for both prevention and repression of fires.

Despite this general accepted opinion for using drones in the firefighting services there were revealed a lot of factors that needs to be solved before implementation of this tool on a larger scale.

First of all, the legislation regulating flying drones, especially smaller drones, was not coherent across Europe, not to mention the entire world. Or, in order to implement this tool and especially by companies like Falck, where a main rule is to provide the same quality of services all round the world, having the same legislation would be very helpful. After that, standard practice and procedures and drone operation guidelines should be written and of course accepted by the fire authority of the country where it operates. The new legislation for flying drones (which is in progress at EU level, as mentioned in the legislation section in this thesis) should also solve the other issues like flying BVLOS (Beyond Visual Line of Sight), night flights and permitted height of flight, which in many countries is not more than 10-15 meters, because above this height the Civil Aviation rules apply.

Another aspect that needs to be taken into consideration is that for flying a drone, the remote pilot must obtain a license. Although, until recently, no specific licenses were recognized from the aviation law perspective. However, under direction of European Commission, the European Aviation Safety Agency (EASA) promoted guidelines on pilot licensing regulations and general rules for drone operation [17]. Based on these guideline licenses for remote pilots, certifications are split into three categories, but the relevant one for this thesis is the low risk category for operating drones with mass below 25kg.

An important conclusion that came up from this study is that implementation of drones in firefighting operations and especially in industrial firefighting services is directly linked with the customer, his needs, his limitations of use, but more than this with the budget that the customer is willing to allocate in order to cover all the costs involved by using this tool. It is important to mention that a drone that can offer specific capabilities for firefighting area of application, might translate into high costs that depend on the type and size of the drone (long battery life, high operating range) and different payloads (sensors, optical cameras, thermal cameras). Along with the equipment costs there are also costs involving human resources, maintenance, insurance, etc. Therefore, it will be the task of the firefighting company to present the customer all the benefits brought by this new tool, that could be of course in terms of cost reduction, for example minimization of personnel used for safety inspections or surveillance, or in terms of health and safety, asset protection and production losses (e.g. leakages of products identified at an oil refining facility).

In addition to the observations made above, another important factor that is influencing the process of implementation of drone in Falck Fire Services, is insurance, as it ensures the covering of risks involved and minimizes potential financial losses. Though, it might be difficult to establish who should be liable in case drone crashes and produces an accident: should it be the operator, the drone manufacturer, the user or the beneficiary?

Another conclusion is that drones can be used in the main three stages of the emergency management cycle: preparedness, response and recovery. It can add value to every phase in a different manner, by minimizing the causes and the consequences of an incident and by evaluating damage and possible risks after the incident. Some of the identified benefits are: increased safety during emergency response, incident coordination support for the emergency response team, optimized data gathering processes during inspections and fire repression, financial benefits by reducing facilities downtime and production interruptions.

The analysis also highlights that drone manufacturers are ready to offer a wide variety of solutions that can aid firefighters in their operations through the use of live video-feed, visibility in smoke, thermal imaging or visualize hard to reach places. There are also some existent drone prototypes that can directly fight the fire with different payloads (e.g. fire extinguish ball), while some drone manufacturers already produced drones that can extinguish fire in high rise buildings with a water hose attached.

From a different perspective, if the operator loses control of the drone while it is in the air, then the drone can become the risk factor. In this respect, the Bow-Tie analysis revealed control measures for minimizing the causes and the consequences of a possible drone crash. The analysis is qualitative, only for identification purposes, but inspires to a more focused study in the future that would quantify the level of risks.

References

[1] A. Berman and J. Dorrier, “Technology Feels Like It’s Accelerating — Because It Actually Is,” 2016. [Online]. Available: https://singularityhub.com/2016/03/22/technology-feels-like-its-accelerating-because-it-actually-is/#sm.0000un9xyiqm5dn0uh41pv4wg2tcc. [Accessed: 19-Oct-2018].

[2] “Drone, UAV, UAS, RPA or RPAS ….” [Online]. Available: https://altigator.com/drone-uav-uas-rpa-or-rpas/. [Accessed: 19-Oct-2018].

[3] “TOP 12 NON MILITARY USES FOR DRONES.” [Online]. Available: https://airdronecraze.com/drones-action-top-12-non-military-uses/. [Accessed: 19-Oct-2018].

[4] I. Kwai, “A Drone Saves Two Swimmers in Australia,” 2018. [Online]. Available: https://www.nytimes.com/2018/01/18/world/australia/drone-rescue-swimmers.html. [Accessed: 20-Oct-2018].

[5] “FDNY Launches Drone For The First Time To Respond to Fire In The Bronx,” 2017. [Online]. Available: https://www1.nyc.gov/site/fdny/news/article.page?id=fa1517&permalinkName=fdny-launches-drone-the-first-time-respond-fire-the-bronx#/0. [Accessed: 20-Oct-2018].

[6] “Denmark’s great ambitions for drone technology,” 2017. [Online]. Available: https://ufm.dk/en/newsroom/press-releases/press-releases-2017/denmarks-great-ambitions-for-drone-technology. [Accessed: 20-Oct-2018].

[7] P. Cohn, A. Green, M. Langstaff, and M. Roller, “Commercial drones are here: The future of unmanned aerial systems,” 2017. [Online]. Available: https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/commercial-drones-are-here-the-future-of-unmanned-aerial-systems. [Accessed: 20-Oct-2018].

[8] SESAR Joint Undertaking, “European Drones Outlook Study,” no. November, pp. 1–93, 2016.

[9] R. Ferrari, “Writing narrative style literature reviews Correspondence to,” *Med. Writ.*, vol. 24, no. 4, pp. 230–235, 2015.

[10] U. Flick, E. von Kardorff, and I. Steinke, *A companion to qualitative research*. SAGE Publications Ltd, 2004.

[11] J. Dadzie, G. Runeson, G. Ding, and F. Bondinuba, “Barriers to Adoption of Sustainable Technologies for Energy-Efficient Building Upgrade—Semi-Structured Interviews,” *Buildings*, vol. 8, no. 4, p. 57, 2018.

[12] K. Schmeer, “Stakeholder Analysis Guidelines.”

[13] G. Johnson, K. Scholes, and R. Whittington, *Exploring corporate strategy*, 8th ed. Harlow: Financial Times Prentice Hall, 2008.

[14] “Multi-level emergency management,” 2012. [Online]. Available: https://brs.dk/eng/aboutus/Documents/Multi-level emergency management.pdf.

[15] Falck A/S, “Annual Report,” p. 118, 2017.

[16] J. Weidinger, S. Schlauderer, and S. Overhage, “Is the Frontier Shifting into the Right Direction? A Qualitative Analysis of Acceptance Factors for Novel Firefighter Information Technologies,” *Inf. Syst. Front.*, vol. 20, no. 4, pp. 669–692, 2018.

[17] EENA, “Remote Piloted Airborne Systems (RPAS) and the Emergency Services,” 2015.

[18] T. O ’, B. Belgium, / Eena, and R. Durscher, “EENA / DJI Pilot Project Report Authors Country/Organisation Title The use of Remotely Piloted Aircraft Systems (RPAS) by the emergency services; A Report from the joint EENA and DJI Pilot Project.”

[19] L. L. Persons, “Drone Efficacy Study (DES).”

[20] C. Neustaedter, “An Exploratory Study of the Use of Drones for Assisting Firefighters During Emergency Situations,” 2018.

[21] B. Vergouw, H. Nagel, G. Bondt, and B. Custers, “The Future of Drone Use,” vol. 27, pp. 21–46, 2016.

[22] A. Restas, “Drone Applications for Supporting Disaster Management,” *World J. Eng. Technol.*, vol. 03, no. 03, pp. 316–321, 2015.

[23] P. Airshield and F. R. Rotterdam, “Case Study Project AirShield Description of the Project AirShield and its results in the final demonstration at Falck RISC Rotterdam,” pp. 1–11, 2012.

[24] E. Lygouras and I. M. Dokas, “Identifying Hazardous Emerging Behaviors in Search and Rescue Missions with Drones: A Proposed Methodology,” vol. 301, pp. 70–76, 2017.

[25] R. A. Clothier, B. P. Williams, and K. J. Hayhurst, “Modelling the risks remotely piloted aircraft pose to people on the ground,” *Saf. Sci.*, vol. 101, no. August 2017, pp. 33–47, 2018.

[26] M. Pappot and R. J. De Boer, “The Integration of Drones in Today’s Society,” *Procedia Eng.*, vol. 128, pp. 54–63, 2015.

[27] R. B. Ferreira *et al.*, “A Risk Analysis of Unmanned Aircraft Systems (UAS) Integration into non-Segregate Airspace,” *2018 Int. Conf. Unmanned Aircr. Syst. ICUAS 2018*, pp. 42–51, 2018.

[28] T. P. Nielsen, “Copenhagen Fire Brigade benefits from drone support,” 2015. [Online]. Available: https://iffmag.mdmpublishing.com/copenhagen-fire-brigade-benefits-from-drone-support/. [Accessed: 20-Nov-2018].

[29] IEC, “International Standard Iec/Fdis 31010,” vol. 2009, p. 92, 2009.

[30] “When Birds Attack,” 2017. [Online]. Available: https://waypoint.sensefly.com/bird-drone-attacks-avoid-threat/. [Accessed: 20-Dec-2018].

[31] P. Kardasz and J. Doskocz, “Drones and Possibilities of Their Using,” *J. Civ. Environ.*

Eng., vol. 6, no. 3, 2016.

[32] Civil Aviation Safety Authority (CASA), "ADVISORY CIRCULAR - Remotely piloted aircraft systems - licensing and operations," *Ac 101-01*, no. February, pp. 0–67, 2017.

[33] M. Hassanalian and A. Abdelkefi, "Classifications, applications, and design challenges of drones: A review," *Prog. Aerosp. Sci.*, vol. 91, no. May, pp. 99–131, 2017.

[34] Danish Transport Authority, "Order on flights with drones outside built-up areas," *1*, vol. 149, no. 1256, 2017.

[35] M. Protti and R. Barzan, "UAV Autonomy – Which level is desirable ? – Which level is acceptable ? Alenia Aeronautica Viewpoint," *Platf. Innov. Syst. Integr. Unmanned Air, L. Sea Veh. (AVT-SCI Jt. Symp.*, pp. 1–12, 2007.

[36] A. N. Khanke and P. N. Khanke, "Quadcopter to Locate & Assist Endangered Person in a Place of Fire," *2018 3rd Int. Conf. Converg. Technol.*, pp. 1–4, 2018.

[37] "No Title." [Online]. Available: https://hobbyking.com/en_us/turnigy-tgy-i6-afhds-transmitter-and-6ch-receiver-mode-2.html?___store=en_us. [Accessed: 11-Nov-2018].

[38] "NAZA M-LITE." [Online]. Available: https://www.dji.com/naza-m-lite. [Accessed: 11-Nov-2018].

[39] A. Cervantes, P. Garc, E. Morales, F. Tarriba, E. Tena, and H. Ponce, "A Conceptual Design of a Firefighter Drone," 2018.

[40] A. Ilah N. Alshbatat, "Fire Extinguishing System for High-Rise Buildings and Rugged Mountainous Terrains Utilizing Quadrotor Unmanned Aerial Vehicle," *Int. J. Image, Graph. Signal Process.*, vol. 10, no. 1, pp. 23–29, 2018.

[41] B. Champagnie and A. Simonis, "EML 4905 Senior Design Project PREPARED IN PARTIAL FULFILLMENT OF THE Highway Wind Turbines," 2013.

[42] W. Manager, K. Hughes, U. Search, and R. T. Leader, "Supporting Operational Response Mid and West Wales Fire and Rescue Service Drone Operations."

[43] O. Lorusso, A. Rescue, and C. Office, "Using Remotely Piloted Aircraft Systems (RPAS) in Rescue Operations of Italian National Fire Corps (CNVVF)."

[44] H. Branson-Potts, "L.A. Fire Department used drones for the first time during Skirball fire," 2017. [Online]. Available: https://www.latimes.com/local/lanow/la-me-ln-lafd-drone-skirball-fire-20171214-story.html. [Accessed: 20-Nov-2018].

[45] "Drone played 'decisive' role in fighting fire at Danish hospital," 2018. [Online]. Available: https://www.thelocal.dk/20180607/drone-played-decisive-role-in-fighting-fire-at-danish-hospital. [Accessed: 20-Nov-2018].

[46] J. DuPlessis, "Case Study: Using drones in fire and rescue services in the United Kingdom," *Drones Humanit. Action*, no. 12, pp. 0–6, 2017.

[47] "No Title," 2018. [Online]. Available: https://www.aerones.com/eng/firefighting_drone/. [Accessed: 25-Nov-2018].

[48] "SKYRANGER R60." [Online]. Available: https://www.aeryon.com/skyranger/r60/. [Accessed: 12-Dec-2018].

[49] "Inspire 1." [Online]. Available: https://www.dji.com/inspire-1/info. [Accessed: 12-Dec-2018].

[50] "MAVIC PRO." [Online]. Available: https://www.dji.com/mavic/specs. [Accessed: 12-Dec-2018].

[51] "MATRICE 600 PRO." [Online]. Available: https://www.dji.com/matrice600-pro?site=brandsite&from=nav. [Accessed: 12-Dec-2018].

[52] C. Act *et al.*, "Consolidated Air Navigation Act," no. 1149, pp. 1–57, 2017.

[53] Danish Transport Authority, "Order on flights with drones outside built-up areas," *1*, vol. 149, no. 1257, p. 7, 2017.

[54] Danish Transpor Authority, "Order on flights with drones in built-up areas," *1*, vol. 149, no. 1256, p. 14, 2017.

[55] J. European Union, "REGULATION (EU) 2018/1139 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL," *Euratom*, vol. 2001, no. May, pp. 20–30, 2015.

[56] Department for Transport, "Taking Flight : The Future of Drones in the UK," p. 97, 2018.

[57] "Slovakia Drone Regulations." [Online]. Available: https://uavcoach.com/drone-laws-in-slovakia/. [Accessed: 01-Dec-2018].

[58] "Drone Laws in Romania," 2018. [Online]. Available: https://www.dpvue.com/2018/10/drone-laws-in-romania.html. [Accessed: 01-Dec-2018].

[59] "ROMANIA DRONE LAWS," 2018. [Online]. Available: https://www.uavsystemsinternational.com/drone-laws-by-country/romania-drone-laws/. [Accessed: 01-Dec-2018].

Appendix

Appendix 1

Interviewer: Vlad Tiberiu Radu

Interviewee: Søren Vincent Brydholm, Global Operational Support Manager for Falck Industrial Fire Services at Falck Denmark A/S

Interview Setting: Interview conducted in Falck offices in Copenhagen, Denmark at 12:00 on 22-11-2018.

Søren Vincent Brydholm:

If I can say that things to be considered in a way or in locations where drones should be used in emergencies, I would believe that there will be a number of locations where due to function or maybe due to the one who is owning this area it is not permitted to use drones. If I now have to take an example where there is a fire in an Airport but this fire in a first place is not necessarily in a first place affecting the air traffic, meaning that the run ways are still clear to be used, but having suddenly a drone flying up in the air and around, if there is a fire in a terminal building then probably the airport operator will say you can forget all about that, bring it down it's a risk for the traffic for the air traffic and I can also believe that can maybe be situations where the owner of a very high risk or maybe a business that is producing something that is encompassed with very high level of security… it could be developments for the defense business or a defense area, then having a drone flying out there and recording a lot of things and things that can also be recorded outside the location then the will say unfortunately we cannot accept this, or we look for a fire in a production area for air fighters, if something there is going on there maybe they would say we cannot accept that .So, combined with the legal requirements that of course unfortunately are not the same in Europe… could be…or in the world… not at all, there can be some limits, but I can still believe that in majority of the cases it would be possible to use a drone for emergencies, but the question is again what kind of technology should have this drone…

Vlad:

What type of payload, what type of sensors as you said earlier…

Søren Vincent Brydholm:

Exactly how much can it actually carry and now I am looking form a business perspective not as a public authority but here in Falck we always say that if we have to invest in drones, somebody have to pay for it

Vlad:

Yes

Søren Vincent Brydholm:

And it requires that we are able to convince our clients that it is a good idea to have a drone, the value of a drone it can easily be paid by the benefits in case of something is happening by having this drone. But having this business case description I think it is very important to do that even you're having a public fire brigade. They have to look into what do we expect is the outcome of this since the type of drones that they should use they will cost at least fifteen thousand or even more, maybe a hundred thousand or two hundred thousand

Vlad:

Danish krone

Søren Vincent Brydholm:

Yes, Danish krone.

But we have done… if I now just show you up here we looked at the idea of having a drone, seeing from our perspective (Falck) the drone within Industrial Fire Services meaning that we are operating in industry were we are mainly do prevention work, and we are doing preventive maintenance and sometimes of course there are incidents but they are very few emergency incidents, and of course we are doing a lot of training, then we looked at it (the drone) as a tool to be used for inspection, monitoring, surveillance of constructions and installations, fences, damage, leaks, I told about this sniffing function where you could mount sensors on the drone and they could find out if there is a release of dangerous substances here, and then we could make an analyze about that, and also seeing different kind of leaks it depend very much on the sensors *technology.*

Vlad:

But the sensors that you are talking about, and the software they developed from SDU, it was a software that made a drone autonomous so that it only flight alone or was it operated

Søren Vincent Brydholm:

From what I have seen it there are two kind of solutions, one controlled with a remote control and they just flying around with the drone, but can be also as we have seen for instance in agriculture, out of the world, where you can program a flying pattern, and just let the drone the same way that you have these automatic lawn cutters that it launching itself automatically every day 11:00 o'clock and then is now to inspect flying around and aside, come back, and then are some kind of sent the result or the result is already sent to the software there is kind of assessing the observations from the drones and then forward a propose, but we do it more or less advanced depending on what kind of technology you are using, and what you want and you will pay for it.

Vlad:

So, basically was not a person analyzing the video feed or data gathered from the drone, it was a software making it, analyzing it before, so then it just shows like the critical…

Søren Vincent Brydholm:

We are not using it but this is example from what I have seen from many kind of events, where the software is instantly doing the assessment and bring you forward the result, you do not need to sit and do yourself the assessment because the software is already doing it. I can see that there are some companies there are providing such kind of software but some companies are not event there that is why, our view on drones is that is a mean for data gathering and for that purpose it is more or less your imagination that stops how to use a drone, because if you can find a sensor and besides sensors, different camera types, if you choose a certain sensor you can get a certain result out of it and if you want to have a kind of "one drone fits all" meaning that it should carry all types of sensors at one time then of course you should have a rather large sensor or large room for placing it or you should replace it

Vlad:

Each end every time. Yes.

Søren Vincent Brydholm:

What we did is just that we said it could be used in Refineries where you have those special installation with flare for burning gases resulted from production, flare stock inspections, oil pipe line inspections they are spending so much money in having people, having scaffolding, and controlling and if you have a drone you can throw apart and it just could be better.

Vlad:

This could be also the case for the business in Romania?

Søren Vincent Brydholm:

Exactly it could easily be that and in fact you could actually combine this three, four types because you also having gas emission, monitoring it means that either you can use a sensor that is kind of sniffing or else it can see by the use of an infra camera, they can see changes where suddenly they can see kind of a clouds because gases are a little bit colder and the same goes for oil spill, damage detection it can see that something compared to maybe having (again we are taking about software) if we can make a resemblance with how it should be and if we observe changes then there will be an information instantly. General buildings inspection to see if there are cracks on the surface of concrete.

Vlad:

To see about structural resilience…

Søren Vincent Brydholm:

Exactly. Then again an example with an infra camera where you can see high voltage line inspection, but also in regards to production of information material we have seen drones used with a high resolution camera to take picture of a large view of a building or construction and then using this information because it can be done extremely fast, extremely cheap comparing a helicopter flying out there, to be able to support the development of treaty emergence, it can be *used in the development of the emergency response planning and then of course there is something about inspection of goods, but in direct emergency and surveillance work we have been looking at fire support coordination in regards to natural disasters response where it is not only about flames of course. One of the chances for many countries is -for instance if we are now looking of fires in California to have an overview of what is actually happening, where you have to deploy your resources since the area is enormous, how you actually do that? One thing is to get an idea of what is burning but another is to find out what is the spread of this fire so you can guide the fire brigades in the right direction. But the difference is that you cannot use the same type of drones. This one here will be long battery and you need to have a very expensive drone that is maybe not rotor drones but fixed wing drone, you should fly around this area and they should have a certain range of course. And again you can combine when you look at the fires you can combine the high resolution of a normal camera with infra cameras were you also use as a safety support instrument so you can see where are your firefighters.*

Vlad:

So it can be used like safety measure for firefighters

Søren Vincent Brydholm:

Exactly. The drone knows always where they are and then of course you can combine it you want to be very advanced they could have an electronic receiver that will send information about yourself, firefighters 347but again depends on the technology and the software that you're having behind because one thing is that the drone can present this picture but if you can combine it in a software where the software immediately places a box and sais this is a firefighter this and that, and you can pick up of that.

Vlad:

Ok I understand. So you know directly who is reporting what and where is that person.

Søren Vincent Brydholm:

It is only a matter of the kind of software that you want to have and you want to use a combined of pictures here with GPS and then having a very advanced capability of communicating due to the *fact that you know exactly where the people are. That will be a huge improvement. The limitation is of course the same moment when they are walking into the building because they are out of range and you cannot see there. And then it was the surveillance part the type of industries where in some cases we are working with they are I would say kind of opposite using drones, they are very conservative about having hostile drone flying in the area so having a drone detecting system, I am not saying that will be instantly shut down that is maybe too advanced but they can provide an alert for that. That is another way that could be used. And then we have been looking at different kind of types but what we did also it is what we thought of multi rotor drones what could the advantages be, because we can have it what you can buy in a toy store, but it of course it could be extremely advanced and you could have one that starts with one hundred thousand krona and then up to a million. Another possibility is use in a nuclear power plant if would be allowed you could mount a radioactive sensor and if there would be a risk of a release you can fly it over there.*

Vlad:

So this would be like some sort of a sensor that detects radioactivity.

Søren Vincent Brydholm:

Yes but it's like the same that you are using when you are searching in general for radioactivity like a Geiger counter, the same technology can be used here and it is already existing. But you can see here (showing a presentation) the type of sensors, thermal imaging, cameras optical, cameras high resolution, acoustic sensors, GPS to always know where the drone is, sniffer, gas free, laser scanner heats and maybe they are some more. And if we want to go into which would be our requirements for a drone or which are also the external requirements and you can see here what we've put in: transport, drones must be easy to transport, preserve drone, drones must be able to operate on a rain cold,

Vlad:

So weather...

Søren Vincent Brydholm:

Yes. At least 30 minutes shall be operating range, be able to be controlled on a range of 3 km, *liability comprehensive insurance,*

Vlad:

So from your perspective you say that a drone should be insured by a third party?

Søren Vincent Brydholm:

Yes. It depends what you mean by third party.

Vlad:

Like for example if the drone produces an accident who should be responsible for this.

Søren Vincent Brydholm:

Exactly if the case of a drone that falling down from the sky hitting someone it is so important that you are aware of that and you need an insurance for that part of it… of course you can be insured but you need to put it in the business case that I've mentioned previously. What would be the cost for the drone? What would be the cost for insurance? What would be the maintenance costs? What would be the cost of having people to operate it? You need to be sure that all your costs will be paid your investments are paid and that all your operational costs are paid, and that the benefits that would be achieved by having a drone it cans easy be defended by having these costs. Again our focus (Falck) will be on the business case but it is a little be different if you are a fire brigade authority, you do not need necessary to look it that way but on the other hand in some extent you need to do it because the amount of money is not unlimited. So we have to find out: should we now buy some expensive fire extinguishing equipment or should we buy a new drone. So that is actually the challenge and then you have the discussion who is going to operate it in case of a fire, is the fire brigade, is the police, but that's another discussion.

What I can add to the emergency use is that I have also seen that if you look at risk or emergencies in the water and if somebody is informing the authorities or 112, that they have seen a small ship in the need in the sea outside and you do not have instantly a rescue helicopter in the area can you then use a very fast and dedicated drone for this purpose looking out for this person, you can have a microphone, and you can have a loud speaker in a drone flying close to these people and say rescue is on the way and what I didn't saw but now they got a little bit advanced, people lying *there may be on a flee and they were freezing extreme then you can use a drone for transport of heating blanket so is just dropped down… But having the drone flying out there and constantly keep these people in contact with the rescue authorities that is gradually arriving that is another way to use a drone. They tested it I think in Scotland or Ireland but what was the outcome I don't know yet. I don't think I have any more…*

Vlad:

I think I saw a similar case where they should have sent like rescue boats to people in the water with the drone and just dropped it.

Søren Vincent Brydholm:

OK but this is what we are having and can be used for the transport of quite a lot of things and again it requires a drone with a certain capacity depending on what you transport but without any doubt it is something that we will see much more in the future. We can see that some of the US transport companies they already are using drones for transporting packages…

But it was our view on this and we could see that some of the limitations we met is was for instance requirement that you must never leave a drone out of sight and sometimes in different kind of legal complexes you could see that the sight distances was sometimes 300 m, sometimes 500 m and in other countries depending on the circumstances it was 1 km, but again, there are special rules for I would say urban surroundings,, you must not use a drone where you could be in suspicion for looking into people's windows and then there were different kind of rules on country side area, but the problem is of course that if you should use it for sea rescue service you must accept that you should not be able to see the drone but since the drone has a camera and has a GPS for instance you will always find out where it is.

Vlad:

But what about flying at night?

Søren Vincent Brydholm:

That is without any doubt another challenges a thing that quite few drones they are operating the night even if they can easily manage by the use of the GPS, but it will be something that will change *overtime so we will see in the future and from my perspective we will see drones of all types will be flying around for not at least the transport issues and inspection issue as one of the main activities.*

I believe that you have also seen this video with a drone and a heart starter

Vlad:

Yes it was from the Nederland…It was really good.

Søren Vincent Brydholm:

Yes but you can ask yourself why haven't this been establish in several countries?

Vlad:

Because of legislation and cost?

Søren Vincent Brydholm:

But is the view that we've have had on that part of it and as I said to you previously that our experience in Falck and at least in Industrial Fire Services it is kind of limited but our primarily focus hasn't been on support to emergency response but it will be to have a broader view and using it for inspections and detections of releases whatever it is.

Vlad:

So it will e used more for preventive measures

Søren Vincent Brydholm:

Yes and I can assume that in some extent they can be also used if you look at public fire brigade exactly in the same way but is a matter of where since there is not the responsibility of the public fire brigade to inspect a lot of things currently.

Vlad:

OK

Søren Vincent Brydholm:

So is kind of where we are those who has I would say very precise knowledge of this it will be Capital fire brigade who has it and if you talk to DEMA? they also have some experience. Now with any doubt I would assume that if you talk to DEMA and the guys of the fire brigade they will be also able to guide you to other fire brigade in Denmark that are using drones but if you look at the number of fires then the fire brigade in greater community area they will have the most experience.

Vlad:

Has to deal with the most.

Søren Vincent Brydholm:

Yes, exactly. There are some guys working with it for 6-7 year and I would have no doubt that they are quite skilled and they can tell you a lot.

Vlad:

OK but thank you a lot for the answers today

Søren Vincent Brydholm:

Yes, I gave you some ideas of how they can be used.

Vlad:

A really good overview.

Appendix 2

Interviewer: Vlad Tiberiu Radu

Interviewee: Ján Jeňo, Fire & Safety Division Director Central & Eastern Europe, Falck Fire Services - General Manager for Romania and Slovakia

Interview Setting: Interview conducted in Falck offices in Ploiesti, Romania at 14:00 on 18-12-2018.

Vlad:

So, I am gone to present myself, I am Vlad Tiberiu Radu, I am studying at Aalborg University in Esbjerg Denmark, and as part of my Master Thesis I am conducting a research about how drones could improve the activity of firefighting, and I am looking at Falck specifically.

So I have here eight questions, they can be skipped of the interview can come more like a narrative way if you want to talk more on the subject.

The first one would be: Does Falck, here (in Romania), or in Slovakia have had experience in using drones?

Jan Jeno

We do not have experience in using drones in activity up to now but we have a couple communications with Slovak companies, for example we have now a project with a Slovak refinery for evaluation of safety conditions of fuel tanks, also for measuring of buildings heating or corrosion of pipes. In my view this (using of drones) will have a big development in the firefighting, in the future. Now in European Union same like in Slovakia and Romania we have problems with Civil Aviation national rules, and there are much more obligations when you use drones for professional purpose, for instance that the remote pilot has a valid license, and similar to the training for airplane pilots, the remote pilots for drones must follow a training.

For the future, in one year or maybe one and a half year will have possibility start using drones in Slovakia and also in Romania. I also have in my thinking a project for using drones in our activity in refinery in Romania for using drones for checking status of the hydrant networks. If for the moment for checking this hydrant network we use firefighters that travel around refinery 3-

3,5hours. By using drones for checking status of the one hydrant i.e. without damages, without water leakages it takes for a drone, only 1.5 seconds, by using GPS maps drones have possibility to cover in 30-35 minutes all area of refinery for checking the hydrant networks and then come back to the fire station for downloading he data. Also in this case we have two options: one is that using digital maps and communication equipment, the drone send information live, online, or other possibility is that drone is equipped with SD cards and after coming back to the station from SD card information in uploaded in the system. Inside each version mentioned above, for instance for online we can have online video, but maybe this is not important and more important is digital interpretation of data on the digital map. Example if everything is OK information transmitted on the digital map turns the points on the map into green or if there are nonconformities turn the points into red. Another issue for live transmission of video is related to technical issue of transmitting of video data and necessity of huge capacity. This is why is better to register on a memory all data and send online only short information about this and this hydrant nonconformity and then come back to the station and see the video and identification of real problem like: this hydrant does not have the cover or other hydrant show water leakages etc.

<u>Vlad:</u>

But it will be someone operating the drone or it will be autonomous?

<u>Jan Jeno:</u>

Depending on the investment, we could have version when the dispatch person or the shift commander sits in the commander room and remote controls the drone, or we can have the version when the drone is loaded with GPS coordinates and fly independently collecting the data and then landing at the station.

<u>Vlad:</u>

So this will be in the prevention operations.

<u>Jan Jeno:</u>

Yes, this is for prevention.

For repression I have experience of last year while visiting Dubai Exhibition. Dubai is registering *a very high speed development and especially in construction of very tall buildings. For those kind of buildings if the fire starts at a high floor there are systems for fire repression only inside, but if the fire starts outside, and outside for construction the material used is not concreate or steel but prefabricated panels of plastic sandwiches then there are no possibilities of killing the fire, if the fire starts above 13-14 floor (where a normal platform could reach) then there are no means to kill the fire. And one company was presenting a system with using more drones, maybe 5 drones having a hose attached with nozzles and operative cameras. The systems go up 60-70 meters, the operator starts the fire and in 10 minutes the fire can be liquidated.*

Also investigating the fire could be best solution. There are many possibilities of mounting on a drone of thermal camera, infra camera etc.

One special remark for your research is that we have to take into account today the National Civil Aviation rules as well as the GDPR rules for who is using the data and for what.

Other limitation is using drones could be that many companies do not want to share outside all information or to authorities while using a drone when starting a fire everything will be registered in all area.

Another thing to mention like benefits is safety for firefighters. Firefighters can have GPS systems and it is the possibility of monitoring all persons from the top. Ok if person enters inside the building this chance is lost. Today in the Europe there is no separate function for safety in incidents.

In American system NFPA there is a safety manager that stays outside the incident, usually this manager is specialized in construction and analyses stages of fire and if for example the fire runs for 20-30 minutes he decides that it is not safe for the firefighters to enter into the building anymore because it is the risk for the building to collapse.

So it seems I have answered already to many questions.

Vlad:

That’s good it can be narrative…

Another idea to clarify was about who should be liable in case the drone produces an accident?

Should be the pilot, the producing company of the drone, the contracting company,

Jan Jeno:

Now we do not have an answer…We have for example now using in LA California autonomous cars and the question is the same for who is responsible for an accident? If it is fully automatic normally is the producer, but who has produced the intelligent software who is responsible for this software? Ok for drone we have version with fully automatic systems but in the case we have people operating the drone, generally responsible is the person but we do not have today an answer. This is one of the reason for the needed training of the pilot.

Vlad:

In the project you were talking about the hydrants how is the legislation impact?

Jan Jeno:

We do not have legislation today. This is other big topic. Generally internal on one territory of a company it is possible to use but for example the use inside refinery for checking tanks that often height is over 10-15 meters this is falling under aviation rules. This is similar with the high building having on top flash light, silver and red flash that are under aviation sector with total different other rules…

Vlad:

Of course we can see the benefits, we can use it as you said for the hydrants we can map it…

Jan Jeno:

Yes, we can map it, we can reduce cost with personnel, increase safety, but this is secondary effect of reduction of people but direct effect will be professional analyze the status of the hydrant network. Time to time the personnel does not perform complete observation work. For instance, now is cold outside, and running the bicycle is difficult and make the person skip some aspects, while using drones, with electronic system you have 100% scan of all items, so eliminate human error and increase safety and finally have financial benefits.

As from the risks to take into account using drones we must consider possibility of hacking the *drone by other people that could direct the drone to do bad things instead of good things.*

Vlad:

Yes, cyber security risks.

Jan Jeno:

Yes, this is also one of the risks that for the moment drone is not use too much in the public sector but more in military sector.

This subject was also discussed by me at Falck corporate level with Soren Brydholm one year ago and when wanted to promote idea of using drones but many times reasons for stopping start-up were linked to the legislation, responsibility and cyber security protection.

Vlad:

Drones could be also used for rescue of people for instance for transportation of some emergency materials.

Jan Jeno:

Depend. I will send you a presentation we prepared for the implementation project of using a drone in Slovak refinery. Actually the refinery approved the testing of this implementation but unfortunately the refinery is placed near the airport and limitation of implementation is linked with two lines: one is that it not yet possible insure cyber security 100% and second as mentioned the position of the refinery facilities near the airport. The presentation is about real testing of drone for monitoring the buildings, my feeling is that in the future using drones will have excellent development. I have been in Dubai Exhibition and I will go next year and I am sure that they will implement using drone in each fire station. It will be much easy…they do not have so many rules, investment money is not a problem, it is country which promote strong progress while Europe it is little bit slowly. Every year they present a new technology for firefighting. As an example this Year (2018) they presented a robot used as firefighter.

Vlad:

I think it has been answered to all of the questions.

What about if society is prepared for implementing this new technology. Is it possible to implement in Romania?

Jan Jeno:

I think yes but not tomorrow, it is a long process, involving training people, changing mentalities. If we are looking at Arabic countries, 10 years back they were driving camels and now they use the most modern technologies.

So it is possible but it needs good preparation, good education, training and good communication to the people. Another part is linked to the personal interest of the people, if the people are not interested is difficult. Now drones seem science fiction but it can be done.

Vlad:

That is all, thank you very much!

Appendix 3

Email received on 20-12-2018 from Ovidiu Romer, Process Quality Expert at OMV Petrom SA.

13:27

Romer, Ovidiu
to me
12/20/2018 View details

Esteemed Mr. Vlad,

Please find below my answer of your questions (highlighted in red)

If future clarifications are required, please feel free to send it to me

Cu stima

Kind regards

Ovidiu Römer

13:26

1. Do(es) you/your company have any experience with using drones? If yes, tell me about it.

· Our company has no experience in using the drones

2. Where do you see drone capability useful? (in which type of scenario/situation/accident; for response, for recovery, for preparedness)

· I think that can be useful in case of fire interventions in order to obtain an overview especially of low visibility areas

Hide quoted text

3. What type of payload attached on a drone would provide critical information? How would that information be useful?

· They can also be used for the thermal camera with infrared spectrum of temperatures measurement for determination of hot areas and consequently to redirect the fire intervention to these areas and for measure the gas emissions

4. What are the benefits that drones could provide for your company?

· Evaluation from the distance of an Emergency Situation (Without Exposing Personnel at Risks) & Increased Intervention Efficiency

5. When you think about using drones, do you see any risks in it? If yes, describe them.

· The drones can be used in depots only if are under Ex. construction, in conformity with refinery standard regarding the equipment's

6. Who should be liable in case drone produces an accident?

· The drone user is responsible for any accident

7. Describe how the legislation is limiting and encouraging drone activity in firefighting at the present time.

· Regarding the use of fire-fighting drones, I know that this project is pioneering and there is still no viable technology available for efficient use in this area

· I do not know the legislation that regulates this area

8. How do you see firefighting drones in the future?

· If the technical barriers are overcome, I think they will be used on a large scale in fire-fighting intervention

Appendix 4

Email received on 24-12-2018 from Stelorian Voicu, Department Manager (Manager of Services Contracts) at OMV Petrom SA.

13:25

Voicu, Stelorian
to me
12/24/2018 View details

Dear Vlad,

You will find my answers in blue color in your Email.

Please be aware that if you will use name of our company in your report/documents the respective paragraph have to be send to us for approval.

Have a nice day !

Cu stima,

Kind regards,

Voicu Stelorian

AALBORG UNIVERSITY
DENMARK

1. *Do(es) you/your company have any experience with using drones? If yes, tell me about it.*

Our company does not have any experience in using drones.

2. *Where do you see drone capability useful? (in which type of scenario/situation/accident; for response, for recovery, for preparedness)*

In the case of interventions, I think that they are useful for creating an image over the points where the visibility is reduced because of the particularities of the installations. Also, I think that they can be useful for measuring the composition of gases and temperatures.

3. *What type of payload attached on a drone would provide critical information? How would that information be useful?*

In accordance with the previous response: video camera, gas detectors

4. *What are the benefits that drones could provide for your company?*

Increasing the efficiency of the interventions

5. *When you think about using drones, do you see any risks in it? If yes, describe them.*

The equipment that are used in refinery must be in Ex construction

6. *Who should be liable in case drone produces an accident?*

The user

7. *Describe how the legislation is limiting and encouraging drone activity in firefighting at the present time.*

I am not familiar with the legislation in this domain

8. *How do you see firefighting drones in the future?*

Very useful and widely used

Appendix 5

Mail received on 17-12-2018 from Paul Frankland, Technical Director of Falck Fire Services UK.

13:28

Vlad Radu 12/14/2018

Hi Paul, Thank you for your availability and willingness to help. Here are some general

Paul Frankland

to me, Florentin, Paul

12/17/2018 View details

Hi,

I didn’t really get this project off the ground locally as I was told that Falck were looking at this at a corporate level. I wanted to work with a company called Retrix on Teesside who were specialising in drones for the emergency response industry led through a well know ER specialist called Kevin Westwood who works for BP.

I have attached some thinking we had for developing locally but alas there was no inertia from group to look at this here.

I have answered some of the questions below where

Best regards

Paul

13:28

1. Do(es) you/your company have any experience with using drones? If yes, tell me about it.

Please see the above notes. I was very keen to introduce this in our UK business but there was no appetite to follow this through. There was work carried out in group but none of this has materialised locally.

2. Where do you see drone capability useful? (in which type of scenario/situation/accident; for response, for recovery, for preparedness)

I saw great potential of using drones for training and exercising both in the UK and as part of the training academy. A lot of response teams are acquiring drones with new fire trucks. As a leading ER provider I think we are falling behind other specialist in the technology field. They can be used during incidents for monitoring of hazardous chemicals and there are many good examples of using drones to prevent putting responders into hazardous areas.

3. What type of payload attached on a drone would provide critical information? How would that information be useful?

I didn't get this far with the analysis. Project stopped.

4. What are the benefits that drones could provide for your company?

We could use them at incidents, they have a commercial benefit, they can add unique elements to our commercial training, early entry would have been a USP but as I said earlier, we are falling behind and playing catch up. Falck should be leading the field in best practice if we are the largest independent provider of fire services.

5. When you think about using drones, do you see any risks in it? If yes, describe them.

There is always the risk of use in high risk areas such as petroleum licenced areas, risk of them crashing and there is always a need to look at the training and deployment. There is a need to do a CBA on the introduction but I still believe they can be an asset.

6. Who should be liable in case drone produces an accident?

There should be clear parameters of their use, how they are deployed and the training. Ultimately it will depend on what the incident was and what a root cause analysis showed to say who would be liable. A clear contract will have liabilities on both the provider and the client I would assume.

7. Describe how the legislation is limiting and encouraging drone activity in firefighting at the present time.

Not got this far

8. How do you see firefighting drones in the future?

I still see this as a step forward and should be fully embraced and the deployment of drones can make a real impact and positively enhance emergency response tactics.

Appendix 6

Interview question guide for both the email and the face-to-face interviews.

1. Do(es) you/your company have any experience with using drones? If yes, tell me about it.

2. Where do you see drone capability useful? (in which type of scenario/situation/accident; for response, for recovery, for preparedness)

3. What type of payload attached on a drone would provide critical information? How would that information be useful?

4. What are the benefits that drones could provide for your company?

5. When you think about using drones, do you see any risks in it? If yes, describe them.

6. Who should be liable in case drone produces an accident?

7. Describe how the legislation is limiting and encouraging drone activity in firefighting at the present time.

8. How do you see firefighting drones in the future?