A Qualitative Risk Assessment Applied Using SORA: UAV Technology Supporting Maintenance Operations on Rødsand II Offshore Wind Farm

Master Thesis

Belal Miari

AALBORG UNIVERSITY
DENMARK

Aalborg University

Risk and Safety Management

AALBORG UNIVERSITY
STUDENT REPORT

Title:
A Qualitative Risk Assessment Applied Using SORA: UAV Technology Supporting Maintenance Operations on Rødsand II Offshore Wind Farm

Theme:
Master thesis

Project Period:
Autumn Semester 2018

Group number:
5

Author:
Belal Omar Miari

Professor:
Anders Schmidt Kristensen

Supervisor:
Saqib Mehmood

Page Numbers: 47

Date of Completion:
January 10th, 2019

Risk and Safety Management
Aalborg University
http://www.aau.dk

Abstract:

The offshore wind industry is developing quickly with an average yearly market development rate of nearly 7% in the next five years [4]. Services of wind turbines has ended up being costly and hard, in terms of safety, to be performed, especially the offshore ones.

Denmark was the first nation to introduce a business offshore wind farms 30 years back and has been first mover in the wind business for a considerable length of time [2]. Standardization as a part of Danish Legislations are being established, these are to maintain a certain standard if UAVs produced and used in Denmark [6]. Danish legislation concern is on conducting risk assessment to apply for UAV exemption. The thesis in-hand does not include any type of quantitative data because of the lack access to same. Therefore, SORA was chosen to be a supporting risk assessment tool used since it can handle qualitative inputs.

The purpose of this thesis was to identify and assess the operational risks in implementing UAV into supporting a maintenance crew in offshore wind turbine. A case study on Rødsand II was conducted where an application for UAV operator is proposed, using SORA, to identify the risks. The result of the SORA analysis was found to be with medium robustness for the proposed threat and harm barriers according to the inputted criteria.

Preface

The thesis is intended towards understudies and experts in Occupational Health and Safety, Risk managers and unmanned aerial vehicles (UAV) operators. It tends to be helpful to proposed wind turbine operators and owners to comprehend the risks of utilizing UAV for maintenance supporting tasks and to assess the legitimate potential outcomes of enhancing the UAV industry in Denmark. The reader will find a proposed scenario of UAV technology for helping with ascending tools to the maintenance team on a top of a wind turbine on Rødsand II. This thesis is written, by Group number 5 that consists of the author, for the 4th semester as part of the Risk and Safety Management master thesis at Aalborg University in Esbjerg through the period from September 1st, 2018 to January 10th, 2019 and counts for 30 ECTS.

In this thesis, tables and figures are arranged with one successive index. The sources in the content are demonstrated by number in square brackets that are recorded in the reference part as IEEE style for referencing for example [1]. Equations where labelled by sequence numbers to the right of the page to be referred to in the text, if needed. The sources that were utilized in the report are intended to be as academic and legitimate as could be expected under the circumstances.

At the point of the thesis for selecting the UAV I contacted some UAV companies to help me in supporting specs of their UAVs since it was a difficulty to retrieve data on research engines. The UAV manufacturer favoured to suggest other manufacturer names since they build their own UAVs based on customer requirements and unfortunately, they refused to share information. It was not so important dialogue, but it led to relevant UAV manufacturer that serves the thesis and shares the specs. A copy of the email thread can be found in Appendix A.

Lastly, this thesis has been produced through a time frame of four months in which I was full-time employee and a full-time family man. This is, by itself, is a hard task to perform. However, it teaches multi-tasking and increase the challenge ability to accomplish aa much as fine report. I am proud of myself that I was able to accomplish this great work with the excessive dedication and honesty research and input.

Acknowledgement

I would like to offer my greatest thanks for my Professor, Anders Schmidt Kristensen from the Department of Civil Engineering at Aalborg University for his supervision and liberal help and direction during the time spent composing this thesis. Also, many thanks to my supervisor Saqib Mehmood for dedicating time for our regular meetings. The measure of information that I have increased through our discussions is enormous. The dimension of motivation and inspiration that you have offered through your direction is significant.

I appreciatively recognize the help from every one of my partners that I have gotten during the time spent working on this thesis. An uncommon thank to Yassin Kissami, for the exciting and rewarding dialogs we had; as well as being my mentor during the working procedure. Likewise, a special thanks to Mille Skovgaard, the best partner, who dedicated time for commenting on my thesis and supporting throughout the working process.

Last but not least, I want to offer my most profound thanks to my father Omar Miari, my uncle Farouk Miari and my wife Mariam Awad. Without your consistent help, comprehension, consolation, and love I would have been lost. Much thanks with love for having faith in my abilities and being part of my life.

This thesis is prepared by:

Belal Omar Miari,

Bachelor of Science in Mechanical Engineering, American University of Sharjah, UAE,
bmiari17@student.aau.dk

Acronyms

AEC	Airspace Encounter Category
ALARP	As Low as Reasonably Practicable
ARC	Air-Risk Class
ConOps	Concept of Operations
Crew	Transfer Vessels
EASA	European Aviation Safety Agency
GRC	Ground Risk Class
HAZID	Hazard Identification
ISO	International Standard Organization
JARUS	Joint Authorities for Rulemaking of Unmanned Systems
MTOM	Maximum Take-off Mass
NOS	Northern Offshore Services
NPA	Notice of Proposed Amendment
O&M	Operation and Maintenance
OSH	Occupational Health and Safety
R&D	Research and Development
SAIL	Specific Assurance and Integrity Level
SORA	Specific Operation Risk Assessment
TMPR	Tactical Mitigation Performance Requirement
UAV	Unmanned Aerial Vehicle
VLOS	Visual Line of Sight
WT	Wind Turbine

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1 Introduction

1.1 Background

Denmark is a global pioneer in the usage of a sustainable, secure and cost-proficient vitality framework utilizing a high offer of wind control. In 2016, Denmark accomplished a wind control entrance of 38%; while providing 99.996% of local electrical power all through the year, bringing about one of the most elevated vitality security levels in Europe [1]. Denmark was the first nation to introduce a business offshore wind farms 30 years back and has been first mover in the wind business for a considerable length of time. In 2016, onshore and offshore wind turbines gave around 40% of Denmark's power utilization and the plan is to run further with over 50% of power utilization to be produced by wind energy by 2021 [2]. Danish learning and improvement of environmentally friendly power vitality has likewise pulled in remote financial venture in sustainable power source. Figure 1 shows the Danish onshore and offshore wind power limit and the infiltration level of wind power in Danish electricity utilization somewhere in between of 2009 and 2016.

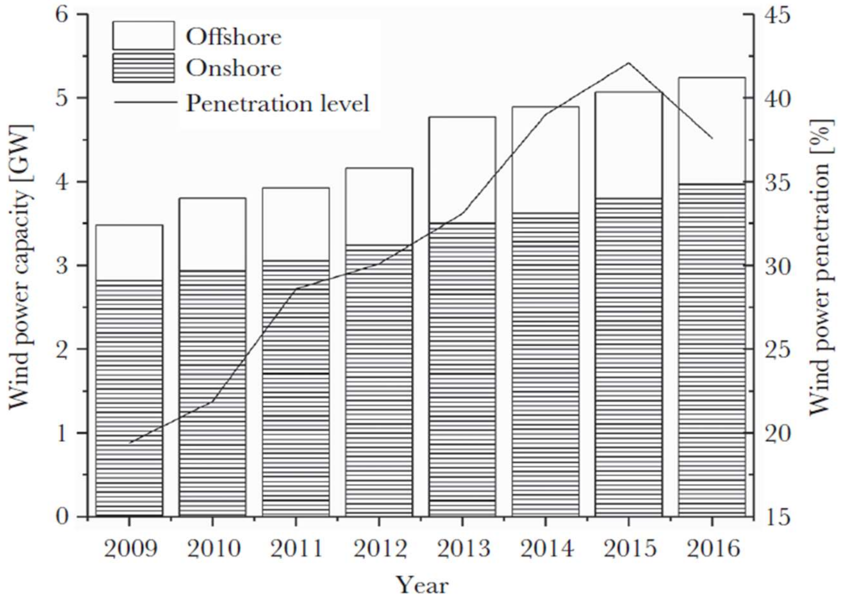

Figure 1 Wind power capacity and penetration level in Denmark from [3]

At present, the European wind energy division offers occupations to 192,000 individuals, and a lot of more well-trained specialists are required in areas going from assembling to project management. It has been anticipated that by 2020 there will be 446,000 employments in the breeze vitality segment in Europe [4]. In spite of the fact that wind energy is considered green and useful for the environment, it doesn't really mean it will be useful for the health and safety of personnel [5]. Wind energy personnel can be presented to hazards that can result in fatalities and genuine wounds within the different periods of a wind farm scheme. The goal of this report is to propose an implementation of UAV technology that could help supporting the maintenance crew to reduce their exposure to hazardous situations.

A well-planned support association and enhanced maintenance systems is required to successfully lessen the expenses related with wind turbine (WT) support [6]. This additionally incorporates dealing with capacity of spare parts. These kinds of issues are evident in many businesses and not at all exclusive for WTs. The operational expenses of offshore wind turbines that are currently and financially accessible, appear to be too high to even consider making wind projects extends economically appropriate. For offshore wind, the expenses for Operation and Maintenance are assessed to be 30 to 35 % of the costs of the electricity.

UAV technology is undergoing continuous development and enhancement in the developed world [7]. Utilizing UAVs compared to dispatching vessels can help diminish costs by up to 90% for vessel administrators and managers [8]. One of the leading maritime industry companies, Wilhelmsen, estimates that UAV could offer cost savings over the whole business of up to $675 million [8]. UAV can possibly offer various delivery choices from an area to another. UAV with its ability to be operated or autonomously flying can contribute to the matter of having less labor dependency [8].

In March 2016, Maersk Tankers tried delivery to vessels on UAV that have been ensured for explosive situations [9]. The reason for this test is to utilize a UAV that is approved for explosive situations and see how the idea functions. The test in cooperation with Bauer's automaton producer Amen Technologies [9] was the first of its kind to utilize UAV to make a transportation to board a vessel. The utilization of UAV is advantageous as per the supply chain manager at Mærsk Markus Kuhn [9] *"Drones can make savings in both costs and time. There are high costs for on-board delivery of small parcels, filled with urgent spare parts or mail, because of the need for a barge".* In the early of 2018, four Norwegian companies investigated the use of UAV with Olympic subsea, an offshore vessel owner, to transport cargo between offshore vessel and installation [10]. The research project will be funded by the Research Council of Norway and will include a collaboration of specialists in motion-compensation technology [10].

In 2017, the Ministry of Education and Research in Denmark has allocated a huge sum of DKK 27.5 million [11]. This is to be consumed within several research areas which UAV technology happens to be a major part of. The Danish state looks for more lucrative fields and operations where UAV-technology could be used and benefited from. Meanwhile, development of the technology is also one of their main targets for the upcoming years [11]. A national UAV institute has also been established, it consists of three universities across Denmark which are Southern Denmark, Aalborg and Arhus universities. The UAV-Ability project, an investment worth DKK 30 million is meant to develop and enhance UAV technology within several fields, which risk and safety are part of. The government currently targets 6 ambitions and has published studies explaining the approach and reasons for each one.

Standardization as a part of Danish Legislations are being established, these are to maintain a certain standard if UAVs produced and used in Denmark [12]. However, many regions of the world have developed standards that are way beyond the capabilities of small startups. This causes an imbalance in the private sector where only major companies can maintain a business model with UAVs. However, in Denmark the state is attempting to involve companies from all scales into the discussions of the standards to be implemented [12]. The Danish Technological Institutes have been given the task to establish this standardization from 2016 to 2018. There have also been attempts by the international community to establish standards for all UAV manufacturing countries. Denmark is determined to influence the international standards and become a key player within the UAV technology industry, as the support for international conglomerates to adopt UAV-technology can boost the efficiency of the world economy [13].

The use of UAVs in any operation comes with a certain risk assessment it must overcome to be proven a viable technology to replace human interactions [14]. This comes from the aviation law, Act of Aviation, which is a branch of the Danish law that matters all air navigation and transport activities in Denmark [15]. Acts had changed commonly since the date they were embraced in the Danish legislation due to oblige changes i.e. changes in the market, the conduct of the general population and political motivation. The Danish enactment on smaller UAV were first to be thought of as model aircraft in 2004 [15]. These progressions were identified with control smaller UAV, and the modification of safety guidelines. SORA was utilized in this thesis as an assessing tool that copes with lack of data to perform a risk assessment and satisfy the needs of legislation.

Given Denmark's well-established infrastructure for UAV technology [16], it is worth investing effort and time into adding to this industry. Fields such as risk and safety when operating UAVs into many operations is still a growing field and open for a lot of development and enhancement. Also, with technology development, ambitions to implement UAV technology into more difficult areas will become more desired. This will cause a higher demand on research within the risk and safety concerned with these operations.

1.2 Purpose

The purpose of the current study is to assess the risks that may occur with Unmanned Ariel Vehicle (UAV) flying from the deck of the vessel visual line of sight (VLOS), supporting crew with their tools, to the top of the wind turbine in Rødsand II wind farm where the service personnel is performing the job of a delivering any missing tool or to prepare for the job. This thesis is based on occupational safety and health in which knowledge of risk management is applied. Based on the already existing Specific Operations Risk Assessment (SORA), it is expected that this thesis might be a useful tool that helps in better understanding the risks associated within a given maintenance operation. Looking at the fact that there are not much shared data online about any company using UAVs for such small tool delivery within the wind turbine, it is expected that this report may also be a pretext for enabling UAV as a potential use for the operating company on Rødsand II, E. ON. In addition, this thesis will contribute in widening the horizon for future consideration and research in UAV technology and its use in the logistics industry in Denmark.

1.2.1 Scope

The thesis will focus on the risks associated with the use of UAV in offshore maintenance work. Including preparation for the job, operating the UAV and assuming full dependency on the it to lift tools to the top of the wind turbine. Also, it aims to evaluate the operation using SORA, a step-by-step procedure, for assessing the associated risks qualitatively.

1.3 Methodology

This section of the thesis subsidizes in understanding of the structure and gives a fair overview of the tools and methods used.

1.3.1 Research approach

Since the problems with risk management in the offshore wind farm industry were unknown when the research began, the subject of risk management is extensively explored by companies especially in offshore industries [17]. The literature studies were conducted mainly on two topics, wind turbine and its maintenance and UAV use in offshore industry. Since the focus of this study was the application of SORA, I used [18] as a guideline to perform this task. However, the copy found in-hand had limited access to the Annexes and I couldn't reach a full access to all Annexes. Despite the limitations, another report [19] did a comparison between SORA and a different method in which the author performed all steps required by SORA where that was an insight to complete the task in mind.

Potential advantages and disadvantages of UAVs have been considered by logistics companies. For instance, UPS, global leader in logistics, has delivered a package of medicine from a city to an island that is three miles off the coastal. It also tests a higher last-mile efficiency UAVs, decrease of accidents, and quicker deliveries as key potential UAV benefits [20]. In 2016, Mærsk launched a UAV delivery to an undocked vessel where the aircraft were seen dropping a parcel [21]. The main goal of implementing UAVs into delivery use is to have a risk-free environment. Most of the literature found were focused on the UAV and its classifications and the reliability of such which was not an aid in this thesis since the idea was to dig into the ability to deliver.

Different keywords were used in this thesis to try to find the ignition that could lead to proper analysis using different search engines and science databases i.e. google, google scholar, science direct, IEE and research gate. Starting with words like drones, unmanned aircraft, drones and offshore, drone's delivery offshore, risk analysis, offshore, wind turbine, wind energy, maintenance and operation, spare parts, tools, drone delivery, risk assessment, hazard identification, Rødsand, logistics and drones or UAV and SORA. Unfortunately, most of the drones/UAVs with delivery were not resulting in a useful information since the idea is still new and not adopted. Therefore, the principle of UAV supporting a maintenance personnel on a wind turbine was assessed by the application of risk assessment with the good use of SORA and the best knowledge of the author.

Key findings of this thesis are with no data recorded for the use of UAV in the wind turbine industry, still a risk analysis can be performed. Qualitatively speaking, hazards and mitigations could be given a value based on parameters represented by the number of fatal injuries to third party on ground [18]; as well as a value for assurance and integrity. At the end, it will suggest the applicant where to implement missing mitigations to have a robust operation.

1.3.2 Terminology

Hazard: anything built-in to a business that could have the potential to cause harm to safety, health, environment, property, plant, products, or reputation [22]. In this context, it was used as the definition states in relation to safety, health, and property damage.

Risk: it has different meanings depending on different contexts. Mainly, risk is defined as obtaining unfavorable outcome accompanying with an action or it is the magnitude of probability by the likelihood of an event occurring [23]. This thesis is a self-research based, so no data and quantities are known to the author. Therefore, it makes the risk comes in the context as a qualitative outcome.

UAV: technologically, a drone is a flying robot without a pilot on board that can be controlled remotely or fly autonomously [24]. It could be referring to different other names i.e. drones, unmanned aircraft systems (UAS), unmanned aircraft vehicles (UAV) remotely piloted aerial systems (RPAS) and unmanned flying objects (UFO). For consistency in the thesis, UAV term will be accredited and used through the whole report to refer to the aircraft.

Equipment: simply equipment is, by definition*, "tangible property (other than land or buildings) that is used in the operations of a business. Examples of equipment include devices, machines, tools, and vehicles* [25]*."* The author uses equipment in the thesis context referring to handy tools that are used by the personnel to perform a maintenance on the wind turbine.

Maintenance: from a technical point view is *"All action taken to retain material in a serviceable condition or to restore it to serviceability. It includes inspections, testing, servicing, classification as to serviceability, repair, rebuilding, and reclamation* [26]*."* The personnel in the context of this thesis will be providing a routine maintenance where they will be inspecting, testing or servicing the wind turbine using handy tools.

Operation: it might carry multiple definitions consisting of medical, human actions, mathematical or business. In this thesis, operation refers to an organized activity carried out by a group of people i.e. flying UAV and performing maintenance.

1.3.3 Methods and models

Brainstorming method

At the initial stages of this project, the Star bursting methodology was implemented. This is by listing a series of questions which would require further research, a narrowing down procedure is used to eliminate the unnecessary question put beforehand. The questions selected were put in a structural order for the whole problem to be researched in a step-wise manner, rather than a random way. The questions were mostly meant to deliver the where, how and why aspects of the project. The questions put in place would change frequently when the research within one question leads to deviations of the project towards other questions. Given the lack of knowledge within the wind energy industry at the beginning of the project, the questions listed during the brainstorming process would begin from the basics of knowledge, going up towards a more detailed area to be analyzed and assessed. An unstructured form of brain storming was conducting after the questions were laid out, the ideas and thought were written down to target the solution to each question from different perspectives.

Bow-tie

The bowtie method itself is a risk assessment tool that can be used to analyze and communicate how high-risk scenarios expand [27]. The core of it consists of reasonable risk scenarios around a specified hazard, and ways in which the organization eliminates those scenarios from happening. The method gains its name from the shape of the diagram that shapes it, which looks like a men's bowtie [27].

Numerous objectives make the use of bow-tie, for example:

- Deliver a structure to analytically analyses a hazard,
- Help deciding whether the level of control is satisfactory,
- Help identifying how investing resources have the greatest impact,
- Increase risk awareness and communication.

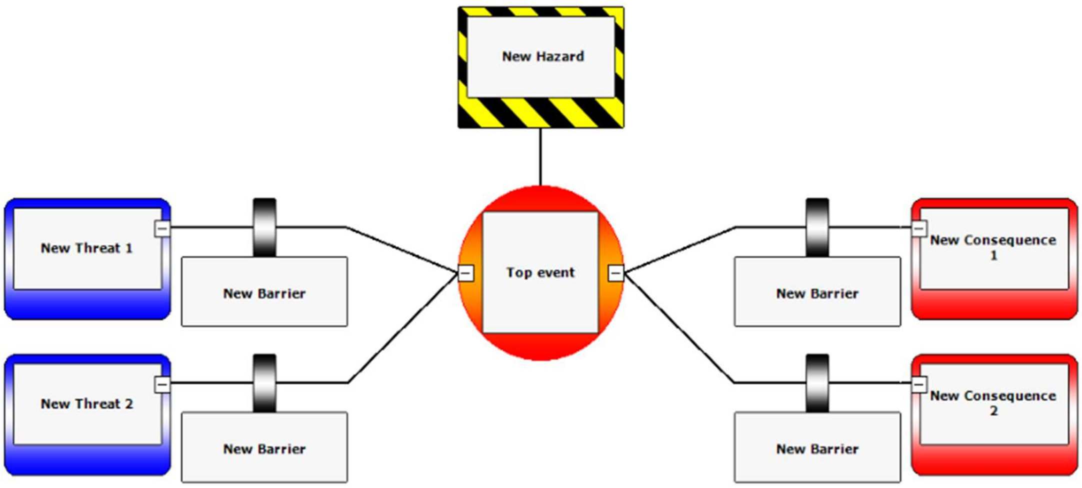

Figure 2 Typical bow-tie diagram [28]

The elements that make up a bowtie diagram are summarized in four steps as identifying hazards, top events, threats, consequences and identifying preventive and recovery barriers. A general bow-tie diagram is represented in Figure 2 below, where the left side, in blue, represents the threats and the right side, in red, represents the consequence.

SORA

The methodology supports a logical process to analyze the proposed operation and carry out an acceptable level of confidence that in return can be conducted with an acceptable risk level [18]. With a compact understanding of threats, harms and their barriers, SORA can be established as in below Figure 3. SORA focuses on the ground and air risks created by the operation in hand. The fourteen steps of SORA are summarized in following Figure 4 [18].

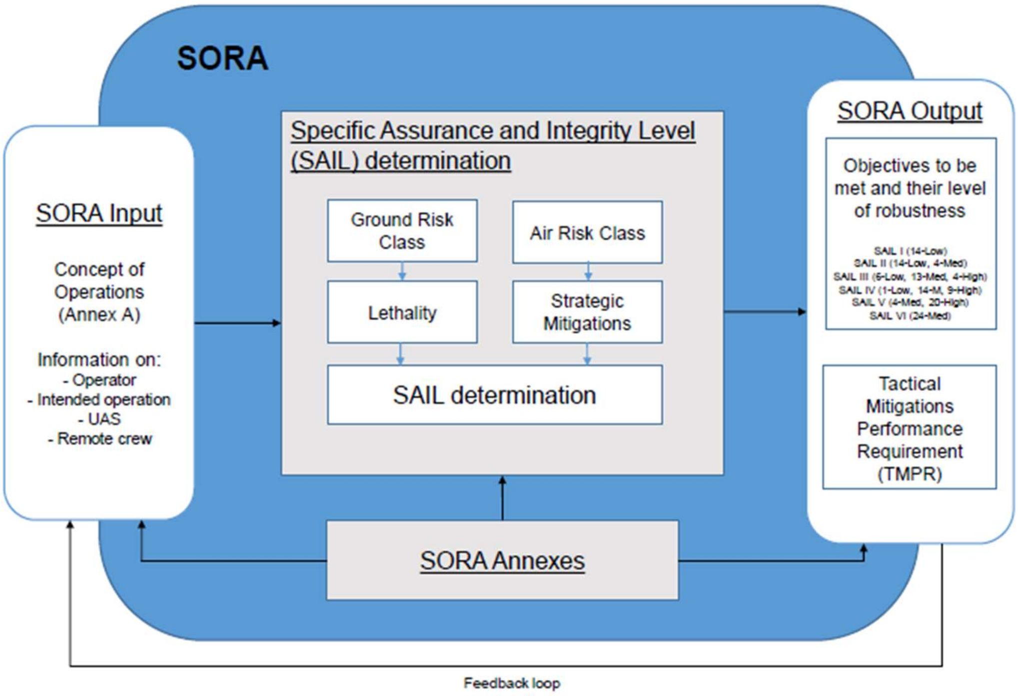

Figure 3 SORA overview [18]

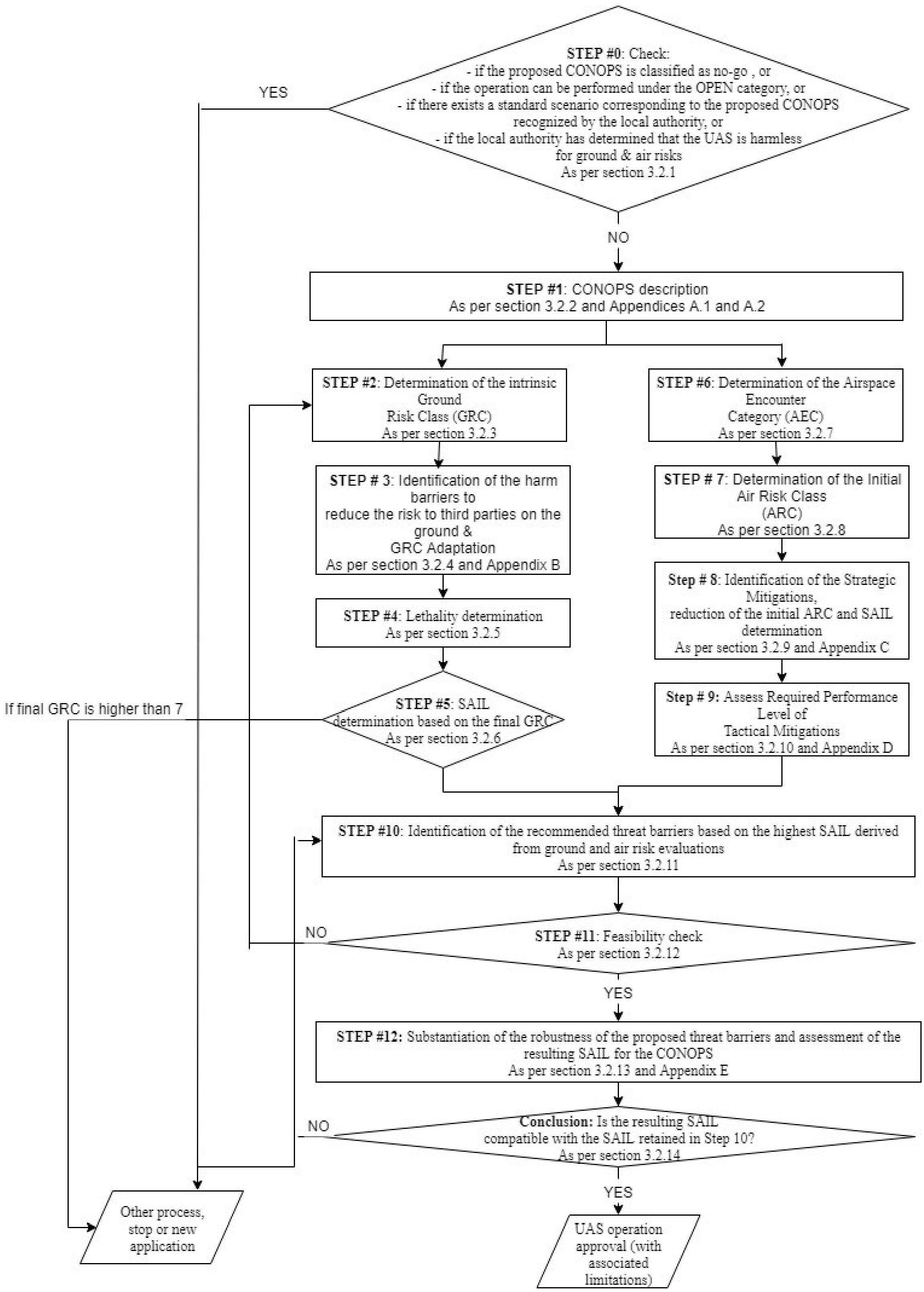

Figure 4 The SORA process from [18]

1.4 Problem analysis

Post the brainstorming stage, Figure 5 was concluded and constructed prior to proceeding with the problem analysis. Several areas of interest were laid down for further investigation, these are to eventually be narrowed down to a one problem which is to be analyzed and assessed in detail within the scope of risk, health and safety.

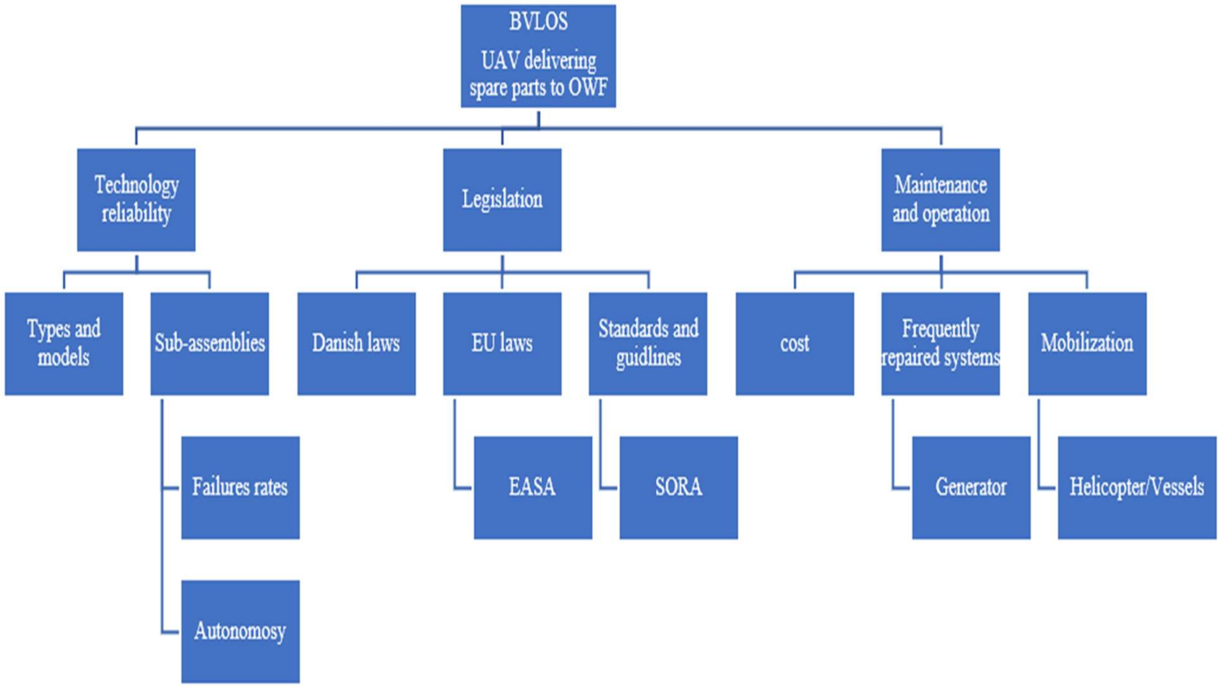

Figure 5 Crude brainstorming for the interest before narrowing down to problem analysis

Below figure 6 shows the roadmap that was implemented and is to be followed, key words were selected to identify the process stages for the assessment and analysis of the selected problem.

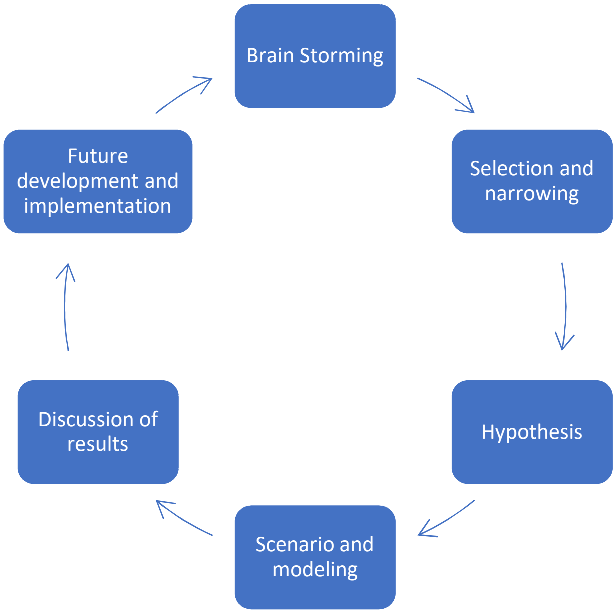

Figure 6 Problem analysis

As seen in Figure 6, the main areas that were researched and investigated are technology reliability, legislation, maintenance and operation. After narrowing the down, the study, a specific task within the maintenance and operations area was selected. After conducting the required research within several aspects in the operations of transferring tools to a certain wind farm a hypothesis and a series of questions were concluded for further analysis.

1.4.1 Legislation and guidelines

This section aims to highlight on the Danish legislation that could be used for the proposed scenario for the operating company. Standards were found for the existence of complex systems that requires quality control and monitoring. In Denmark all standardization has been centralized into one organization called Dansk Standard [29]. The operating company, E. ON, starts the process of flying UAV to support the maintenance crew on top of the wind turbine from the supporting vessel at the WT. Unfortunately, it has not been possible to research similar cases, perhaps that the legislation has only recently been changed. Anyhow, the Danish will not be used in this thesis as SORA will be the guidance for the operator's application of operation.

In Denmark, UAV legislation can lead to the consolidation Act No. 1149 of 13. October 2017 concerning Air Navigation. Conformity, two different Acts conforming to the two main application areas of UAVs have been accomplished:

- Consolidation Act No. 1257 [30] (Order on flights with UAVs outside built-up areas)
- Consolidation Act No. 1256 [31] (Order on flights with UAVs in built-up areas)

The presented scenario in this thesis concerns UAV flight within a wind farm, so a better discussion of specialized legislation will be focused on the conditions of consolidation Act No. 1257 of 24 November 2017 [31] (Order on flights with UAVs outside built-up areas) suitable to this scenario.

The Act states:

"§ 3. Flights with small drones outside built-up areas shall be operated in such a way that the lives and properties of other persons are not exposed to danger or other unnecessary inconvenience, and that special consideration is shown for wildlife and animal farming, cf. § 126 c of the Danish Air Navigation Act." [30]

During flights outside built-up areas, it is the responsibility of the remote pilot to always keep track of the surrounding as the Act states:

"§ 11. The surrounding airspace shall constantly be surveilled by the remote pilot and the flight shall aborted immediately if a manned aircraft approach" [30]

As well as, the remote pilot should be aware of other setups during the UAV flight knowing the flight levels, distance requirements and permissions as follows [30]:

- The flight shouldn't be higher than 100 m above terrain,
- Shouldn't fly over residential/private property,
- Shouldn't be closer than 150 m to public roads and railways.
- Shouldn't be closer than 2 km from a helicopter emergency medical service aerodrome.
- Shouldn't be closer than 5 km from a public aerodrome's runway.
- Shouldn't be closer than 8 km from a military airbase's runway.

- Shouldn’t be closer than 150 m from royal residences, embassies, properties belonging to the police, prison and probation services, military installations, without prior consent.
- Shouldn’t be closer than 50 m from manned ships/boats and other offshore installation, without prior consent from their owner.
- Shouldn’t be closer than 150 m from the scene of an accident/intervention of emergency services.
- Shouldn’t be closer than 50 m from persons not participating/spectating the flight.
- Shouldn’t be closer than 5 m from current-carrying overhead power lines.

Information related to UAV forecast can be found on [32] as it shows the critical areas that require special attention i.e. airports. Below Figure 7 shows the area of a medium airport in Lolland with circle filled in dark orange and the chosen wind farm with yellow circle.

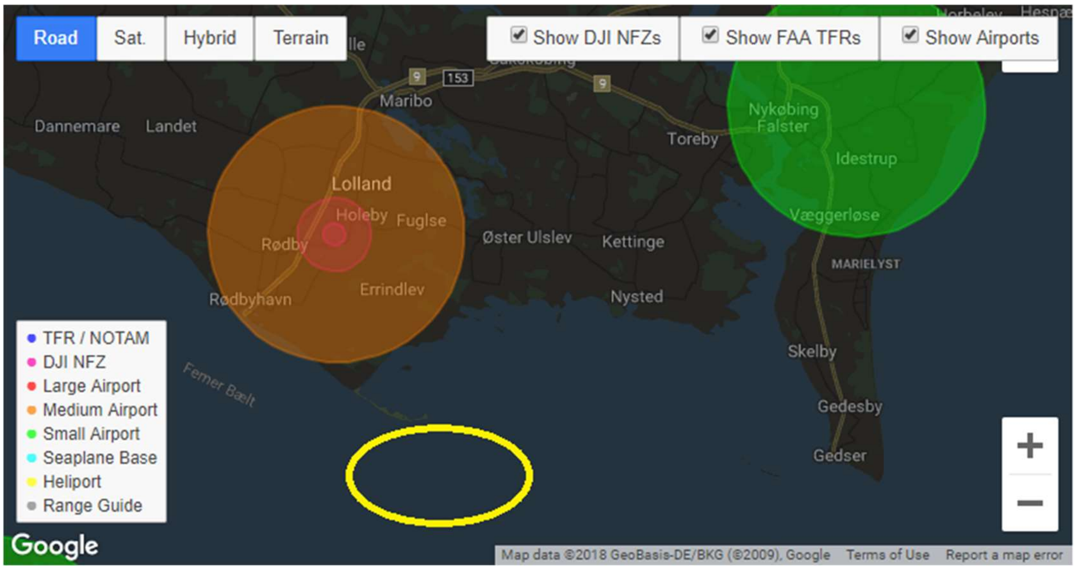

Figure 7 UAV forecast obtained for the nearest area of Rødsand II shown in yellow circle [33]

For flight operations for professional purposes, the Act of Aviation states that:

“§126c Flying with smaller drones must be carried out in such a way that other people's lives and property are not exposed to danger or other unnecessary inconvenience.” [15]

In this way, the fundamental concern is conducting the risk assessment that is essential for applying for exemption. In this thesis, the proposed task for E. ON., wind turbine operating company, is to demonstrate that operating UAV to support maintenance team will not disrupt with §126c.

1.4.2 Selected UAV

After an extensive research, the author could not find a special UAV that had performed similar operations in offshore industry. Contact with a drone manufacturer (Drone Major Group) has also come to failure to provide the specs of a capable UAV. The contact thread can be found in Appendix A.

The selection therefore came down to the A6 plus professional heavy payload UAV Figure 8, which is an enhanced and of versatile usage with wide range of payload handling [34]. This drone uses a universal mounting hub with a regular plug-in design. The mounts used can be switched to different various types easily for the drone to change its functionality [34]. The maximum permitted weight to be applied as the payload on the A6 Plus is 7 kg. This UAV is also designed with care for stable flights, along with the capability of maneuver in harsh weather conditions. These specifications give the A6 Plus UAV an edge to meet the requirement of the industrial users and a good asset to be used in this thesis. Summary of its specs is found in below Table 1.

Table 1 A6 plus specs [34]

UAV dimension	228*207*620 cm
Package dimension	87*81*69 cm
Mass (with 2x batteries)	12.12 kg
MTOM	19.12 kg
Flight control system	MMC FC-1
Max ascent speed	5 m/s
Max descent speed	3 m/s
Max wind resistance	8 m/s
Max flight altitude (above sea level)	4.500 m
Max speed (no wind)	18 m/s
Flight endurance	70 mins.

Figure 8 A6 Plus from MMC, the company [34]

1.4.3 SORA

For this thesis, the SORA will be used as a guideline for addressing the requirement for flying UAV VLOS. The purpose of the Specific Operation Risk Assessment is to perform a risk assessment mainly required to support the request for an authorization to operate UAV within the specific category, as it is also valid for the open and certified categories [18]. These categories are later elaborated on in the next section 1.4.3.1. The application is an acceptable move to evaluate risks related to the specified operation of the UAV. This method might as well be used to support activities needed to determine air integrity requirements

A holistic system described as risk-based assessment model is used to evaluate the risks related to a given operation as the principle of this methodology [18]. The operator must cope with the structure of the model as it initiates with specifying the hazard for the relevant operation and ends by evaluating mitigations strategies and relevant designs. This allows the operator to regulate acceptable risk levels and validate accordingly. SORA and the measures proposed in this thesis are intended to aid as a guidance to the entities, i.e. E. ON., vessel support crew, performing the risk assessment.

To have a meaningful result, SORA had been chosen to be performed using one scenario based on VLOS flight operation and generated by varying 4 distinct parameters shown in below Table 2.

Table 2 Parameter variations

Parameter	
Type of UAV	12.12 hex copter - A6 plus
Overflown area	Partially rural
Parachute	No
Tethered system	Yes

Overflown area
It is not actually a flight path as much as it is a track that the UAV will follow from the top of the crew vessel to the nacelle. Partially rural means that outside built-up areas but still there will be a gathering of crew members on board and on top of the nacelle.

Parachute
An emergency recovery capability is considered a significant asset for an unmanned aircraft; however, in this UAV it is not mentioned in the technical specs that either a parachute could be fit or is installed.

Tethered system
It is a supplement for the power system to prolong the flight endurance. It is usually mounted on UAVs under surveillance, monitoring and other public security circumstances where continuous flight is required. The tethered system will be installed on the A6 to ensure a flight time of 7 * 24 hours [34].

1.4.3.1 The European Aviation Safety Agency (EASA)

The European Aviation Safety Agency (EASA) developed Notice of Proposed Amendment (NPA) in line with the Basic Regulation and the Rulemaking Procedure (RRP). This activity is included in the EASA's program under Rulemaking Task (RMT) 0230 [35]. Based on the valid input of different UAV experts in the field, this NPA was established by EASA.

A new proposed basic regulation, the new Basic Regulation, presently under discussion between the Council, the European Commission and the European Parliament, aims to solve this issue of MTOM of less than 150 kg, by extending the competence of the EU to legalize all UAVs regardless of their MTOM. In the lights of the adoption of this new regulation, below are the objective of the NPA 2017-05 as to [35]:

- Ensure an operation-centric, balanced, risk- and performance-based regulatory framework for all UAV operations conducted in the open and specific category,
- Assure a high and stable level of safety for UAV,
- Strengthen the development of the UAV market,
- Be part in enhancing privacy, data protection, and security.

The NPA 2017-05 [35] recommends a creation of a new regulation that defines the measures that helps in mitigating the risk of operations in the open category by a combination of limitations, operational rules, requirements for the skills of the remote pilot, in addition to technical requirements for the UAV. Meanwhile, it recommends for the specific category a system that includes a risk assessment conducted by the operator before running the operation, or him/her complying with a standard scenario, or him/her holds a certificate with honor.

The classification of UAV operations in the open, specific, and certified category is based on the risk of the operation [35]. The NPA sets the borders of the open category for operations performed:

- With a UAV of an MTOM <25 kg,
- Below 120 m height,
- In VLOS.

If the proposed operation exceeds one of the limits set for the open category, then it falls into the specific category.

The NPA requirements introduce an operation-centric concept. This concept branches from the fact that the consequences of an accident or incident with a UAS not carrying people are highly dependent on the environment where the accident or incident takes place. The requirements have been developed applying also a risk-based and performance-based approach.

The risk-based approach in the open category is demonstrated by introducing subcategories, where the subcategorization is based on risk assessment in which risks includes both ground and air risks. Also, how are these risks are mitigated by a set of limitations, rules, expertise of the remote pilot and the technical requirement of the UAV. Meanwhile in the specific category is illustrated by placing the requirement for a risk assessment to be conducted by the operator before initiating an operation [35] which is SORA. Finally, the performance-based approach is applied by providing the main requirements in the draft regulation.

In this thesis, the proposed operation follows the open category where the A6 Plus has MTOM of 19.12kg < 25kg, the height of SWT 2.3-93 is 65m <120m and there will be a pilot who operates within visual line of sight. However, the purpose of the Specific Operation Risk Assessment is to propose a methodology for the risk assessment mainly required to support the application for an authorization to operate UAV boundaries of the open, specific, and certified category [18].

This methodology itself is aimed at assessing the risks involved with the operation of UAV of any class and size and for any type of operation. As well as, it is particularly suited, but not limited to specific operations for which a hazard and risk assessment is required. Since the number of uncertainties in this thesis is high, so it is better recommended by SORA to follow a qualitative risk assessment [18].

1.4.4 Description of current logistical approach

Operation and Maintenance (O&M) phases come post the construction stage of the WT. The initial stage of the O&M procedures is to transfer the required equipment along with specialized personnel. Transporting the required spare parts or tools is mostly done through Crew Transfer Vessels (CTV) or Helicopters. The method chosen is highly dependent on the loads to be transferred, wind conditions, wave altitudes and the availability of Helicopter pads on the WT [36].

When a CTV is used to transfer spare parts and personnel performing the operation normally consist of a rubber section, which ensures its capability to withstand grinding against the transition piece. A crane is then used for the transfer the part from the CTV to the transition piece through a hoisting action which is controlled by an electrical winch. The part is then lifted from the transition piece to the nacelle or elsewhere if required via the same method. Transferring the parts to the nacelle is normally the most extensive process due to the longer distances of hoisting action required. Meanwhile the specialized personnel are required to use ladders to move to different levels of the windmill. Using helicopters for the logistics process of the spare parts and personnel is usually performed when less time is available to complete the O&M procedure required [36]. They are normally lowering the needed part onto the nacelle along with the personnel, from this point it's a similar process to the previous one where hoisting is required to move and deliver the spare part to other locations in the WT.

Figure 9 Bottom of one of SIEMENS Gamesa WT SWT 2.3-93 [37]

As seen in Figure 9, the vessel shown on the left picture is a typical approach to the foundation of the SWT2.3-93 SIEMENS Gamesa wind turbine [38]. Due to the limitations of resources to retrieve more on the typical approach of handling equipment and tools, it will be presumed how the operation goes on. Apparently, there is no crane hoisting operation that is installed at the foundation of the WT as it can be seen in a closer view on the right picture.

So, the crane and hoisting operation can be seen used from the foundation of the WT to the top of nacelle. The tower below, Figure 10, and a design sketch of the WT used in Rødsand II shows the height of the ladder that could possibly be climbed by the personnel [39].

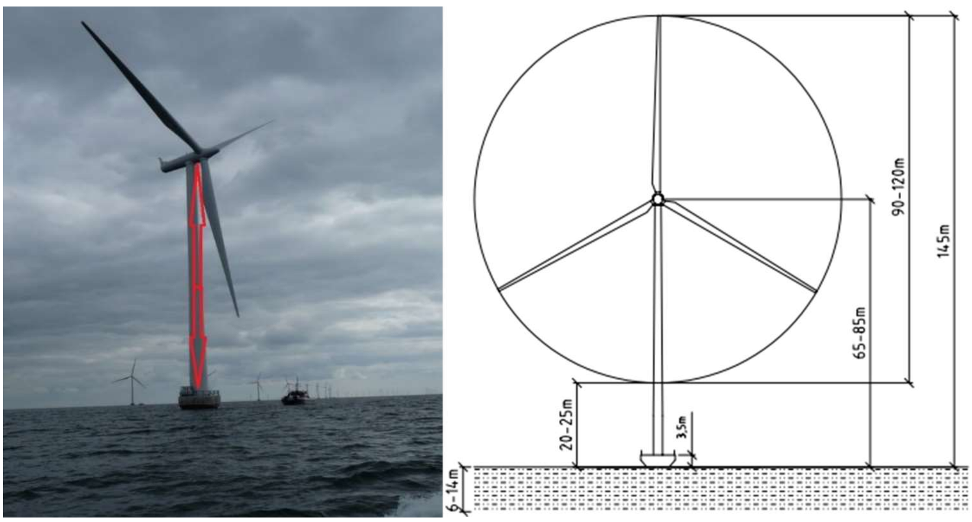

Figure 10 Arrow indication shows where the ladder normally is located [39]

The red arrows indicate the hoist and lift operation that could be taken out on SIEMENS Gamesa SWT 2.3-93. It is also possible that the personnel could lift some tools or food all the way up. The weight of the equipment can vary depending on the task that must be performed but the service personnel need to bring everything associated to the job starting from tools, spare parts and ending with food supplies for themselves. After completing any maintenance activity in the nacelle, the equipment that was brought up must be cleared and be transported down the tower and then to the crew vessel again. This process is time consuming and could involve new risks to the personnel during hoisting and craning of the equipment.

The farthest distance for a ladder climbed was recorded by Guinness World Record as 114.17 Km in 24 hrs. [40]. Since this is the only piece of useful info that could be found about climbing ladders to help in calculating the speed that could be possible for a human being, so it will be considered as the average speed of human climbing a ladder.

$$^{114.17}/_{24} = 4.76\ Km/hr \qquad (1)$$

Conversion of equation 2 to m/s is done by multiplying by the conversion units as follows:

$$4.76 \frac{\cancel{km}}{\cancel{h}} x \frac{1000\ m}{1\ \cancel{km}} x \frac{1\ \cancel{hr}}{3600\ s} = 1.32\ m/s \qquad (2)$$

This is assumed to be the speed of a competitor at Guinness World to beat some records, but it would not be the case as personnel on the job carrying some equipment. So, as an assumption, the speed in equation 3 will be reduced to half of its value to be 0.66 m/s.

As a result, calculating the time required to climb a 65 m WT from bottom to top of nacelle will take:

$$\frac{65}{0.66} = 98.5\ s = 1.64\ min \qquad (3)$$

1.4.4.1 Defiance in the current logistical approach

The wind energy is still generally new, with wind turbine innovation continually advancing in tower structure and segment innovation [41]. These adjustments make an on-going duty to guarantee that personnel who direct establishments, routine activities and upkeep methods on wind turbines do so under the most secure possible conditions.

It could be argued that the hazards found inside a wind farm are not altogether different from those that exist in different businesses today [41]. Nevertheless, thinking about the occasionally special and extraordinary conditions in which these hazards are discovered, the new blend of these dangers and the lack of knowledge of a portion of the personnel in this division, it is conceivable that these hazards may not be controlled or oversaw suitably [42].

A few regular difficulties have turned out to be clear with respect to Occupational Safety and Health (OSH) in the wind energy part and are summarized in lack of data and information, skills shortage and training and procedures and standards [41]. One of the main reasons for the lack of data within the energy sector is the lack of research data on risks exposures of personnel on field, which is an evidence that the amount of available information related to OSH is either sparse or tremendously unclear.

1.5 Thesis hypothesis

The UAV technology can serve various purposes within the offshore industry [43]. One of them is using the UAV to carry equipment or tools and by that reduce lifts and crane operations. Implementing it into the offshore wind industry does however involve additional challenges. Basically, this thesis deals with risk associated with maintenance and operation and whether UAV can be used as a tool to support the personnel up on the wind turbine or not. This thesis will analyze the routine maintenance operation descriptively and will research the following hypothesis:

a. How can the UAV technology be integrated with the daily hoisting operation that goes on a wind turbine and as a result improve the offshore wind industry without composing a higher risk to the safety of the personnel and the surrounding structure?

1.5.1.1 Problem formulation

The initiating problem of this thesis revolves around the lack of UAV technology implementation into the offshore wind industry. This is due to the shortage in already performed operations. Hereby, SORA comes into action to diminish the obstacles that could be found in specific operations. So, the thesis is based on the following problem statement:

Can a qualitative approach such as SORA prove the viability of further execution of UAV technology by supporting the maintenance crew with tools on one of Rødsand II wind turbines?

1.5.1.2 Delimitations

To narrow down the problem analysis, several delimitations were considered for simplification purposes. Understanding that a more thorough and broader inclusion of different factors and parameters would yield a more intensive study, but unfortunately due to time and resource constraints some delimitations were necessary. These delimitations are further explained below.

Operation and Maintenance cost analysis
Acknowledging that the economic analysis of the suggested approach is a very important study, however it was unfortunately not taken into consideration due to the sensitivity of such information to be shared to public.

Technology of UAV
The technology assessment is limited and constrained to the pay load capacity of the drone and the volume where the payload fits. Other specification such as speed limitations, battery endurance and drone reliability are not taken into consideration.

Weight of tools
Since the research on this topic did not result in relevant data, based on the author's knowledge, it will not be mentioned in the analysis. However, the weight does not add value to the risk assessment to be conducted.

Stakeholder analysis
Due to the lack of cooperation between the author of the thesis and the operating company of Rødsand II, stakeholder analysis will be eliminated in this study. Although it is an interesting analysis to perform as it adds a value to the result; however, the lack of shared data and reports makes it hard to perform.

Operation of flight from A to B
As this project is more concentrated on the improvement of an operation and maintenance procedure, the logistics that are related to the drone going for the onshore base to the windmill is not considered. The process that takes place after the operation is also neglected from this analysis. The only concern is the drone transferring a wind mill spare part from the vessel up to the windmill at certain situations. The laws concerned with using such technology of this purpose are also not part of the analysis and assessment in this project.

Weather conditions
Another important factor which was excluded from the analysis are the weather conditions. However, to include such factors. a complete study is required on several drone types and their endurance in different weather conditions, especially their use in offshore applications were weather conditions are harsh.

Legislation and standards
It will be highlighted but the Danish legislation will be not discussed in detail as this is not the scope of the thesis. Legislation is used in this thesis to show that with this type of operation (UAV size and level of autonomy) has no special permission required. The focus will be using SORA as an application for risk assessment.

1.5.1.3 Report outline

To get an answer for the problem formulation, the structure of this report is fitting in with the ISO31000:2018 standard [44] d as this standard is a perceived risk management tool for completing extensive and all-encompassing risk assessment [45]. This thesis has been created utilizing wording that starts principally from ISO Guide 73:2009 [46] , and ISO31000:2018 [44] .

To build up a uniform structure in the arrangement of this thesis, Figure 11 underneath, outlines an adjustment of the Risk Management Process, found in ISO31000:2018 [44] by redoing the present report setting. SORA will be integrated in the process of ISO as it is considered in this thesis as a risk analysis tool.

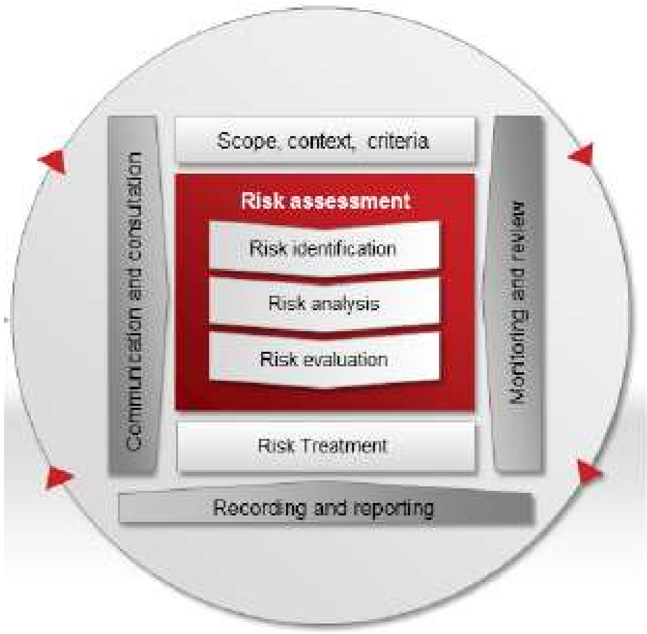

Figure 11 Thesis structure as per ISO31000:2018 [44]

The last components "Communication and Consultation" and "Monitoring and Review" from ISO31000:2018 [44] are excluded in this thesis because of the thorough point of the examination, in which the applicability of SORA application is not tended to. Besides, the absence of collaboration with relevant organization confines these two procedures to just be on a hypothetical dimension.

Chapter 1 builds up the setting of the thesis, in which motivation and how Denmark is involved in research and development. Besides, the chapter tends to the potential business chance of UAV implementation could be for E. ON to its owned wind turbines.

Chapter 2 identifies the complete picture of the available system and addresses the selection process leading to the final proposed one. The illustrative strategy of analysis is based on qualitative research that aims to investigate with own knowledge of the author of the thesis. The holistic risk assessment is shaped after the completion of system identification. The application of SORA method was modified based on the available material in hand.

Chapter 3 applies SORA as an application and identifies the hazard recognized by the author in flying UAV within visual line of sight on one of Rødsand II wind turbines. This technique is used to help in case of having qualitative data in hand and satisfies the need of Danish legislation.

Chapter 4 discusses other types of risk analysis techniques that can be used as a treatment and evaluation in theoretical scope.

Chapter 5 concludes with suggestion and improvement for future investigations.

The structure of the report is expressed as shown in Figure 12 beneath:

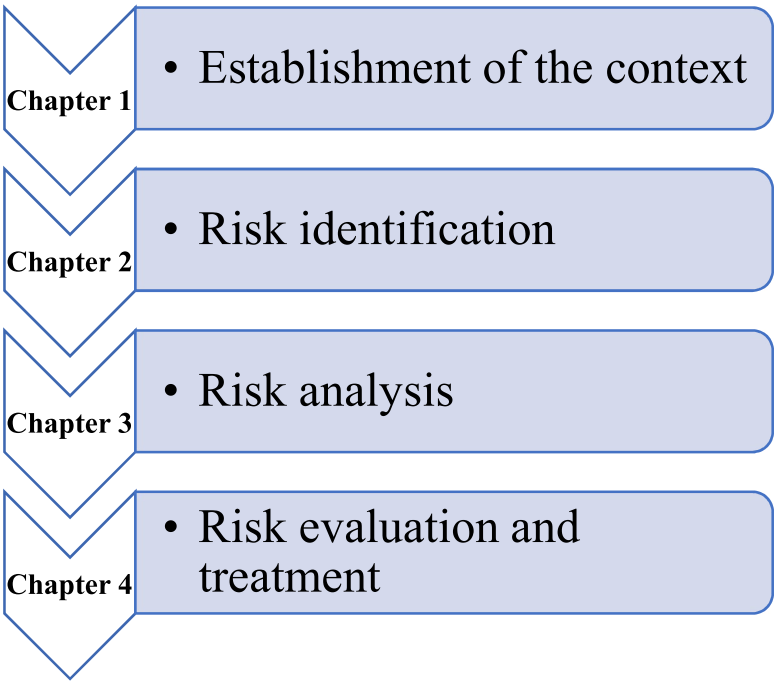

Figure 12 Structure of the thesis based on ISO standard, risk management process

2 Risk identification

This chapter is more of a general, technical chapter to provide the reader with an insight how risks were identified and selected throughout the process. It starts by the methodology of selecting the case study and how shifted from macro to micro description of the system. Then, it discusses the technical description of the UAV and the different available types of it as the author selects one aircraft for the scope of the thesis. An overview on the Danish legislation and guidelines related to general rules about flying a UAV in the small category; in order to help establishing the context for SORA.

The assessment reveals the complexity of the system to be analyzed, from the time E. ON decides to implement UAV in its operations. SORA will easiness the application for the aircraft operator. Moreover, it will look at the different techniques to reduce the risks resulting from such an operation.

2.1 System identification

This phase is one of the most important in identifying the risks, as risks to be identified clearly, a clear system identification is required. The main aim is to note all the known parameters and details to note them down in a risk database [47]. In the business-as-usual scenario, this done by professionals from several fields through regular meeting and brainstorming [48].

The framework identification is utilized as an apparatus for decision makers. For this situation, if executing a UAV into the activity and support of an offshore maintenance team is an attainable thought, as it makes an incentive in time and that it is sufficiently safe concerning personnel and surrounding structure. The framework identification traces the limits of what are the hazards the operator ought to be concerned if decided to go for the application. Moreover, it recognizes a hypothetically proposed scenario and a sort of activity performed. Furthermore, system identification is used to simplify diverse risk situations for the framework. There are distinctive situations that could be generated; however, a narrowed down situation is selected for the simplicity of the application of the different risk assessment tools.

2.1.1 Selection of case study

Creating an overview of the system is a necessity in order to assess and analyze the system. When commissioning an offshore wind turbine, the specifications must fulfill the required codes of design and specific contract requirements. This reveals that all aspects, from the design, to the choice of materials, to the construction, to the installation, ending with the maintenance and operation. Due to the complexity of the offshore WT sector a breakdown structure is necessary to create a visual and systemic overview. Figure 13 shows the system from the Danish offshore sector, to a specific wind farm in mind.

Figure 13 Location of wind farms in DK, modified by the author, the black circle created, with the permission of authors of the report [49]

2.1.1.1 Wind Industry in Denmark

Due to the political will of the ruling government, Denmark had initiated the creation of the first offshore wind farm back in 1991 [50]. The Indebt offshore wind farm was the first investment within this sector which was expected to generate a total capacity of 5 MW as seen in Table 3 Since then, Denmark has managed to accumulate a total of 1,300 MW through offshore wind farms. Such wind farms require more capital investment than onshore wind farms, however; there is a higher capacity and power production due to the consistent and favorable wind speeds. Currently, wind farm projects are done through contracts given to operating companies via a competitive bidding process. Table 3 Shows the total capacity of all windfarms constructed up to 2012 and the ones which currently being deployed, these are expected to double Denmark's wind power generation by 2020.

Table 3 Operating offshore wind farms in Denmark by end 2016. Upcoming wind farms shown in red [50]

Name of OWF	**Year of commissioning**	**Number of turbines**	**Total capacity**	**Location**	**Km to shore**
bindery	1991	11	5 MW	54°58′12″N 11°7′48″E	1.8
Tunb Knob	1995	10	5 MW	55°58′10″N 10°21′20″E	6
Middelgrunden	2001	20	40 MW	55°41′27″N 12°40′13″E	4.7
Horns Rev 1	2002	80	160 MW	55°31′47″N 7°54′22″E	18
Samsø	2003	10	23 MW	55°43′12″N 10°34′48″E	4
Rønland	2003	8	17 MW	56°39′46″N 8°13′10″E	0.1

Frederikshavn	2003	3	8 MW	57°26′40″N 10°33′40″E	0.3
Nysted	2003	72	165 MW	54°33′0″N 11°42′36″E	11
Horns Rev 2	2009	91	209 MW	55°36′00″N 7°35′24″E	32
Avedøre Holme	2009/2010	3	11 MW	55°36′0″N 12°27′30″E	0.1
Sprogø	2009	7	21 MW	55°20′24″N 10°57′36″E	10
Rødsand 2	2010	90	207 MW	54°33′36″N 11°33′0″E	9
Anholt	2012	111	400 MW	56°36′00″N 11°12′36″E	23
Horns Rev 3	2020	49	406.7 MW	N/A	N/A
Nearshore (2 projects)	2019	N/A	350 MW	N/A	N/A
Kriegers Flak	2021	N/A	600 MW	N/A	N/A

The selection of wind farm in this thesis is done by looking up the available wind farms in Denmark. There are no criteria for selection since this project is not established mutually with a specific company; however, the selection of the wind farm to be analyzed was based on the average distance to shore most far location to shore as a challenge for the drone that will be selected further in the report. Figure 14 shows the list of wind farms and their location on an up to date map.

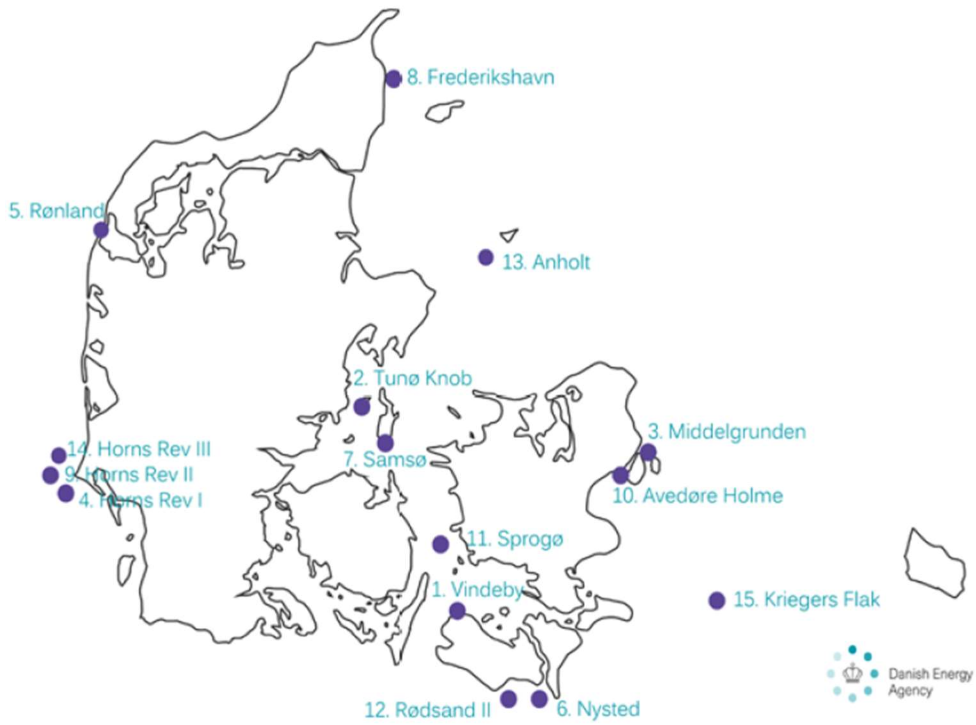

Figure 14 Location of offshore wind turbines in Danish waters [51]

A simple calculation is performed by summing up the distance to shore and then divide them by the total number of known distances of wind farms as shown in below equation 1:

$$\frac{1.8 + 6 + 4.7 + 18 + 4 + 0.1 + 0.3 + 11 + 32 + 0.1 + 10 + 9 + 23}{13} = 9.23\ Km \tag{4}$$

Thus, the nearest wind farm to the shore as seen from Table 1 is Rødsand II. Therefore, this thesis will spot the light and perform the research on this selection.

2.1.1.2 Rødsand II

Rødsand II is located in Rødby and Nysted and is considered the third-largest wind farm in Denmark, where it is owned by 80 percent by Danish sector [52]. It covers an area of 36 Km^2 with 90 installed Siemens Gamesa turbines of SWT 2.3-93 type that allows the farm to produce electricity of approximately 830,000,000 kWh per year [52]. The contract for operating and constructing the Rødsand II windfarm located near the Nysted wind farm, was given to E.ON. Vind Sverige [51]. To the north of the wind farm are the two islands of Lolland and Falster. The windfarm is also surrounded by sand barriers from the eastern, western and southern directions. These sand barriers border shallow lagoons from the northern direction, these lagoons are of importance to several aquatic species. Further information on the geographical location can be seen in Figure 15 which shows the Fehrman Island along with the Windfarms and a seal sanctuary.

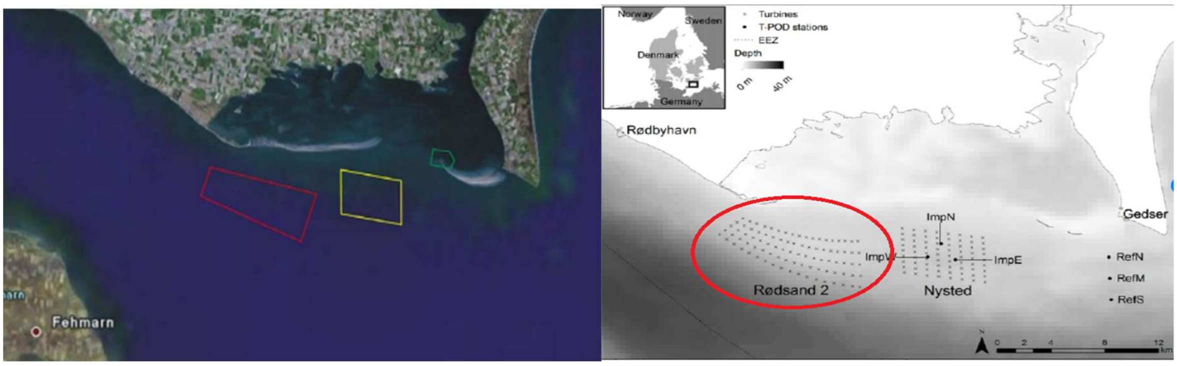

Figure 15 Satellite image of Fehmarn Belt and the area south of Lolland and Falster [4] [5] and a highlighted red circle around Rødsand II [53]

The sea floor area of the Rødsand II wind farm is at a shallow 10 m depth, while most of the sea flow consists of sand and silt [51]. Several ridges can also be observed through the geologic contour maps, accumulations of pebbles, gravels and shells are also existing as a result of these ridges of variant sizes. Salinity of the water is inconsistent as it varies depending on the influx and exodus of saline waters coming through the Danish straits of Kattegat [53]. The variations in the water level are dependent on the wind velocity and the difference between the pressures of the straits of Kattegat and the Baltic proper.

2.1.1.3 Wind turbine

A wind turbine is a machinery that depends on wind which provides its rotationally moving parts with kinetic energy which is then converted to electrical energy [54]. It normally consists of four main parts, these are the foundation, a column, Nacelle and the substructure as seen in Figure 16. The foundations like in all other construction projects is required to provide stabilization. The column is normally used to add height to the turbine, this is required to adjust the optimum height required for a better wind capacity. The Nacelle is the section at the top of the turbine which protects all its interior mechanical and electrical components. While the substructure is necessary to maintain a firm and stable connection between the foundation and the turbine itself [55].

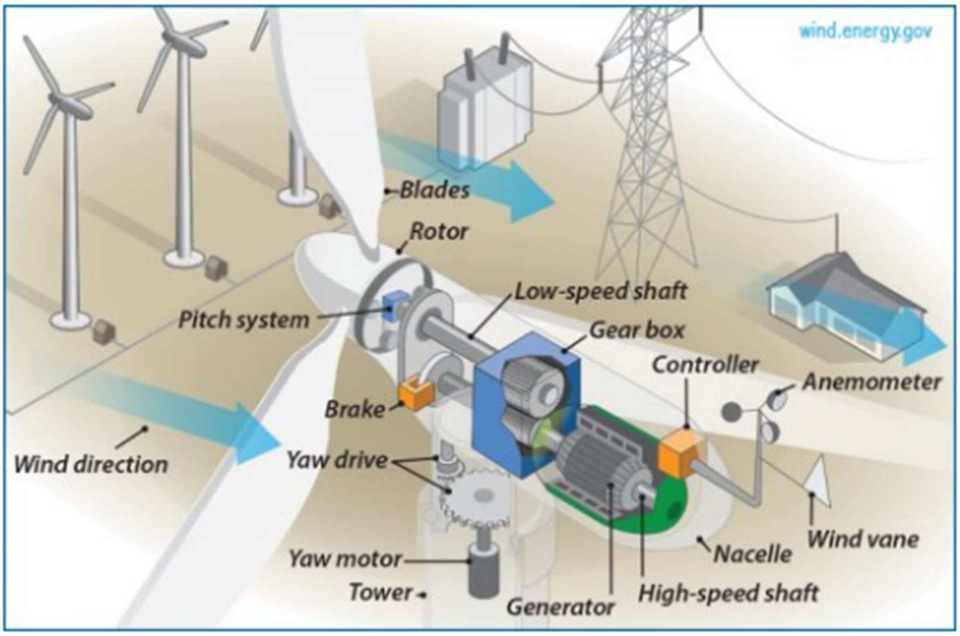

Figure 16 The inside of a wind turbine [56]

SIEMENS Gamesa

Siemens is a very diverse organization when it comes to technology. Its wind power business unit is currently one of the leaders within this industry [57]. This due to the massive investment the company allocates for the R&D sector. Having access to different units of the organization also gives the wind power unit an edge within the industry, due to the many different components they can obtain from these different units of Siemens. Continuous expansion is always taking place by Siemens across the globe within the wind energy sector, as they seek the same statues of leadership within offshore wind energy like that acquired within onshore wind energy.

In the last quarter of 2008, Siemens declared that they would take part of one of the largest wind farms of that time [57]. Taking the role of wind turbines supplier to E. ON for the Rødsand II wind farm, the contract included 90 wind turbines with a total capacity of 207 MW and a 2-year services agreement. This contract was valued at € 275 million.

Technical description and specification of SWT 2.3-93

The SWT-2.3-93 wind turbine is an upgraded version of the classical SWT-2.3-82 machine and includes the new B45 blade [57], a rotor diameter of 93 m, and therefore a 25 percent increase of the swept area relative to the SWT-2.3-82 wind turbine.

Figure 17 SWT 2.3-93 Siemens WT [58]

Rotor

The SWT-2.3-93 wind turbine has a three blades-rotor which includes a pitch synchronization to enhance the energy production of the wind turbine. The rotational speed of the rotor is adjustable depending on the required conditions, this helps maintaining more efficiency within aero-dynamics. This adjustable speed option is important as lowering speeds maybe important to comply with energy capacities of transmission lines [58]. Table 4 below summarizes the details of the rotor.

Table 4 Rotor details [57]

Diameter	93 m
Swept area	6,800 m^2
Rotor speed	6-16 rpm

Rotor hub

The rotor hub is connected to the shaft and is made of casted iron with extra details shown in below Table 5. This s is required as it provides a stable connection between the shaft and the gear box in the turbine. It is also made to provide the enough space for two working personnel in case of required maintenance in the shafts [58] .

Table 5 Rotor hub details [57]

Type	3-bladed, horizontal axis
Position	Upwind
Diameter	93 m
Swept area	6,800 m^2
Speed range	6-16 rpm
Power regulation	Pitch regulation
Rotor tilt	6 degrees

Nacelle

The nacelle contains the key components of the wind turbine, including the main shaft and bearing, gearbox, the electrical generator, mechanical brakes and other control systems [59]. Service personnel can enter the nacelle from inside the tower of the turbine and perform different maintenance tasks.

Main shaft and bearing

The main shaft is cast in steel and has an interior of void space to allow the conveyance of power to the pitch synchronizers in the blade [58]. It is held by a bearing of the roller type, which contains an automated system to control the lubrication process and normally require no maintenance.

Gearbox

The gearbox is specifically made for the operation required, it is designed as a planetary-helical gearbox. This design with 3-stages and capable of withstanding a high torque provides an efficient power generation process [59]. The gearbox is designed to also contain its own filtration and cooling system, this is important to ensure the optimum conditions for the power generation process.

Generator

The generator is a machinery equipment which is defined as completely encompassed asynchronous machine with a rotor connected to it. This rotor is designed in a way that prevents efficiency decrease at partial loads. A heat-exchanger is used to maintain the regulated temperatures of the generator through an air inlet and outlet system [58] .

Table 6 Generator details [60]

Type	Asynchronous
Nominal power	2,300 KW
Voltage	690 V
Cooling system	Integrated heat exchanger

Mechanical brake

The mechanical brakes are required in some cases of emergencies to shut down the operation. It is an integral part of the gearbox with built-in hydraulics [59]. It is also considered to be the secondary-safety procedure. Table 7 describes the specs of the mechanical brake.

Table 7 Mechanical brake details [57] [60]

Type	Hydraulic disc brake
Position	High-speed shaft
Number of calipers	2

Yaw system

The yaw system consists of an external ring, 8 electric engines controlled by planetary gears [59]. The engines include a braking system which are used in the cases where holding the yaw system at a fixed position as maintenance is required.

Controller

The controller is normally a computer system which is used for industrial purposes. It consists if a keyboard to input data and commands easily and a screen to observe the outputs from the turbine [59]. The computer is also established to self-detect errors.

Tower

The SWT-2.3-93 turbine is placed at the top of a steel column identified as the tower of the wind turbine. The tower is put in place by a hoisting procedure [57].

Table 8 SWT 2.3-93 tower specs [60]

Type	Cylindrical and/or tapered tubular
Hub height	80 m or site-specific

2.1.1.4 Northern Offshore Services

Northern Offshore Services (NOS) is one of the major service providers for the Rødsand II wind farm. They are mainly providing operations and maintenance vessels which are used for crew personnel transportation [61]. The company can modify their vessels depending on the required specifications. Some the services provided by Northern Offshore Services are painting personnel along with all required equipment, surveying projects as part of the construction stage, divers, electrical supply for the wind turbines through mobile generators and heavy shipments of equipment which could weigh up to 50 tons as well as supply of maintenance crew [50]. The fleet is huge and consists of 36 vessels that are ready to take missions to offshore wind farms [61] i.e. Advancer, Attender and Performer.

Figure 18 Attender, one of NOS vessels, at sea [62]

2.2 Description of proposed logistical approach

In order to rely on UAV technology to replace personnel handling equipment while climbing, hoisting and craning, an aiming technical is to be provided. As described in section 2.3, the anticipated procedure for maintenance operations of typical offshore wind farm is a risky and exhausting process. It engages maneuvering through narrow spaces/ladders, moving with the weight of tools, equipment and spare parts, while working in a relatively harsh condition [63]. The focus of this thesis will be concerned on the risks integrating UAV technology within the WT and the routine maintenance and how to mitigate them.

As mentioned earlier, the UAV will bring up equipment and spare parts for the personnel on the nacelle, making the climbing up and down significantly easier and safer. This will start by the personnel climbing to the nacelle and prepare himself to receive the UAV sent from the vessel. The payload will be secured at the vessel down the tower, flied up to the personnel then the payload is unloaded. This operation will take less time than personnel would take the payload on the ladder. Because personnel might have to carry tools for the desired job, this weight could affect their balance and ability to arrest a fall; as well as, cause a fatigue and the risk of having a dropped object [41]. As calculated from equation 4 that the time required to climb a ladder is 1.64 mins; meanwhile, the UAV will make the same trip with an ascending speed of 5m/s then the time will be:

$$\frac{65}{5} = 13\ s = \ 0.22min \qquad (5)$$

It is noticeable that the time has reduced significantly by using UAV, which could be an initiating motivation for the implementation of UAV in supporting the maintenance team.

Once the payload is unloaded, the UAV returns to the crew vessel and be reloaded or be ready for the next job, without requiring any of the personnel to descend, which reduces the associated risks i.e. personnel fatigue. Since the UAV would take significantly less time to ascend and return to the crew vessel for reloading, flying it several times to the top will still be a time-efficient alternative to current practices.

As a result, the subsystems within the system that is being analyzed are; the offshore wind turbine, the transporting vessel, UAV, the personnel working at the wind turbine, the equipment that is used to carry out the different tasks and the surrounding of the system as shown in below Figure 19.

Figure 19 Subsystems illustration overview, modified by the author [64]

3 Risk analysis

The objective of this chapter is to carry out a risk analysis to create a risk picture to identify causes, conditions and components that are critical to risk [65]. The risk introduced in this thesis is related to flying an UAV within a wind turbine within visual line of sight (VLOS) and losing control of the UAV then colliding.

By using a bow-tie and SORA, a methodology for risk assessment could be proposed to support the application to operate UAV within a specific category [18].

3.1 Bow-tie

BowtieXP is risk assessment tool that visualizes complex risks in an understandable diagram [66]. It follows a risk assessment, which allows to structure thinking and uncover holes in the risk management. It was used as an aiding tool to help in building the bow-tie diagram with a trial version requested by the author.

The hazard below which is in the black and yellow stripe box together with the top event which is with the orange circle below. The hazard can be described as the dangerous aspect of an organization; therefore, the hazard as shown in Figure 20 is selected to be using UAV for delivery. Below of it is the top event. The top event is the first moment the UAV losses control over the hazard. It hasn't hit anything yet and there is no damage, but it has lost control. In this case, the generic wording loss of control and colliding works quite well. The blue boxes on the left are called threats and they represent different scenarios that will cause the top event. One of the possibilities, for instance, is one of the components fail during flight which could cause a loss of control. Another threat, however, could be careless personnel attitude which might also cause a loss of control of the UAV and collision.

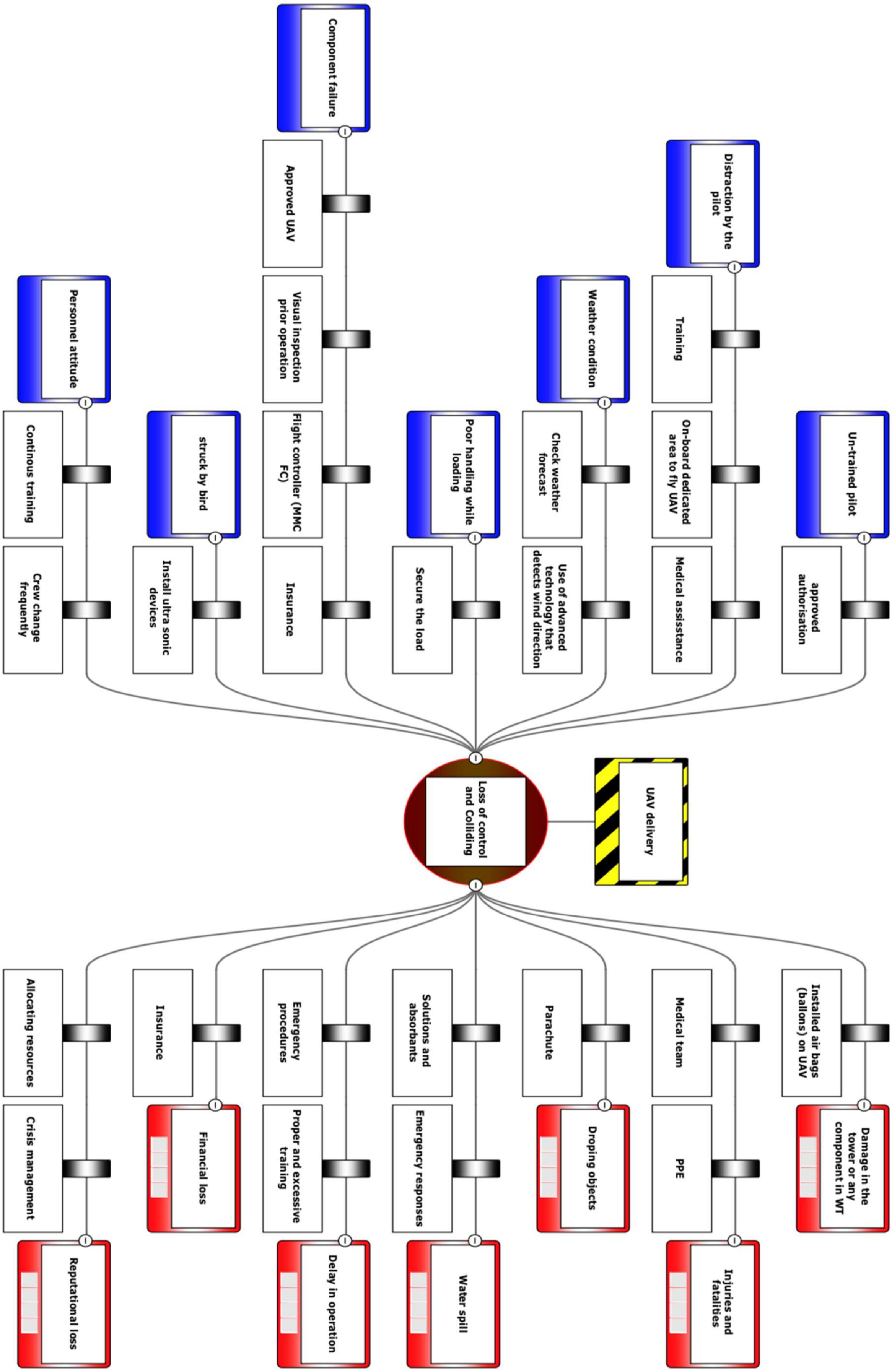

Figure 20 Bow-tie model

On the right side, there are the red boxes, which are called consequences. There can be different consequences resulting from a single top event. One could be, for instance, the object dropping from the UAV or another could be a financial loss because of infrastructure damage. Together with the threats, the bow-tie is shaped. The combination of all these threats and consequences gives an overview of the possible incidents that might occur. Some of them could have already happened and some might not. One of the benefits of the bow-tie method is that it includes all credible scenarios, not only the incidents that have already happened, which allows to be truly proactive in managing risks.

After the scenarios have been identified, barriers could be added according to organization or previous experiences that could prevent the unwanted scenarios from onfalling. In the case of a component failure, the pilot can check the test certificates of an approved UAV, which is one barrier. If the UAV is approved then a visual inspection performed by the UAV pilot will help preventing the loss of control over the UAV, which is a second barrier. A flight controller could also be installed, manufacturer recommendation, for multiple protection of the flight such as detecting malfunctions and faults [67]. The insurance is the last line of defense and if this barrier also fails then the UAV loses control and collides. There is also barrier on the right-hand side. These barriers aim a recovering from or mitigating a loss of control before more serious consequences occur.

So far, the bow-tie diagram gives an overview of all the unwanted scenarios and how barriers are planned to prevent them; however, no barrier is perfect. There are holes in any barrier, either because the barrier isn't adequate for a scenario or because the reliability is lacking.

3.2 SORA

The SORA guidelines were published by JARUS in the first quarter of this year [18], they are intended to assess the risks concerned with any flight operations. Its main aim is to provide an understanding of the coherence and assurance of a given flight operation. To do so, SORA is a complete analysis of the required arrangements, paper work and mitigation to initiate the operation with the appropriate and acceptable amount of risk.

Given the effectiveness of estimating and quantifying risk quantitatively, communication barriers could be a viable issue when delivering such information. This is due to the contrast between risks quantified through probabilistic approaches and those which have a wider qualitative spectrum of risk analysis. The latter is normally what is perceived by all average citizens and could lead to major misunderstanding when reports of quantitative assessments are to be addressed. However, although quantitative risk assessments provide a significant amount of important information, yet it does have several limitations. The accuracy of the assessment is very dependent on how the uncertainties in a certain parameter are managed. If mismanagement of unreliability takes place in a certain variable, it could to lead unrealistic quantitative assessments which could have been replaced with a more effective qualitative assessment. Therefore, SORA guidelines recommend conducting precise studies of the uncertainties before deciding on the type of assessment to be done. If the number of uncertainties is of a high value, qualitative assessments maybe a better option.

When attempting to model a situation from the real-world, completeness uncertainty should be introduced. These are required to establish a firm understanding of how far the model deviates from the real-world problem. For example, Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) are not valid when attempting to model reality, as they do not incorporate the completeness uncertainty. In the case of a UAV, to be able to model a scenario form the real-world, it would be required to incorporate the risks concerned with different areas of the process. Such areas could be the uncertainties within the parts of the UAVs, the crew in charge of controlling the UAV and the traffic control personnel. Therefore, performing a quantitative assessment for a complete scenario is labor intensive and requires data from several stages of the process. Other aspects to be modeled mathematically which are concerned with the weather for example can be intricate when performing quantitative analysis.

Other uncertainties can come from parameters inputted to the model, this type of uncertainty is called the parameter value uncertainty. This is to be considered, due to the large variance of data and the conditions thy are based on. For example, considering the uncertainty associated with a certain component of the UAV required a study on what the conditions such claims were made upon. Such failure rates are normally based on a series of statistical studies; an uncertainty should be incorporated for statistical data as well. However, to consider uncertainty in the statistical data, one should analyze the confidence interval which could provide reasonable reasoning on whether to continue with or without taking uncertainty into account.

To conclude, quantitative assessments are challenging due to the uncertainty within many different variables. Therefore, a qualitative assessment proves to be more efficient for UAV flight operations. Such assessments would of course include failure rates or such if available; a qualitative analysis does not necessarily infer disregarding such information. But rather it means the assessment would be more dependent on an engineering sense from experienced individuals.

3.2.1 ConOps description

The operator is obligated by SORA to collect adequate operational, technical and human data for the intended UAV operation [18]. A framework for data collection and compiling is attached in Annex A in SORA [18] and will be, as much as possible, illustrated for the selected scenario. Basically, the ConOps is considered the substance for every activity that will take place and should be described in detail. It doesn't aim to be only descriptive as it aims also to increase the awareness of the operator by the safety culture of the operation.

Some of the steps can't be established by the author of the report because of the lack of contact with the operating company, E. ON; however, the other sections of the SORA guidelines are described in section 3.2.2. The steps 3.2.2 through 3.2.5 are for determining the risk associated with ground impact [18].

3.2.2 Determination of the intrinsic Ground Risk Class

The "UAV lethal area" and the intended type of operation the first parameter for determining the Ground Risk Class (GRC). The lethal area is quantified by the max UAV characteristic dimension which for the A6 Plus is 2.28 m [34], putting the aircraft in the '3 m' category (Figure 8 in SORA [18]) with an expected kinetic energy of < 34 KJ. Though, the actual kinetic energy of the aircraft, at mass, with payload, 19.12 kg and cruise speed 18 m/s, using below equation 6 is around 3.07 KJ

$$\frac{1}{2} mv^2 \tag{6}$$

The value is below expected max value of 34 KJ for the smaller < 3 m category. Consequently, the 3 m category is suitable. The next parameter to determine GRC is "Operational scenario". From section 1.4.3, a partially rural scenario is considered where this will be the category of '*VLOS over controlled area, located inside a populated environment*'. This results in the GRC values listed in Table 9, obtained from SORA.

Table 9 Intrinsic UAV Ground Risks Classes summarized

UAV Ground Risk Class	
Max. UAV dimension	3 m < 34 KJ
Operational scenario for aircraft	A6 Plus
VLOS over controlled area, located inside a populated environment	4
Flight path after applying harm barriers	3

3.2.3 Identification of harm barriers

This step grants the adaptation of GRC based on the harm barriers that the operator chooses. There are three harm barriers listed in Table 2 of the SORA [18] with a relative corrective factor. For the first barrier I will assume the existence of a Low/None integrity Emergency Response Plan (ERP) since nothing is mentioned in the manufacturer's specs. For the second barrier, the A6 plus is not equipped with means of reducing the ground impact effects i.e. parachute. For the third barrier, the aircraft can be equipped with tethered system [68] so it will be considered as a medium robust barrier. As per Table 2 in SORA [18], this gives a reduction of the GRC by 1, as summarized in below Table 10 according to SORA.

Table 10 GRC adaption

	GRC
Initial	4
An Emergency Response Plan (ERP) is in place, operator validated and effective	+1
Effects of ground impact are reduced (i.e. emergency parachute, shelter)	0
Containment in place and effective (i.e. tether)	-2
Final UAV GRC	3

3.2.4 Lethality determination

The current version of SORA [18] does not provide much details on lethality determination. In fact, the lethality can be expressed as AVERAGE if there are no detrimental circumstances for the aircraft. An extra care should be taken to the

3.2.5 SAIL determination

The last step in ground risk assessment is figuring out the Specific Assurance and Integrity Level (SAIL). This is quantified by using Table 4 in SORA [18], and the result is represented in Table 11. The operation in hand has a final GRC equals to 3 and the lethality had been assigned AVERAGE for the ground impact. So, the SAIL for ground risk will be II.

Table 11 SAIL value for Ground Risks

Operation scenario for UAV	**SAIL**
Flying with tether in place	**II**

3.2.6 Determination of the Airspace Encounter Category (AEC)

The grouping of airspace types in [18] reflects levels of collision risks that are 12 AECs listed in Figure 9 in SORA [18]. For rural areas the AEC is 6, which corresponds to "*Operations within Class A, B, C, D, E, or F Non-Airport Environment below 500 ft AGL*".

3.2.7 Initial Air-Risk Class (ARC) Assignment

The initial ARC is quantified directly from the AEC using Table 5 in SORA [18]. The results are shown in Table 12 below. ARC 3 is generally defined as *"airspace where the risk of collision between a UAS and manned aircraft is low to moderate"* [18]. This collision risk class requires more collision mitigation between Class 2 and Class 4. The amount of mitigations and performance level of collision mitigations will be *low to moderate*.

Table 12 Air Risk Values

Scenario	Partly rural
AEC	6
Initial ARC	3
SAIL	IV
Final ARC Operational Restrictions	3
Final ARC Structures and Rules	3
Tactical Mitigation Performance Requirement (TMPR)	Medium

3.2.8 Identification of the Strategic Mitigations

SORA doesn't provide enough information on mitigations within air risk and traffic density. In the proposed scenario in this thesis, there are no strategic mitigations of any kind that could be applied because this is study focuses on operation within the wind turbine and on the vessel, so no traffic density is determined. Therefore, neither the *"operational restrictions"* nor *"structures and rules"* mitigative means will reduce the initial ARC. The resultant SAIL is derived from Table 6 in SORA [18], and the result is listed in Table 12.

3.2.9 Tactical Mitigation Performance Requirement (TMPR) Assignment

Tactical mitigation is a short time horizon mitigation (seconds to a few minutes) applied to mitigate the collision risk to achieve airspace safety. After the determination of final ARC, the TMPR are assigned as listed in Table 12. According to SORA [18], being operated within Visual Line of Sight these TMPR levels gives a raise to a medium performance.

3.2.10 Identification of recommended threat barriers

The next step of the SORA process is to evaluate the recommended threat barriers and the associated level of integrity depending on the SAIL (the highest SAIL derived from the ground and the air risk evaluation). Table 8 in SORA [18] provides a qualitative methodology to make this determination. The various threat barriers in Table 13 are grouped and evaluated based on the threat they help to mitigate.

Table 13 Threat barriers evaluated according to the highest SAIL

SAIL (Highest SAIL derived)	**IV**
Proposed threats from Bow-tie	Evaluation from SORA
Technical issue with UAV	
Use of advanced technology that detects wind direction	M
Approved UAV	M
Flight controller (MMC FC [67])	H
Visual inspection prior operation	M
Install ultra-sonic devices	M
Human error	
Secure the load	M
Crew change frequently	H
Medical assistance	M
Approved authorization	H
Training	H
Adverse operating conditions	
On-board dedicated area to fly UAV	M
Check weather forecast	M

3.2.11 Feasibility check

With the SAIL assigned to the operation and with full coping to the recommended objective, most of the threat barriers are recommended with medium robustness. The threat barriers were grouped so they can be easily used to help in mitigation process. Therefore, if the UAV operation is decided to have lower GRC, an implementation of an extra barrier i.e. parachute is recommended.

3.2.12 Verification of robustness of the proposed barriers

In this step, the operation should take place and be executed in order to validate harm and threat barriers. The robustness of harm barriers is the main thing that change the value of SAIL, if adopted. It defines the level of integrity and the level of assurance to fulfil that the objective of the operation has been satisfied. Since the version of SORA, in hand, is limited with no access to the different Annexes that it refers for it, a general guidance for the level of assurance is drawn out.

3.3 Discussion

Sensitivity analysis is a strategy used to decide how independent factor values will affect a specific dependent variable within a given arrangement of presumptions [69]. Its use will rely upon at least one info input within explicit limits. In other words, it could be called a what-if analysis. So, if sensitivity analysis would be applied in SORA to observe new behavior of the system, then changing operational scenario will result in different GRC value. Consequently, the SAIL value will differ, and proposed mitigations would vary in robustness. For instance, what-if the operator decided to fly the UAV from onshore station to the wind turbine instead of flying it from top of vessel, then the operation scenario will be changed, as in this thesis, from flying UAV within VLOS to BVLOS. Also, the populated area will be taken into different consideration. Therefore, the value of GRC will be either higher or lower and based on that the operator can adopt and modify the harm and threat barriers. Another parameter could also be changed i.e. the UAV size where it will have the effect on the kinetic energy of it and as a result lead to different GRC and SAIL values.

Other studies [19] had compared SORA with different methods i.e. High-Fidelity Risk Model (HFRM) and the results showed harmony and agreement to a large extent. In this thesis, only SORA was used for the analysis and the result showed a lower value of SAIL II arising from ground impact risk; meanwhile, a value of SAIL IV was obtained in the air collision risks. This does not indicate anything but the significance of applying the harm and threat barriers. If the application was quantified according to mutual contribution among stakeholders, then it could have resulted in enhanced SAIL values.

It is noticeable that SOAR considers adding harm barriers i.e. tether dramatically reduces the value of GRC by 2 if it was considered with a medium robustness. The uncertainty associated with the risk assessment comes from the lack of experience and data collection. The current SORA approach is not considered an enough analysis to perform since some parts were not revised and quantified [18]. Thus, many assumptions and considerations are taken into this thesis based on the author knowledge. In other words, a huge uncertainty could be found in this application. As a result, it is suggested to re-build this application by a group of experts and the different stakeholders that could be involved in this operation.

As seen after completing SORA as an application for the proposed scenario developed by the author, it was observed that it could be implemented knowing that it is a qualitative approach. Looking at the fact that most of the barriers had a medium robustness, that answers the problem statement of the thesis which is the feasibility of SORA as method to execute UAV. In the author's point of view, even though SORA does not contradict the continuation of its applicability, but it seems to be non-reliable assessment unless executed.

4 Risk evaluation and treatment

This chapter describes the process of determining the significance of risks. Normally, there are two ways to evaluate risks; either performing a qualitative risk analysis or a quantitative risk analysis. Usually, it is hard to respond to all risks and neither should be the case. Risks must be prioritized based on the amount of risk that the company is willing to accept.

Risks can be found in daily life actions, but it is not necessarily that eliminating them is a must. The important thing is to know what these risks are and prioritize them accordingly. After identifying the hazards, then you can know how likely the harm will occur. Based on these harms, a range of options for mitigating the risks can be proposed. The highest rated risks must be addressed and treated correspondingly.

Generally, selecting the most convenient risk treatment indicates that a good balance between implementing and the benefit gained; therefore, it must be reasonably practicable. This implies adjusting the dimension of hazard against the measures expected to control the genuine hazard regarding money, time or inconvenience. In other words, no action on the off chance that it would be horribly unbalanced to the dimension of hazard.

In the following sections, hazard identification and ALARP will be explained descriptively to be as a continuation for evaluation of the performed risk analysis, SORA.

4.1 Hazard identification

Hazard is generally identified by well-prepared people in a workshop that are experts in the offshore projects, operations, installations and the hazard itself. A group is always a better choice than a single person to approach such cases alone because a group can add their knowledge and skills together to cover all the aspects of the hazard [70]. Hazards can mostly be identified by the operational staff that is practically involved to the hazard itself.

As the difficulty of the operation increases, the identification of the hazard will become more complicated. For the smoother undertakings that are easily managed, hazards may have been already identified, and the shrinkage of risk quantity that is needed to be controlled, will be detailed in proper standards and codes i.e. Good Practice. Complicated operations will need all the component items of the operation that is allied with the hazard, for instance, the interacting of all equipment used should be known.

When operational, wind farms are basically unmanned amenities. Personnel get to them whenever they need to do some repairs and maintenance. Except if they are associated with either arranged or spontaneous maintenance on a wind turbine, it is unexpected for laborers to be nearby. Amid the construction stage, there could be in excess of 500 individuals functioning at the site; however, an average operational group will comprise of two individuals for each 20 or 30 wind turbines in a wind ranch. For littler wind farms, there may not be a committed operational activities and maintenance group; rather, normal visits from provincial groups are depended on. Despite whether the wind turbine is on coast or seaward, when the expert is inside the turbine, the operational and maintenance roles are equivalent. Furthermore, the hazards and threats that the labors confront are fundamentally the same. The primary dissimilarities among the coast and seaward facilities are the methods for transportation and how the laborers access the turbine. As of now, a large portion of the operational information on turbines is kept private by the manufacturer, which may delay the safe subcontracting of the operation and its proficient support [71]

4.1.1 Risks in Rødsand II

One of the reports [72] had distinguished that most threats in Rødsand II were connected to either the climate or the seabed conditions. The offshore construction is influenced by the climate in light of the fact that there is a wave height and wind speed limit to which the offshore vessels can work in. The lifting process in the installation of the base and turbine erection is particularly influenced by the wind itself. In the operational stage, the electrical yield of the breeze farm can be affected by the wind speed. Every circumstance or condition can have a negative impact on the project's cost. Anyhow, those threats and risks are not thought about as they are referenced in the delimitation section.

4.1.2 Maintenance hazards

Cleaning blades, parts lubrication, full generator update, supplanting components and fixing electrical control units are some basic and common preps that are usually incorporate the maintenance activities [73]. These tasks are often repeated, which implies that the maintenance experts move toward becoming, by and large, progressively aware with the threats and the systems set up for working at heights, interfacing with power and working in small spaces. Even so, operational maintenance on wind turbines can be risky and challenging which may cause different OSH risks. The kinds of obstacles that are tackled by laborers doing offshore wind farms repairs are different and connected as much to the difficulties related with the establishment itself as to outside conditions connected to the atmosphere conditions, which can be to a great degree of a troublesome, particularly at the sea.

The more failure rates in the wind post components, the more repairs involvements it will need. To add up, extraordinary climate conditions, snow and heavy rain as an example, would all be able to result in the change of temperatures that ranges from a low degree to a high one, and these cruel conditions, along with dirt, dust and lightning, all add up to the blades being fixed or cleaned consistently. For instance, the main edges in the end indicate wear that changes their aerodynamic properties to the point where the production of the control power drops essentially and repair work is required in spite of the hard-composite nature of wind turbine blades or edges.

As detailed by production manager for safety equipment manufacturer, *"climbing 80 m to go to work may be routine for maintenance crews but three times in a day is a lot of climbing. Lugging up 10 kg or more of equipment makes a climb more demanding. What's worse, say maintenance people, is lugging it down"* [5]. Climb helps give access to personnel at the point when towers are excessively small or are basically not intended to oblige a service lift.

4.2 ALARP

As low as reasonably practicable (ALARP) has been delivered to clarify the idea of "sensibly practicable" basically for HSE staff and joins direction as of now held on HSE's site [74]. It's intended mainly to staff new to HSE and those new to basic leadership. Most of the time, choosing whether the hazards are ALARP includes a correlation between the control estimates an obligation holder has set up or is proposing and the measures that would typically expect to see in such conditions i.e. applicable good practice

The triangle below symbolizes an increasing level of overall risks (all risks, or the total risk, that people are exposed to) from a low risk, signified by green at the bottom of the triangle, to a high risk, represented by red at the very high of the triangle. The ALARP principle is demonstrated in Figure 21.

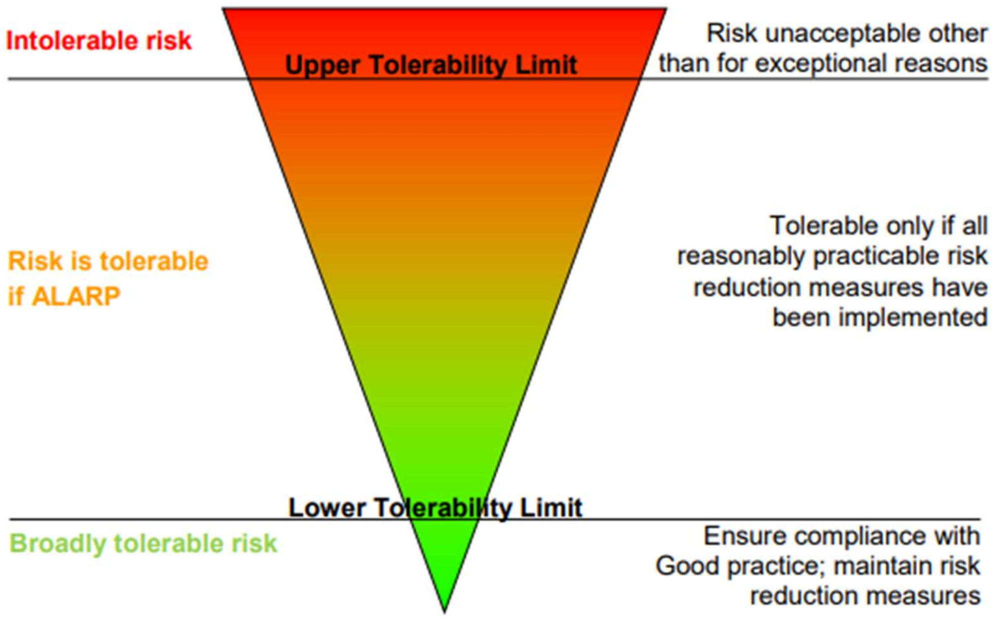

Figure 21 Schematic diagram representing ALARP principle [75]

The Upper Tolerability Limit is the above dimension in which the hazard is insufferable and might be acknowledged for outstanding reasons. Beneath the Upper Tolerability Limit, the hazard is just middle of the road in the event that it is ALARP. This concludes all possible hazard decrease estimations must be known and those that are sensibly practicable connected. The term practically practicable demonstrates a slenderer range than all physically conceivable hazard decreases measures.

Before the implementation of any risk reductions, an evaluation of the cost in terms of money and time should be conducted. If this is evaluation is not done and completed properly, it could lead to the unnecessary reduction of risks. Risk reduction can only be considered to be unnecessary after a hazards analysis of course which should indicate the reasonability of such actions. For example, when the total risk ranks within the Lower Tolerability Limit, the ALARP Assessment will be concentrated on achieving the regulations of Good Practice only.

When good practice has been resolved, a great part of the talk with decision makers about whether a hazard is or will be ALARP is probably going to be an importance to good practice, and how properly it has been or will be executed. Where there is significant, perceived good practice, a decision maker is expected to track it. In the event that a need to accomplish something other than what's expected, a demonstration of the measures proposed must be at least as effective in controlling the risks.

For evaluating and treating the risks of the overall scenario and personnel working conditions, it is recommended to follow the proposed methods in this chapter. As a result of hazard identification, not only the UAV operator will be aware of the different hazards but also the personnel working at the wind turbine. It will help, with the best experience of the management and operators, improving the harm and threat barriers and as a result get better practice of the ALARP method.

5 Conclusion

The performed SORA resulted in a medium robustness level of applicability of UAV in offshore wind installations. This result indicates the permissibility of implementing the suggested scenario. Even though given the lack of data inputted in this study, SORA has proven a feasible method to perform a reasonable qualitative risk assessment. Nevertheless, implementing this qualitative risk analysis tool has some drawbacks. Such as the lack in real-life feedback operations, which reduces the credibility of the method. UAV Lethality is an important process not incorporated in SORA. Due to the lack of lethality consideration in this study, the SAIL determination of ground risks could have resulted in a better selection. Meanwhile, the air space SAIL doesn't depend on lethality and therefore it depends on the airspace encounter categories.

To consolidate risk management procedure, risk evaluation and treatment are recommended by ISO 31000:2018 [44] after completing the risk assessment. SORA itself as a risk analysis tool does permit the implementation of the suggested operation. However, this thesis is intended to perform and execute a complete risk management study. Therefore, HAZID and ALARP must be conducted as part of the evaluation and treatment stage of the process; in order to grasp the full picture of the risk management.

It is inferred that risk management is a branch in offshore wind farm expansion which is considered important and given a decent measure of resources. The risk management plan in Rødsand II as well as the SORA utilized in the task pursues a general risk management procedure, where important tools and strategies were utilized. There are a couple of viewpoints which could be improved. Finally, it is proposed that the risk management plan ought to be customized to the operation it is utilized in.

5.1 Future development and research

Supplementary research in risk management in offshore wind farm development should focus on examining the advantages and disadvantages of using UAV technology to support maintenance operations. The requirement of UAV operation data bank is highly suggested to be accessible to researchers for further investigation development. Establishing better communication between the academia and the offshore windfarm operating company, E. ON., would also enhance the reliability of the conducted research. Further improvement within Danish legislation and the update of SORA shall be taken into consideration for the enhancement of this study.

6 Bibliography

[1] ENERGINET, "SECURITY OF ELECTRICITY SUPPLY REPORT 2017," [Online]. Available: https://en.energinet.dk/About-our-reports/Reports/Security-of-Electricity-Supply-Report-2017. [Accessed 06 January 2019].

[2] State of Green, "WIND ENERGY MOVING AHEAD How wind energy has changed the Danish energy system," State of Green, Denmark, 2017.

[3] J. Wang, Y. Zong, S. You and C. Træholt, "A review of Danish integrated multi-energy system flexibility options for high wind power penetration," *Clean Energy,* vol. 1, no. 1, pp. 23-35, 2017.

[4] EWEA, "Wind energy's frequently asked questions (FAQ)," [Online]. Available: http://www.ewea.org/wind-energy-basics/faq/. [Accessed 06 January 2019].

[5] European Agency for Safety and Health at Work, "Occupational safety and health in the wind energy sector," Publications Office of the European Union, Luxembourg, 2013.

[6] A. Patrik, On the Optimization of Support Systems, Nordsteds Tryckeri, 1997.

[7] Chemonics International Inc., "Unmanned Aerial Vehicles Landscape Analysis: APPLICATIONS IN THE DEVELOPMENT CONTEXT," United States Agency for International Development, Washington, DC, 2017.

[8] M. Johansen, "Wilhelmsen," 29 May 2017. [Online]. Available: https://www.wilhelmsen.com/ships-agency/are-drones-a-game-changer-for-last-mile-deliveries/. [Accessed 04 November 2018].

[9] M. L. Staff, "Maersk Tests Drone Delivery to Cargo Ship," Informa, Cleveland, 2016.

[10] Baird Maritime, "NORWAY INVESTIGATES OFFSHORE DRONES DELIVERING CARGO," [Online]. Available: https://www.bairdmaritime.com/work-boat-world/offshore-world/1676-norway-investigates-offshore-drones-delivering-cargo. [Accessed 06 January 2019].

[11] Ingeniøren, "Regeringen afsætter 27,5 millioner til udvikling af droneteknologi," [Online]. Available: https://ing.dk/artikel/regeringen-afsaetter-275-millioner-udvikling-droneteknologi-196393. [Accessed 27 December 2018].

[12] Uddannelses og forskningsminiteriet, "Ambition 5: Standardisering," [Online]. Available: https://ufm.dk/forskning-og-innovation/indsatsomrader/droner-i-danmark/danmarks-dronestrategi/ambition-5-standardisering. [Accessed 26 December 2018].

[13] Uddannelses og forskningsminiteriet, "Ambition 6: Internationalisering," [Online]. Available: https://ufm.dk/forskning-og-innovation/indsatsomrader/droner-i-danmark/danmarks-dronestrategi/ambition-6-internationalisering. [Accessed 26 December 2018].

[14] NaviAir, "AIC B 08/14," 2014. [Online]. Available: https://www.trafikstyrelsen.dk/~/media/Dokumenter/02%20NYHEDER/Luftfart/2014/AIC%20B%2008%202014.pdf. [Accessed 20 December 2018].

[15] Ministry of Transport, Building and Housing, "Act on amendment of the Aviation Act," 2016. [Online]. Available: https://www.retsinformation.dk/Forms/R0710.aspx?id=181630. [Accessed 20 December 2018].

[16] Uddannelses og forskningsminiteriet, "Ambition 6: Internationalization," [Online]. Available: https://ufm.dk/forskning-og-innovation/indsatsomrader/droner-i-danmark/danmarks-dronestrategi/ambition-6-internationalisering. [Accessed 26 December 2018].

[17] I. T. O. Lazakis and R. T., "Risk assessment for the installation and maintenance activities of a low-speed tidal energy converter," Royal Institution of Naval Architects, 2012.

[18] L. Murzilli, "Specific Operations Risk Assessment (SORA)," Joint Authorities for Rulemaking of Unmanned Systems, Switzerland, 2017.

[19] A. La Cour-Harbo, "The Value of Step-by-Step Risk Assessment for Unmanned Aircraft," in *International Conference on Unmanned Aircraft Systems (ICUAS)*, Denmark, 2018.

[20] F. Lithia, "UPS Tests Residential Delivery Via Drone," 2017. [Online]. Available: https://workhorse.com/newsroom/2017/02/ups-tests-residential-delivery-drone. [Accessed 31 December 2018].

[21] R. Brandom, "Maersk just made the first official drone delivery to an undocked ship," 2016. [Online]. Available: https://www.theverge.com/2016/3/8/11181756/maersk-drone-delivery-shipping-tanker-nautical. [Accessed 31 December 2018].

[22] W. S. University, "Hazard Identification, Risk Assessment and Control Procedure," [Online]. Available: https://www.westernsydney.edu.au/__data/assets/pdf_file/0020/12917/12917_Hazard_Identification,_Risk_Assessment_and_control_Procedure.pdf. [Accessed 01 January 2019].

[23] L. Crane, G. Gantz, S. Isaacs, D. Jose and R. Sharp, "Introduction to Risk Management," Extension Risk Management Education and Risk Management Agency, USA, 2013.

[24] M. Rouse, "drone (unmanned aerial vehicle, UAV)," internetofthingsagenda, October 2018. [Online]. Available: http://internetofthingsagenda.techtarget.com/definition/drone. [Accessed 30 December 2018].

[25] BusinessDictionary, "equipment," [Online]. Available: http://www.businessdictionary.com/definition/equipment.html. [Accessed 01 January 2019].

[26] Federal Standard 1037C, "Maintenance (technical)," [Online]. Available: https://en.wikipedia.org/wiki/Maintenance_(technical)#cite_note-1037C-5. [Accessed 01 January 2019].

[27] BowTieXP, "Bowtie Methodology Manual," IP Bank B.V., Amsterdam, 2015.

[28] Y. E. Saud, K. (. Israni and J. Goddard, "Bow-Tie Diagrams in Downstream Hazard Identification and Risk Assessment," *Process Safety Progress,* vol. 0, no. 0, pp. 1-10, 2013.

[29] DS DANSK STANDARD, "Om standarder," [Online]. Available: https://www.ds.dk/da/standardisering. [Accessed 29 December 2018].

[30] Ministry of Transport, Building and Housing, "Order on flights with drones outside built-up areas," Danish Paliament, Copenhagen, 2017.

[31] Ministry of Transport, Building and Housing, "Order on flights with drones in built-up areas," Danish Parliament, Copenhagen, 2017.

[32] UAV forecast, "UAV forecast," [Online]. Available: https://www.uavforecast.com/#/. [Accessed 29 December 2018].

[33] "UAV forecast," [Online]. Available: https://www.uavforecast.com/#. [Accessed 10 December 2018].

[34] MMCuav, "A6 plus," [Online]. Available: http://www.mmcuav.com/drones/a6plus/. [Accessed 17 December 2018].

[35] European Aviation Safety Agency, "Introduction of a regulatory framework for the operation of drones," European Aviation Safety Agency, Germany, 2017.

[36] B. Maples, G. Saur, M. Hand, R. v. d. Pietermen and T. Obdam, "Installation, Operation, and Maintenance Strategies to Reduce the Cost of Offshore Wind Energy," National Renewable Energy Laboratory, Netherlands, 2013.

[37] "165 MW Nysted Offshore Wind Farm. First year of operation - performance as planned.," [Online]. Available: https://www.google.com/imgres?imgurl=x-raw-image%3A%2F%2F%2F6e55775634cf9b089a3e2451792afa9be5f1cfde470e0f48f12ad9163845116e&imgrefurl=http%3A%2F%2Fwww.offshorecenter.dk%2Flog%2Fbibliotek%2F165%2520MW%2520Nysted%2520Offshore%2520Wind%2520Farm.PDF&docid=rs. [Accessed 14 December 2018].

[38] Susanne, "Offshore Windparkbesichtigung Rødsand," [Online]. Available: https://susanne-in-sverige.blogspot.com/2010/06/offshore-windparkbesichtigung-rdsand.html. [Accessed 16 November 2018].

[39] E.ON Sverige AB, "RØDSAND 2 HAVMØLLEPARK VURDERING AF VIRKNINGER PÅ MILJØET VVM-REDEGØRELSE," E.ON Sverige AB, Malmö, 2007.

[40] Guinness World Record, "Ladder climbing - farthest distance in 24 hrs (team)," [Online]. Available: http://www.guinnessworldrecords.com/world-records/ladder-climbing-farthest-distance-in-24-hrs-(team). [Accessed 29 December 2018].

[41] European Agency for Safety and Health at Work, "Occupational Safety and Health in the Wind Energy Sector," European Agency for Safety and Health at Work, 2014.

[42] S. Bradbrook, M. Duckworth, P. Ellwood, M. Miedzinski, J. Ravetz and J. Reynolds, "Green jobs and occupational safety and health: Foresight on new and emerging risks accociated with new technologies by 2020," Publications O"ce of the European Union,, Luxembourg, 2013.

[43] J. Karpowicz, "4 Ways Drones are Being Used in Maritime and Offshore Services," Commercial UAV News, [Online]. Available: https://www.expouav.com/news/latest/4-ways-drones-maritime-offshore-services/. [Accessed 04 January 2019].

[44] International Organization for Standardization, "ISO31000:2018," International Organization for Standardization, Geneva, 2018.

[45] P. Hopkin, Fundamentals of Risk Management, Lonon: The Institute of Risk Management, 2010.

[46] International Organization for Standardization, "ISO Guide 73," International Organization for Standardization, Geneva, 2009.

[47] W. G, Managing construction projects: an information processing 2nd ed, Iowa: Blackwell, 2010.

[48] N. J. Smith, T. Merna and P. Jobling, Managing risk in construction projects 2nd ed, Malden: MA Blackwell Pub, 2006.

[49] F. PETERSEN and J. THORNDAHL, "Danske vindmøller til havs," Erhvervshistorisk Årbog , Denmark, 2014.

[50] Danish Energy Agency, part of the Ministry of Energy, Utilities and Climate in Denmark, "Danish Experiences from Offshore Wind Development," Denmark, 2017.

[51] Danish Energy Agency, part of the Ministry of Energy, Utilities and Climate in Denmark., "Danish Experiences from Offshore Wind Development," Denmark, 2017.

[52] seas-nve, "Rødsand 2 - our offshore windfarm," [Online]. Available: https://www.seas-nve.dk/eng/green-vision/roedsand-2. [Accessed 28 November 2018].

[53] J. Carstensen, "ResearchGate," [Online]. Available: https://www.researchgate.net/figure/Study-area-with-Nysted-and-Rodsand-2-Offshore-Wind-Farm-Wind-turbines-are-shown-with-an_fig1_258310214. [Accessed 30 November 2018].

[54] Danish Energy Agency, "Wind Turbines in Denmark," Danish Energy Agency, Amaliegade, 2009.

[55] M. J. Kaiser and B. F. Snyder, Offshore Wind Energy Cost Installation and Decommissioning, London: Springer-Verlag London, 2012.

[56] office of Energy Efficiency & Renewable Energy, "The Inside of a Wind Turbine," [Online]. Available: https://www.energy.gov/eere/wind/inside-wind-turbine-0. [Accessed 02 November 2018].

[57] S. W. P. A/S, Writer, *Outstanding efficiency Siemens Wind Turbine SWT-2.3-93.* [Performance]. Siemens Wind Power A/S, 2009.

[58] Direct INDUSTRY, "MODERATE WIND WIND TURBINE / FOR LIGHT WINDS / VARIABLE-SPEED SWT-2.3-101," [Online]. Available: http://www.directindustry.com/prod/siemens-wind-power-renewables/product-102147-956577.html. [Accessed 30 December 2018].

[59] Danish wind Industry Association, "Wind Turbine Components," [Online]. Available: http://xn--drmstrre-64ad.dk/wp-content/wind/miller/windpower%20web/en/tour/wtrb/comp/index.htm. [Accessed 30 December 2018].

[60] S. AG, *Wind Turbine SWT-2.3-93 Technical specifications,* Hamburg,: Wind Power and Renewables Division, 2015.

[61] 4C Offshore, "Vessels working on Rødsand 2," [Online]. Available: https://www.4coffshore.com/windfarms/vessels-on-r%C3%B8dsand-2-dk11.html. [Accessed 15 October 2018].

[62] Northern Ofsshore Services, "M/V Attender," [Online]. Available: http://www.n-o-s.eu/vessel/mv-attender/. [Accessed 20 October 2018].

[63] Broadcast Media Services, "A Day In The Life Of A Wind Turbine Engineer," [Online]. Available: https://www.youtube.com/watch?v=vfUhBKZR4sU&t=289s. [Accessed 2 November 2018].

[64] "BAILIWICK EXPRESS JERSEY NEWS," [Online]. Available: https://www.bailiwickexpress.com/jsy/life/technology/drone-can-clean-wind-turbines/. [Accessed 13 December 2018].

[65] T. Aven, Misconceptions of Risk, Stavanger: John Wiley & Sons, 2010.

[66] CGE Risk Management Solutions Making risk understandable, "BowTieXP," [Online]. Available: https://www.cgerisk.com/downloads/bowtiexp/?utm_source=Software+Trials+V2&utm_campaign=bbf603f5bf-AUTOMATION_BowTieXP_Trial_1_COPY_01&utm_medium=email&utm_term=0_f6fa3c5e12-bbf603f5bf-24551711. [Accessed 15 December 2018].

[67] MMC, "MMC FC-1 Flight Controller," [Online]. Available: http://www.mmcuav.com/product/mmc-fc-1-flight-controller/. [Accessed 14 December 2018].

[68] MMC, "MMC Tethered System," [Online]. Available: http://www.mmcuav.com/product/mmc-tethered-system/. [Accessed 15 December 2018].

[69] EduPristine Empowering Proffesionals, "All you want to know about Sensitivity Analysis," [Online]. Available: https://www.edupristine.com/blog/all-about-sensitivity-analysis. [Accessed 04 January 2019].

[70] HELLENIC HYDROCARBON RESOURCES MANAGEMENT S.A. , "ALARP GUIDANCE," HELLENIC HYDROCARBON RESOURCES MANAGEMENT S.A. , Greece, 2018.

[71] International Finance corporation, "International Finance Corporation (IFC) annual report 2007 : creating opportunity," International Finance corporation, Washington DC, 2007.

[72] E. AHLGREN and E. GRUDIC, "Risk Management in Offshore Wind Farm Development," CHALMERS UNIVERSITY OF TECHNOLOGY, Gothenburg, 2017.

[73] E. R. Observatory, "Occupational safety and health in the wind energy sector," Office of the European Union, Luxembourg, 2013.

[74] Health and Safety Executive, "ALARP "at a glance"," [Online]. Available: http://www.hse.gov.uk/Risk/theory/alarpglance.htm. [Accessed 06 January 2019].

[75] ALARP Demonstration Guidance Document, "ALARP Demonstration Guidance Document Part of the Petroleum Safety Framework," The Commission for Energy Regulation, Dublin, 2013.

[76] Google earth, [Online]. Available: https://earth.google.com/web/@54.64156579,11.46436322,7.03033841a,19110.47580927d,35y,0h,0t,0r. [Accessed 14 December 2018].

[77] E.ON, "E.ON facts and figures," [Online]. Available: https://www.eon.com/en/about-us/profile.html. [Accessed 20 December 2018].

[78] E.ON, "Services for Wind Farms," [Online]. Available: https://www.eon.com/en/business-customers/wind-service.html. [Accessed 20 December 2018].

[79] A. Glaser, "The FAA has issued nearly 23,000 drone pilot licenses in just three months," December 2016. [Online]. Available: https://www.recode.net/2016/12/19/14006772/faa-drone-pilot-licenses-three-months-numbers-uav . [Accessed May 2017].

[80] B. Custers, The Future of Drone Use: opportunities and threats from ethical and legal perspectives. Vol.27, T.M.C. Asser Press, 2016.

[81] "Classification of the Unmanned Aerial Systems," [Online]. Available: https://www.e-education.psu.edu/geog892/node/5. [Accessed October 2018].

[82] L. L. Hansen and E. Werlauff, The legal method - an introduction, 2nd, Ed., Jurist- og Økonomforbundets Forlag, 2016.

7 Appendix A

Good Afternoon Belal

Unfortunately as we do not hold the data centrally we would be unable to provide the information you are looking for.

There are a number of manufacturers out there who produce 10+kg payload systems and they should be easy enough to find via Google - MMC, BFD, Vulcan UAV for example.

Regards

ROBERT HEAVER
Partnership Management Consultant
+44 (0) 203 675 1882 / +44 (0) 203 950 1910
robert.heaver@dronemajorgroup.com
dronemajorgroup.com

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On Mon, 17 Dec 2018 at 11:03, Belal Miari <bmiari17@student.aau.dk> wrote:

> Good morning Robert,
>
> Unfortunately no since I don't have a budget to do so. This is because that the type of the study I'm doing doesn't require to own the drone rather than using the technical and design specs in the analysis.
>
> So it would be great if I can have some support by providing details on drones that can lift 10+ kg.
>
> I would love to share a copy of the thesis after completion on the 10th of January.
>
> Sent from my Huawei Mobile

Re: Drone
Tim Spink [tim@dronemajorgroup.com]
Sent: Monday, December 17, 2018 2:04 PM
To: Belal Miari

Hi Belal

Drones can carry approximately up to 200kg. Although there are systems being developed in China that can carry 1 tonne, another that can carry 5 tonnes, and UAVs that can carry 20 tonnes.

Lots of capabilities. 200kg is the about the commercially available best at the moment... this will change soon.

Thanks

TIM SPINK
Director of Operations
+44 (0) 7920 066380
tim@dronemajorgroup.com
dronemajorgroup.com

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On Sun, 16 Dec 2018 at 19:59, Belal Miari <bmiari17@student.aau.dk> wrote:

> Hi
>
> I am a Master student at Aalborg University preparing my thesis in Risk and Safety Management, Part of my thesis includes drones, So I am looking for a drone specifications that could help me in performing some analysis on it,
>
> The topic am working on is about delivery of spare parts to wind turbine and the drone will be used for delivery. The idea is that the drone is with the vessel crew and will be operated from the vessel to the top of the wind turbine with a spare part,
> I don't have a spare in mind because I want to know about the drone payload volume.
>
> If it possible to send an appropriate design with its specs, then I would be grateful.
>
> Thanking you in advance for having the time to read this request.
>
> ---
> Best Regards,
>
> Belal Miari