Safety and security of drones in the oil and gas industry

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This paper describes safety and security challenges and best practices of the use of drones in the oil and gas industry, with consideration of the harsh weather conditions in the Northern Territories of Norway. We have described the present status of the use of drones in air, on water (surface) and under water. Drones are being used in the industry to reduce or remove dangerous, dirty or dull operations from humans and to increase quality of data collection. The Norwegian oil and gas industry and authorities have a high focus on continuous improvement of safety, security and environmental issues. This has for instance resulted in the offshore helicopter transport in Norway to be among the safest offshore transport worldwide. Use of drones in the safety conscious oil and gas industry, should help us to improve the safety practices of drone use in general. Our suggestions are to focus on systematic data reporting of the use of drones, establish guidelines for risk assessments and operations, improve the use and testing of drones in the industry (i.e. build more experience) and support improved robustness and resilience of drone use. In addition, we see the need for improved quality of the interfaces between human operators and drones to ensure meaningful human control.
Keywords: Drones, UAV, ROV, USV, safety, security, best operational practices

1. Introduction

The use of drones in air, sea and subsea has increased significantly lately. Estimated increase of drones in the air is 100% annually, Quilter et al. (2017). There has been an increase in research funding of drones in Norway in the latest period 2018 to 2021, Johnsen and Evjemo (2019).

We have explored the use of drones in the Norwegian oil and gas industry in collaboration with the relevant actors/participants i.e. the Petroleum Safety Authority (PSA) and industry. The area of interest has been HSE (Health, Safety, and Environment) and security issues, with a special focus on use of drones in the Northern Territories of Norway i.e. Northern part of Norway, Norwegian Sea and Barents Sea.

As a result of our exploration we have proposed recommendations in collaboration with industry and PSA. The technology has improved rapidly while industry knowledge of use, best practices of operations and regulation has been lagging.

2. Scope and Methodology

The scope has been to explore the use of drones in the air (Unmanned Aerial Vehicle - UAV or Unmanned Aircraft Systems - UAS), on the sea (Unmanned Surface Vehicle, USV) and under water (Unmanned Underwater Vehicle, UUV), in the oil and gas industry. By autonomy we mean a system that is non-deterministic in that it has a freedom to make choices, and by automated we mean a system that is more deterministic in that it will do exactly what it is programmed to do. Automation can increase from a system that is human controlled to a system that is fully autonomous, without human intervention.

We are exploring issues related to Man (human factors), Technology (the drones with control facilities/human machine interfaces and communication to others) and Organisational issues (responsibilities, training, procedures, regulation…) i.e. an MTO approach. As a first step, we have explored use of drones in general in all modes (i.e. road transport, rail, air, sea) since differences in maturity level and experiences can identify issues of good and bad practices. We have tried to select issues that can be transferred across the different modes.

Information about actual use of drones and planned use of drones are based on:

- Review of key strategy documents, i.e. white papers, from the government; describing unmanned vehicles in sea, road, rail and air.
- Review and summary of existing drone use, technology and development plans.
- Semi-structured interviews with eight key actors (i.e. technology users, operators and developers of drone technology). Themes in the interviews have been to document new

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areas of use, barriers that hinder use, safety and security issues, and suggested actions to support safe use of drones.
- Review of scientific papers discussing use of drones. Key words in the search have been "safety", "security" and "drones"/ "unmanned" in "aviation"/ "air", "sea", "road", "rail".
- Review of research grants given by the Research Council of Norway in the period 2008-2021, focusing on similar key words as documented above.
- Discussion of planned drone use, challenges and mitigating actions in an expert group.

Key research questions have been:
- What is the actual use and plans for drones, with focus on the petroleum sector?
- What are key health, safety, security and environmental issues of drone use (especially in the northern territories)?
- What are challenges and actions to improve health, safety, security and environmental issues of drones?

3. Results

The findings and the results from the reviews, interviews and discussions are summarized in the following sections:
- Strategies and plans for drone use
- Use of drones in all modes, based on reviews of papers related to safety and security
- Key issues from interviews in the industry
- Research plans, financed by the Research Council of Norway

3.1 *Strategies and plans*

In general, drones are being used to reduce or replace dangerous, dull, dirty and difficult operations. Thus, the benefits are improved safety, reduction of emissions, and improved quality (of operations and data).

Key strategic documents have been the National Transportation Plan SD (2017), Strategy for Maritime Transport NFD (2017) and Drone Strategy in aviation SD (2018). The strategies and white papers describing use of drones in Norway has focused on supporting innovation and removing barriers that delays implementation and use of drone technology.

New rules and regulations have been established and developed in order to support pilot projects, especially on roads and at sea . KPMG (2019) has recently evaluated the autonomous readiness of road transport based on four key factors: Policy and legislation, Technology and innovation, Infrastructure and Consumer acceptance. Norway is in third place on this index, due to technology and innovation (i.e. increased testing through pilot projects), consumer acceptance (i.e. positive feedback) and supporting legislation (enabling testing on public roads). Unmanned drones have been prioritized in the maritime sector (especially under water), in addition to pilot projects of automated driving/ road transportation.

The level of pilot projects in road and sea has not been supported in aviation or in rail.

3.2 *Use of drones in all modes – based on reviews of papers*

Drones and unmanned vehicles are used in many areas. In Rail/Metro transportation; automated road transport; automated sea operations (on surface and below) and air operations. This section contains a short description of use in rail, road, sea and air; followed by a list of applications in the oil and gas industry, the relevant challenges and last a summary of relevant experiences:

Rail/Metro: Unmanned metro operations have been in place since 1980, with control through central control rooms. There are at least 48 lines covering 674 km, UITP (2013); in Barcelona, Copenhagen, Dubai, Kobe, Lille, Nuremberg, Paris, Singapore, Taipei, Tokyo, Toulouse and Vancouver. There have been no reported accidents at present, Wang et al. (2016), i.e. an impressive safety record. The operational design domain (ODD) of unmanned metros has supported safety since the rails are isolated from other traffic and the entry doors have been designed to avoid accidents. There has been poor systematic data reporting of the minor incidents of unmanned rail/ metro operations, the reason seems that there are no requirements to report minor incidents, and at present there are very few scientific papers focusing on this issue.

Autonomous road transport: Autonomous transport has been used in enclosed areas and pilot testing areas to transport materials and personnel. We have surveyed experiences from use of autonomous vehicles in segregated areas (Automated Guided Vehicles- AGV) at a hospital (St. Olav hospital in Norway) and from pilot testing at regular roads in the US. Use of AGVs has been without significant incidents, but the AGVs has poor "sense of self" (i.e. sense of body space to be able to move safely) Jenssen et al. (2019) and does not discover all hindrances, thus there have been several collisions and lock situation where the vehicle has halted. With more than 10 AGVs in operations at St Olav hospital, there is a need for a manned control centre with people that can intervene when there is a collision or lock situation. Systematic data reporting of incidents with the AGV operations is missing.

Google Cars has been operating in the US (unmanned but with a driver in the car that may take control) and has been driving 2,208,199 Km with accident rate of 1,36 police reportable incident pr. million km, i.e. an accident rate of 1/3 to similar manned car traffic. There have been new kinds of accidents such as “rage against the machine”, Teoh et al. (2017). The takeover time of the human driver varies from 2 to 26 seconds, Eriksson et al. (2017), challenging the design of autonomous systems to ensure human intervention in time.

It is anticipated that it may take five to ten years before autonomous road systems are safe and available in all areas, Wozniak (2019). In closed areas and in controlled environments i.e. restricted Operational Design Domain (ODD) such as in mining transport, the use of autonomous systems has been successful.

Unmanned vehicles at sea (subsea and on sea): Subsea operations based on drones (ROV – Remotely Operated Vehicle) has been in regular industrial use in the oil and gas industry since 1970, remotely operated through cables from a control centre.

ROVs are important equipment in the oil and gas industry, being used for inspections, maintenance, operating valves, cleaning and installation of equipment. The ROV is typically managed from a ship close by through a cable. The main argument for use has been reduction of costs (such as avoiding using divers), increased safety (removing people from danger) and increased quality of timely data.

AUV- Autonomous Underwater Vehicles have been employed in surveys and collection of geographical data. AUVs are operated from a control centre, with less need for human intervention than ROVs. There has been incidents and accidents in the use of ROVs and AUVs, but no systematic surveys and analysis have been performed.

Surface drones, USVs – Unmanned Surface Vehicles – have been used since shortly after World War II (in minesweeping) and have been used more as technology has developed. Major application areas have been in oceanography and in hydrographic surveys. There has been a great interest in employing USVs in transportation of cargo and personnel. Several pilot projects, research and testing facilities have been established to explore benefits and use of USVs in cargo and personnel transport. As an example, the autonomous cargo ship, Yara Birkeland, should remove 40 000 trailers annually from the road, when in use from 2021. The first test area of autonomous ships was established in Norway (Trondheim) in 2016 and a forum for autonomous ships was established at nfas.autonomous-ship.org/index-en.html There are substantial benefits of USVs related to efficiency, costs, environmental imprint, logistics and safety – thus this is an area of increased development and use.

Safety and security challenges exist but are uncertain at present due to poor operational experience. Security is immature but must be prioritised as remote operations increase. Experience from self-operated cable ferries in Norway has been good, but there have been accidents due to overload, Høklie (2017). However, in Wrobel et al. (2017) they performed a "what-if" analysis on 100 maritime accident reports. The aim was to assess whether the accident would have happened if the ship had been unmanned. Once the accident had happened - would its consequences have been different? The analysis suggested that the occurrence of navigational accidents (e.g. collision, grounding) could be expected to decrease with autonomous and unmanned ships. However, the consequences resulting from non-navigational accidents (e.g. fire, ship loss due to structural failure) could be expected to be much larger for the unmanned ships when compared to the conventional ones, due to missing possibility of intervention from human operators in the vicinity.

Automation in aviation:
Automation in aviation has a long history, where airplane functions have been systematically automated, and the manning in the cockpit has been reduced. Incidents due to unanticipated consequences of automation occur, but in general, aviation safety (commercial passenger traffic) is extremely high. Accidents related to automation in aviation has occurred recently with the Boeing 737 Max. Key recommendations, Endsley (2019), are to ensure compliance with human factors design standards and support for human factors assessment in aircraft testing and certification.

In addition to increased level of automation in manned flights, the use of drones in aviation, UAS, has increased to avoid or reduce dangerous, dull and/or dirty operations such as risky manned helicopter operations. However, automated systems and UAS are vulnerable to attacks through the physical/cyber systems it consists of, such as the sensors, actuators, communication links and ground control systems. As an example, an Iranian cyber warfare unit was able to land a US drone based on a spoofing attack modifying Global Positioning System-GPS data, Altawy et al. (2017).

In Petritoli et al. (2017) the Mean Time Between Failures (MTBF) for UAS was estimated to be 1000 hours; approximately 100 times higher than MTBF in manned flights. The dominant failures were in the power plant, the ground control system and the navigation system.

Experiences of UAS from the US government, Waraich et al. (2013), documents that mishaps may happen (i.e. 50-100 mishaps occur every 100,000 flight hours' vs human-operated aircraft where there is one mishap per 100,000 flight hours). Mishaps are related both to take-off, en-route and landing. The mishap rate of UAS is significantly higher than manned operations, i.e. 100 times higher. Main causes are related to poor attention to human factors science, such as poor design of ground control centres Waraich et al. (2013), Hobbes et al. (2014).

Industrial applications: The use of drones in the oil and gas industry has a varying degree of maturity. Subsea drones have been industrialized, are in regular use and have reached a higher maturity level than drones on surface or in the air. The use of drones on sea and in air is mostly in pilot testing and exploration. Drone applications in air, on sea surface and subsea includes:

- Photography, video recording (in air and subsea) to support training, information gathering and crisis management
- Inspection of (critical) components such as flare towers in oil and gas, windmills, storage tanks and pipelines, in order to improve safety, avoid human exposure, reduce costs and improve quality. The quality of inspections may increase through use of ultra-sound, making it possible to better examine the status of components
- Maintenance, as an example through subsea drones, supporting human operators
- Detection and survey of dangerous emissions or objects such as explosive gas, sea-ice, environmental pollutions or oil spills
- Logistics, delivery of critical components or supplies (such as medicine, blood…)
- Plotting and surveys (of seabed, of traffic, of large remote areas)

Challenges of operations in the Northern Territories of Norway: There are several challenges of drone operations in the Northern Territories of Norway. One of the main challenges in the Arctic is the demanding environment, i.e. temperatures down to -20 to -40 degrees C, polar lows, long period of darkness, fog and possibilities of icing, sleet and snow. Operational equipment may not be tested for these conditions thus definition of requirements and relevant testing are needed. In addition, the operators of the drones must be protected from the harsh environment.

The Norwegian Civil Aviation Authority (NCAA), has established a set of certification levels for professional use of drones (called RO2 and RO3). Flying in the dark requires special procedures that is a part of the RO2 and RO3 certification.

Communication infrastructure is demanding in the north, from 60 degrees to 70 degrees, see Latola (2017). Geostationary satellites are practically not operational north of 70 degrees, due to low horizon and need for small antenna size and difficulties with tracking parabolic antennas on small planes. Even Global Hawk had to revert to iridium at 74 degrees North when it flew to the North Pole in April 2010. Low polar orbit communication satellites like iridium work all the way to the North Pole but have very limited bandwidth, that is about 2 kbps for standard modem solutions. There are ways of combining multiple channels (i.e. Rudics - Iridium Router based Unrestricted Digital Interworking Connectivity Solution) to get higher bandwidth (64 kbps). The new Iridium Next will get up to 500 kbps but hardware is larger and heavier. Within a few years the new low orbit communication satellite constellations One Web, Amazon Kuiper, and Starlink (Space-X) will have launched about 46.000 satellites to provide competing global broadband coverage, thus revolutionizing the opportunities for real-time operation support in arctic regions.

Great steps have also been taken in developing technology to handle icing. In the Arctic Regions icing occurs at low level year-round and clouds will almost always be mixed phase containing supercooled liquid. Most de-icing schemes are power demanding hence challenging the low power long endurance designs often used on drones.

GPS may be a challenge to use due to spoofing attacks (i.e. falsified information) or jamming and must be addressed and mitigated.

Summaries of relevant experiences - all modes: The scope of operations (where, why and how) is decisive when discussing risks of autonomous systems. The autonomous system must include drones, organisation of control, communication, infrastructure and the environment. Autonomous systems have limitations related to "sense of self" and may have difficulties in avoid collisions with other objects, thus barriers, protection, operational envelopes and physical guides should be built around the systems.

Summary of issues are:

- There is a need to establish systematic data reporting from autonomous systems to ensure risk based mitigating actions.
- New kind of accidents will happen, and there is a need to develop relevant and new taxonomies to structure accident and incident data.
- Safety and security of autonomous systems are emerging – the risk associated with

autonomous systems is uncertain at present and depends on area of use and quality of practices.

- Reliability is an area of focus. Data from remote operated drones in air identifies that risks of mishaps is 100 times higher than in manned operations, and MTBF is 100 times higher.
- Probabilities of human harm may be reduced due to reduced exposure when automation takes over, but consequences may increase due to difficulties with human intervention.
- Meaningful human control is important. Autonomous systems must often rely on human intervention thus there is a need to design, build and certify a system with focus on human interfaces (such as control centres or control interfaces). Key principles for automation that prevent accidents should be incorporated, such as described in Endsley, (2019): i.e. automation transparency, user in command, reliability, simplification of tasks, unambiguous alarms, training to support understanding and relevant trust. As the level of autonomy increases, the human operator will be more "out-of-the-loop", a key issue is to design operations in such a manner that the human operator and system can understand the situation and handle deviations without increasing probabilities of failure or consequences.

3.3 *Key issues from interviews in the oil and gas industry*

During the interviews it was highlighted that the oil and gas industry and offshore helicopter operators have a high focus on safety and risk-based regulation. Thus, these stakeholders could be a driving force in ensuring that drone operations have a high focus on safety and security. Drone operators with experience from the offshore helicopter industry have helped to describe and inform about relevant and best practices from the helicopter industry that can be employed when operating drones in the air (the practices are also relevant for operations at sea). Key findings from interviews were:

There is a need for more knowledge of drone technology and potential for use in the petroleum sector. The culture of innovation related to drone use should be improved. The petroleum sector should encourage more pilot projects of drone use also projects supported by the authorities.

The established network between drone users in Norway, UAS, was considered a good network to share practices of remotely piloted aircraft systems. See: www.uasnorway.no/uas-norway/

The drone technology, especially in aviation applications, needs to be improved to handle tough weather conditions (precipitation, strong wind, low temperatures). The technology needs to become more resilient for demanding flight operations and the need for high reliability for industrial use. The low level of automation for the drones at present creates the need for highly skilled and experienced pilots to handle demanding operations.

There is a need to gather experiences from drones that can operate in environments with gas (i.e. danger of ignition and fire/ explosion). There are few drones available that have ATEX-certification ("atmosphères explosibles" for Zone 0-always gas filled atmosphere, 1- periodic gas filled atmosphere or 2- seldom gas filled atmosphere), see guidelines ATEX137, ATEX95 and Bakken et al. (2019). We are not aware of that the petroleum sector has approved and adopted these drones on a wide scale.

The safety authorities seem to have few resources working on the use of drones. There is a need to develop sensible regulations and best practices of operations, thus more resources should be prioritized in this area. The Norwegian Civil Aviation Authority (NCAA) has invited drone operators with experiences from offshore helicopter operations to present their best practices, adapted to drone use. This has been a positive development to support a high level of safety and reliability in the use of UAS.

The oil and gas industry have excellent safety practices such as Safe Job Analysis (SJA) and Work Permits to manage risk, document and coordinate all work in a safety critical environment. These practices have impacted technology, procedures and awareness for the drone operators and has helped to improve the level of safety. These practices can be transferred to other industrial sectors as well.

The operators interviewed perform a thorough risk analysis when operating drones (air) on an offshore installation, defining a flight plan, discussing risks, and specifying risk reduction and mitigating actions.

Experienced operators appreciate the work towards establishing a certification system in aviation, such as described by EASA (2019), i.e. "specific" or "certified". They want the oil and gas industry to demand that all operators have one of these certifications. Similar schemes need to be implemented at sea.

The users and operators want to establish an industry specific course for pilots of drones in the oil and gas industry due to the challenges and risks specific to the industry.

Security issues and protection of oil and gas installations should get priority from the oil and gas industry and the authorities, especially when considering the drone attack in Saudi Arabia (2019). The use of drones should follow the data protection regulation in GDPR (2016).

The users and operators want to establish a set of guidelines and best practices that could be an acceptable standard across the industry. This can cover specifications for equipment, standards for risk assessment, standards for planning and operational procedures. This would ensure an improved safety level, less needed documentation and more simple approval process from the authorities. This suggestion is supported by PSA.

There is a need to establish a professional network for safe use of drones in the petroleum sector. This network should learn from the positive safety experiences from the communities of practice for ships and helicopters established in the Norwegian oil and gas industry, i.e. "The Captains Forum", Antonsen et al. (2007) and "the Cooperation Forum for Helicopter Safety on the Norwegian Continental Shelf", Bye et al. (2018). The helicopter safety forum consists of stakeholders from the authorities, the operators, the unions and the oil and gas companies. The forum is widely regarded as a key success factor for the high safety level of offshore helicopter transport in Norway.

3.4 *Research plans - drones*

Research activities related to autonomous systems are increasing. There is a strong focus on research in autonomous shipping in Norway, a research based centre has been established - AMOS (i.e. the centre for autonomous marine operations and control systems - www.ntnu.edu/amos). In 2018, they conducted research activities of around 323 Mill NOK, (AMOS, 2018). The Research Council has increased funding of mainly aviation-based drones by 100% for each finance period, i.e:

- 2008 to 2012: 36 Mill NOK
- 2013 to 2017: 57 Mill NOK
- 2018 to 2021: 119 Mill NOK

In total we found 31 projects that were financed. The projects were in several areas such as maritime, technology, power lines, air-control and other areas. In the following we have listed the "short name" of funded projects, grouped under the relevant areas:

Maritime area (8 projects): Safe transport between supply ships and oil platforms using drones; Safe maritime landing for UAS; Drones used in unmanned operation of fish farming; ASSUR- airborne ship safety with UAV to search for man-overboard or oil spills; Ice monitoring; Technological improvements in communication; UAS in north for ice monitoring; Inside ships - autonomous inspection of storage tanks.

Technological improvements (7 projects): Improved batteries for drones; Development of composite electrical motor for Drones; Development of hybrid propulsion of UAV; Vertical take-off and landing; Scout for inspection of equipment; Mosquito – technology for small scale UAV; DroneSafe – developing world class drones for video recording in constrained areas.

Power line inspection (5 projects): Maintenance; Fault detection (AI); Autonomous inspection; Smart electricity grid inspection; Remote inspection of wooden utility poles.

Air control systems (3 projects): Air traffic management of UAVs; Autopilot design for UAV in extreme conditions; Low altitude UAV communication and tracking.

Biological/Farming (2 projects): Survey of plant parasites; Counting of seal population.

City management (2 projects): Observe building changes in a city based on drone surveys; Inspection of critical infrastructure – status of bridges built in concrete.

Health Care (2 projects): UAS for fast and secure transportation of blood products and biological material; Development of commercial medical transport service.

Geographical survey (1 project): Measurement of gravity and magnetic fields.

Societal issues (1 project): Responsible adoption of visual surveillance technologies in the news media.

During our survey of research projects, we tried to identify areas that were poorly treated or missing based on our literature review, experiences of drone use and interviews.

Going through the description of the 31 projects, we found that 10 projects used improved safety in operations as a key argument to get financing. However, the projects have almost no focus on security.

Other areas that were missing were logistics i.e. emergency deliveries of equipment, disaster support or critical supplies used in health care.

There was poor focus on research to improve reliability and robustness of drones as documented in our review. Key reliability and safety challenges, Petritoli et al. (2017), has been the reliability of the power system, the low MTBF and the usability of control systems. The human factors deficiencies of ground control systems as mentioned in Waraich et al. (2013) or Hobbes et al. (2014) has not been sufficiently prioritized.

Implementation of new technology is dependent on development of societal and organisational issues (ethics, rules, regulation, communication, accident reporting systems, stakeholder development), user needs, and quality of Human Factors design in operation.

The Government has published a Whitepaper (2018) describing a strategy for the use of UAS in Norway. Key strategies are: Establish rules and regulation; Focus on safety; Inform users about relevant rules and regulations; Prioritize use of drones in government; Support research and innovation related to the use of UAS; Establish test centres. In our opinion, the strategy is somewhat sketchy related to ethical and social aspects, security of drones and documentation of known safety challenges. These areas have not been among the research funded projects either.

In summary, there is poor match between research that has been funded and the needs found through our literature review and interviews of key users in the oil and gas industry. Based on the present research financing there seems to be a need for more focus on:

Ethical and social aspects of the use of drones – as an example the importance of prioritizing safe, secure and ethical use of drones through networks of engaged users (by engaging networks such as the Norwegian UAS member association).

Human Factors based design, to support improved quality of operations and meaningful human control through human factors guidelines for control centres, and interfaces to technology.

Security for safety of drones, especially drones that is going to be used in an industrial setting.

Systematic gathering of operational data, to improve reliability and resilience. There is a need to improve the reliability of industrial drones with focus on improvement of MTBF. To do this, there is a need to gather and systematize actual incidents. In general, there has been poor focus on resilience engineering of autonomous systems to improve the ability to handle deviations and go to a safe state.

Prioritization of regulation and research to support deployment of drones and UAS in urban and rural areas and in controlled airspace.

4. Discussion of challenges and actions

In the following we list challenges and propose actions for the actors in the petroleum sector (where PSA is included as a key actor).

4.1 *Identified challenges*

The challenges we have seen are:

Demanding climate - There are several challenges associated with low temperatures, wind, precipitation, fog and cloud cover in the Northern Territories. Electronics are not normally designed for very low temperatures and can cause loss of airborne drones. In addition, there is the challenges of poor coverage, quality and vulnerabilities of GPS.

Technology - Drones are complex systems where a variety of technologies must work together. Achieving robustness and resilience of critical technologies is challenging.

Co-operation between drones and manned vessels – as the oil and gas industry may move from the use of vessels around offshore installations to more drones in the air, on water and underwater there is a need to handle the increased operational complexity.

Challenges related to safe use - Drone operations must be risk-assessed, and there must be competent operators in place supported by procedures, user-friendly technology and meaningful human control when the unexpected happens. Poor user interfaces are a source of unwanted events.

Planning and operations - The oil and gas industry will see a shift to a greater degree of autonomy, increased use of drones and increased use of land-based control rooms. This complexity calls for requirements related to operational planning and quality of interfaces with human operators.

The demanding climate, the technology challenges, and the future need for more co-operation creates the need for development of safety as a key part of planning and operations.

4.2 *Proposed actions*

The summarized actions are:

The actors in the Petroleum sector should describe and systematize risks and hazards, errors and handling of errors related to the use of drones. Such systemization can form the basis for the industry's requirements for robust technology, including integrity and redundancy, and will be a necessary basis for the individual company's risk assessment of drone technology and operations. The users should collect and report data from drones in line with requirements for airborne drones as specified in regulations from the Norwegian Civil Aviation Authority (NCAA), i.e. at present RO2 and RO3.

The actors in the Petroleum sector should establish a professional network for safe use of drones in the industry. A professional network may be responsible for drawing up requirements, drawing up guidelines and suggestions for technical solutions to intensify the development of robust and secure drone technology and operations in line with governmental strategies and regulations.

The actors in the Petroleum sector should consider the need for securing the area around oil installations related to the use of drones in the air, on the sea surface and under water and assess the need to increase the security zone around oil and gas installations.

The actors in the Petroleum sector should systematize experiences from the use of ROV's with a focus on adherence to the facilities regulation from 2019, especially the quality of Human Machine Interface, and use of alarms when drones are used. They should be **a driving force for collaboration** with other sectors,

establish training opportunities and establish **test and training facilities** for the sector.

In general, there should be more focus on making drones more resilient, robust, safe and secure under all conditions. This could be supported through risk-based regulation and risk-based insurances.

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References

Altawy, R., & Youssef, A. M. (2017). Security, privacy, and safety aspects of civilian drones: A survey. ACM Transactions on Cyber-Physical Systems, 1(2), 7.

AMOS (2018) AMOS Annual Report, ref www.ntnu.edu/web/amos/newsandevents

Antonsen, S., Ramstad, L. S., & Kongsvik, T. (2007). Unlocking the organization: Action research as a means of improving organizational safety. Safety Science Monitor, 11(1), 1-10

ATEX 95 - Directive 2014/34/EU (also known as 'the ATEX Equipment Directive')

ATEX137- Directive 99/92/EC (also known as the 'ATEX Workplace Directive')

Bakken, T. et al. (2019). Use of Drones in Northern territories (Norwegian: Bruk av Droner i Nordområdene), SINTEF report ISBN 978-82-14-06264-9.

Bye, R., Johnsen, S., & Lillehammer, G. (2018). Addressing Differences in Safety Influencing Factors—A Comparison of Offshore and Onshore Helicopter Operations. Safety, 4(1),

EASA (2019) - Commission Delegated Regulation (EU) 2019/945 & Commission Implementing Regulation (EU) 2019/947

Endsley, M. (2019) "Human Factors & Aviation Safety" Testimony to the United States House of Representatives – Hearing on Boeing 737-Max8 Crashes.

Eriksson, A., & Stanton, N. A. (2017). Takeover time in highly automated vehicles: noncritical transitions to and from manual control. Human factors, 59(4), 689-705.

GDPR (2016) -General Data Protection Regulation 2016/679/EU.

Hobbs, A., & Shively, R. J. (2014). Human Factor Challenges of Remotely Piloted Aircraft. In 31st EAAP Conference (pp. 5-14).

Høklie, O.I. (2017): Design av informasjonspanel for Autonom Passasjerferge Milliampere, Part of Master Thesis NTNU, 2017

Jenssen, G.D., Moen, T., Johnsen, S.O. (2019): Accidents with Automated Vehicles, Do Self-Driving Vehicles need a better sense of self, 26th ITS Word Congress

Johnsen, S.O., Evjemo T.E.: "State of the art of unmanned aircraft transport systems in industry related to risks, vulnerabilities and improvement of safety". ESREL 2019

KPMG (2019) "Autonomous vehicles readiness index, retrieved at 2019.12.01 from https://assets.kpmg/content/dam/kpmg/xx/pdf/2019/02/2019-autonomous-vehicles-readiness-index.pdf

NFD (2017) Regjeringens havstrategi Ny vekst, stolt historie. retrieved at 2019.12.01 https://www.regjeringen.no/no/dokumenter/ny-vekst-stolt-historie/id2552578

Petritoli, E., Leccese, F., & Ciani, L. (2017). Reliability assessment of UAV systems. In 2017 IEEE International Workshop on Metrology for AeroSpace (MetroAeroSpace) (pp. 266-270). IEEE.

Saudi Arabia (2019) - https://www.digitaltrends.com/news/saudi-arabia-oil-drone-attack-commercial-uavs/

SD (2018) Norsk Dronestrategi fra https://www.regjeringen.no/no/dokumenter/norges-dronestrategi/id2594965/

SD (2017) Nasjonal Transportplan 2018-2029 Stortingsmelding#33 retrieved at 2019.12.01 www.regjeringen.no/no/dokumenter/meld.-st.-33-20162017/id2546287/

Latola, K., & Savela, H. (Eds.). (2017). The Interconnected Arctic—UArctic Congress 2016. Springer

Teoh, E. R., & Kidd, D. G. (2017). Rage against the machine? Google's self-driving cars versus humans. *Journal of Safety Research*, *63*, 57-60

UITP (2013) Observatory of Automated Metros World atlas report. International Association of Public Transport (UITP), Brussels

Quilter, T., & Baker, C. (2017). The application of staring radar to the detection and identification of small Unmanned Aircraft Systems in Monaco. In Radar Symposium (IRS), 2017 18th International (pp. 1-9). IEEE.

Wang, Y., Zhang, M., Ma, J., & Zhou, X. (2016). Survey on driverless train operation for urban rail transit systems. Urban Rail Transit, 1-8.

Waraich, Q. R., Mazzuchi, T. A., Sarkani, S., & Rico, D. F. (2013). Minimizing human factors mishaps in unmanned aircraft systems. ergonomics in design, 21(1), 25-32

WhitePaper (2018, March) Drone Strategy www.regjeringen.no/no/dokumenter/norges-dronestrategi/id2594965/

Wozniak (2019) https:www.wardsauto.com/autonomous-vehicles/apple-s-woz-sees-autonomous-vehicles-long-way