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Addressing Differences in Safety Influencing Factors—A Comparison of Offshore and Onshore Helicopter Operations

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Abstract: The accident levels in helicopter transportation vary between geographical regions and types of operations. In this paper, we develop some hypotheses regarding the factors that may explain this variation. The aim of this paper is to improve safety in helicopter transportation through better understanding of the causes leading to fatal accidents. We provide an analysis of three segments of helicopter transportation in Norway (i.e., offshore transportation; onshore ambulance/police, and onshore transportation). This analysis refers to international research on helicopter accidents. The number of fatal accidents per million flight hours in Norwegian offshore helicopter transportation was 2.8 in 1990–1999 and zero in 2000–2015. In Norwegian onshore helicopter transportation, the fatal accident rate was 13.8 in the period 2000–2012. Twenty-three onshore helicopters crashed to the ground; seven of these crashes were fatal, killing 16 people. It is reasonable to question why there is such a significant difference in accident rates between offshore and onshore helicopter transportation. We have approached this question by comparing how the different segments of helicopter transportation are organized and managed. Our analysis shows that there are major differences both at the “sharp” end (i.e., in actual operations) and the “blunt” end (i.e., rules, regulations and organization). This includes differences in regulations, market conditions, work organization (i.e., training, employment conditions, and qualifications of the crews), operations and technology. A central argument is that differences in the market conditions and requirements stipulated by the users explain some of these differences. The same differences can be found internationally. If we use best practice and expert judgments, there is an opportunity to improve helicopter safety through improving the socio-technical system (i.e., organizational issues, improved design, improved maintenance of critical components and more focus on operational factors). A reasonable goal is that the international helicopter transportation industry could reduce the accident level to less than one fatal accident per million flight hours (Considering the oil and gas industry internationally, this would reduce the average of 24 fatalities annually to 4 per year, thus saving 20 lives each year).

Keywords: safety; accident prevention; helicopter transportation

1. Introduction

The overall aim of this paper is to develop hypotheses regarding conditions that may influence the probability of fatal accidents in helicopter transportation. We have done this by conducting an exploratory comparative analysis of both quantitative and qualitative data obtained from the Norwegian helicopter transport industry in the period 1980 to 2016, supported by a literature review of international research on helicopter safety.

The background for this study is the significant differences we have observed in accident frequencies between different segments of helicopter transportation in Norway, within the same overall safety regime.

In offshore helicopter transportation, the fatal accidents per million flight hours was 2.8 for the period 1990–1998 and zero for the period 1999–2012 (The fatal accident frequency for the period 1990–1998 is owing to one single accident back in 1997. In April 2016, there was an offshore helicopter accident with 13 fatalities. These accidents have not changed the observation of more accidents onshore than offshore. Using estimates regarding the flight hours during 2016, the number of fatal accidents per million flight hours are estimated to be 1.9 for the period 2007–2016). The corresponding frequency in onshore helicopter transportation in Norway during the period 2000–2012 was 13.8.

In offshore operations, the oil and gas industry in Norway (Shell and Statoil) initiated a helicopter safety study [1], early in 1980. In this study, the main conclusion was that offshore helicopter transport (Norwegian and UK sectors) had a fatal accident rate of approximately 3.8 per million-person flight hours (in the period 1966–1990). This is 10 times higher than of scheduled airline services (fixed wing). It was estimated that it was possible to reduce the number of helicopter fatalities by 40% over the next 10 years. The main area to be improved was technical reliability followed by Air Traffic Control (ATC)-external navigation aids and services, pilot performance, crashworthiness, aviation authorities and manufacturers.

An analysis of Norwegian onshore helicopter transportation in 2013 concluded that the fatal accident risk had increased during the previous five years [2]. The analyses showed a high risk for onshore helicopters, and a variation between different types of operations. The estimated number of fatal accidents of passenger transportation was 0.36 per year. Ambulance and police operations had a considerably lower risk level, with fatal accidents estimated at 0.06 per year.

Our literature review shows that accident frequencies vary between different nations and geographical regions within the same segments of helicopter transportation. A study conducted by the International Association of Oil and Gas producers (IOGP) [3], shows that the risk of fatalities in offshore helicopter transport per million-person flight hours is estimated to be 1.44 in the North Sea area, and 8.15 outside the North Sea area. There are differences in accident frequencies between countries, industry segments and time-periods. Important safety lessons can be learned from studying variations in safety regimes, regulations, training, employment conditions, composition of crews, technology used and operational tasks. These are called the socio-technical system.

When observing the variation in the accident rates it is reasonable to ask the question: What can explain these observed differences? We have conducted an explorative comparative analysis between offshore and onshore helicopter operations in Norway to develop some hypotheses that may explain the observed differences in the accident rates. This analysis specifically addresses operational and organizational conditions. The paper contains the following main five sections (with listed subsections)

- **1: Introduction** (i.e., this section)
- **2: Method and theory description**
    - (-Literature review; -Data from Norway; -Terminology)
- **3: Exploratory study of international helicopter accidents offshore and onshore**
    - (-Accident levels; -Causes, -Measures)
- **4: Comparison of Norwegian offshore and onshore helicopter transportation**
    - (-Type of operations offshore and onshore; -Accident frequencies and descriptions of accidents; -Regulators; -Companies, training and employment conditions; -Implementation of risk-reducing measures);
- **5: Discussion, lessons learned and conclusion**

  - ○ (-Discussion; -Conclusions and lessons learned; -Recommendations)
- **References**

2. Method and Theory Description

In order to make a comparison, we have used a conceptual model of organizational components influencing safety. This model is based on the classical socio-technical model of safety management, described by Rasmussen in [4]. This is a generic model of safety management within organizations in different industries, which has been used to improve our understanding of the relationships between key factors influencing the levels of safety. Rasmussen's model has been a reference in the work of Reason [5,6] and his division between "unsafe acts", "local workplace factors" and "organizational factors". The conceptualization of links between "blunt end" and "sharp end" factors is also essential in the HFACS model [7] and psychological perspectives [8,9] that have influenced the taxonomies of the relevant reporting systems.

We have adapted the generic Rasmussen model to a more specific model for the operational conditions of helicopter transport, see Figure 1.

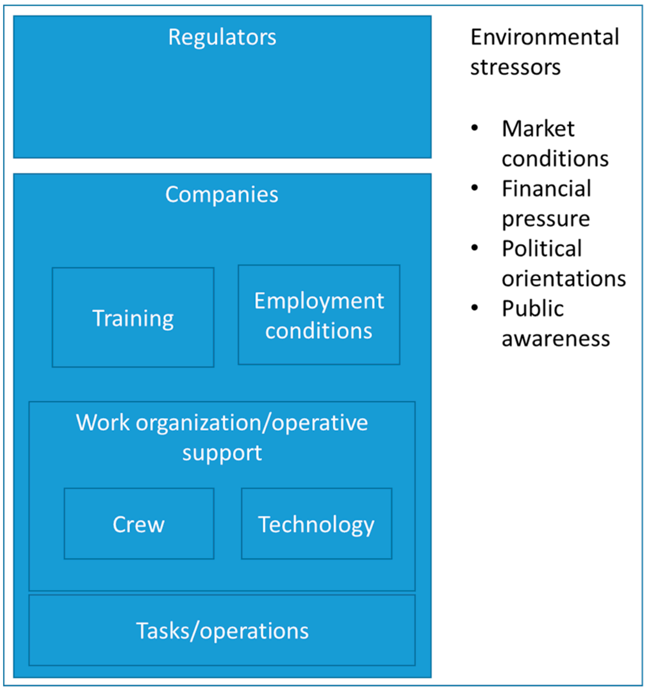

Figure 1. Defined organizational components and environmental stressors (adapted from [4]).

The model indicates a top down relationship from regulators, through companies and how work is performed and supported by the crew and technology. There is also a bottom up relationship between the hazardous tasks (i.e., flights including fatal accidents) conducted at the "sharp" end of an organization (the bottom of the figure) and the regulators at the "blunt end" (the top of the figure). The model also includes the impact of "environmental stressors", such as market conditions, financial pressure, and public awareness.

Based on our study, we have formulated hypotheses related to the differences in accident levels. The main uncertainties in our work arise from the relatively limited number of fatal accidents that have occurred, such as zero fatal accidents in Norway offshore transportation in the period 1999 to 2012 when the yearly flight hours were between 42,000 and 58,000. However, the relatively high number of accidents observed in onshore helicopter transportation may defend making a comparative study to develop possible explanations.

2.1. Literature Review

Our exploratory study is supported by a literature review of international publications on helicopter safety focusing on organizational issues together with human and technological issues in the period 1980 to 2016. The sampling of relevant literature has been done by systematic searches of SCOPUS, Web of Science and Google Scholar using these keywords: "helicopter", "helicopter transport, operations", "safety", "accidents", "accident rates". One example of a relevant Scopus search is: (helicopter or helicopter and transport or helicopter and operations) and (fatal accidents or crashes or incidents or near miss or accident and rates). We have gone through abstracts to identify relevant papers related to fatal accidents exploring the level of accidents and papers analyzing mitigating actions. Using the identified relevant papers, we have followed references to uncover additional papers discussing the safety of personnel transportation by helicopter. Two independent researchers have performed the review and checked the results. Where appropriate, we have followed the main suggestions from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses-PRISMA, found at www.prisma-statement.org.

2.2. Data from Norway

Our study in Norway relies on three different data sources:

- The accident database of the Civil Aviation Authority, Norway
- Records of flight hours reported to the Civil Aviation Authority, Norway
- Findings presented in research reports regarding Norwegian helicopter transportation

The accident database and the records of flight hours have been used to calculate accident rates and identify the conditions associated with the accidents.

The findings presented in the research reports, including statistical analysis of accident data, have been compared across three segments of helicopter transportation in Norway. The research reports have been developed as a part of the "*Helicopter Safety Study Number 1, 2 and 3*" from 1990 to 2010 (see [1,10,11]), "*Trends in Risk Levels*" in the petroleum activity [12], "*Safety study onshore helicopters*" [2], and the ongoing research project "*Work related accidents in road sea and air transport*" [13]. The authors have been involved in these projects, and been responsible for several of the analyses.

The comparisons of the organizational aspects between the three segments rely on different types of data. The description of onshore ambulance and police operations, and onshore aerial work and passenger transportation relies partly on results from the analysis of survey data. Equivalent survey data have not been accessible from the offshore helicopter studies. This lack of synchronicity in data sources is the result of conducting a review of several research projects with different designs. However, this lack of synchronicity in data has been handled by only comparing those organizational aspects that are reflected in accessible, but partly different, data within the three areas of helicopter transportation.

The accident data we have used lack sufficient details about organizational issues. The data should be supplemented by analyses of near misses and successful recoveries to fully understand the reasons for recoveries and accidents, as argued by [14,15]. Since such data are not available at present, more in-depth research is needed. A full analysis of unwanted incidents and successful recoveries based on more instrumentation, such as video recordings, would have given a deeper understanding of incidents, but no such data have been identified. In general incident and accident data are of poor quality and should be improved, as mentioned by [16]. Continuous data transmission of "black box" data to the outside is also absent at present. To support future research, the cockpit should be instrumented with more complete data recording of the flight [17] including video recordings that go beyond the existing "black box" systems. This is also supported by [18] focusing on improvement in the quality and sharing of accident data; the need for metrics for the normalization of accidents; in addition to careful analysis of pilot performance (especially at night and during arrival).

2.3. Terminology

We have used the same definitions of accidents as the Civil Aviation Authority in Norway (NCCA), which also coincides with ICAO's ADREP 2000 taxonomy.

(*Accident:* An occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, in which: (a) a person is fatally or seriously injured as a result of:

—being in the aircraft, or—direct contact with any part of the aircraft, including parts which have become detached from the aircraft, or

—direct exposure to jet blast, except when the injuries are from natural causes, self-inflicted or inflicted by other persons, or when the injuries are to stowaways hiding outside the areas normally available to the passengers and crew: or;

(b) the aircraft sustains damage or structural failure which:

—adversely affects the structural strength, performance or flight characteristics of the aircraft, and

—would normally require major repair or replacement of the affected component, except for engine failure or damage, when the damage is limited to the engine, its cowlings or accessories; or for damage limited to propellers, wing tips, antennas, tires, brakes, fairings, small dents or puncture holes in the aircraft skin: or (c) the aircraft is missing or is completely inaccessible. See http://www.iprr.org/manuals/Annex13.html).

"Fatal accidents" are accidents that involve the death of one or more people. This terminology has also been used to identify relevant papers in our exploratory review. The term "helicopter crash" denotes an accident where the helicopter collides with the terrain or structure, or tips over because of start or landing, and is destroyed.

The literature review shows variations in what has been used as the denominator to normalize accidents, and the theoretical justification for the choice is limited. The denominator varies between the use of total flight hours, flight hours per passenger (passenger flight hours), and the number of missions. In the oil and gas industry, IOGP [3] has gathered normalized data worldwide based on fatalities per million-person flight hours. Using the flight hours per passenger gives us the individual occupancy risk or personal risk when using a helicopter. In reports and articles related to transport safety, the denomination passenger transport hours is often used to compare safety across different modes of transportation i.e., train, subway, bus, car, ships and fixed wing airplanes. In onshore helicopter transportation, passenger transportation represents only a part of the operations and the companies have not been obliged to report the number of passengers to the authorities. In our comparison of the different helicopter segments in Norway, we have normalized the available data by using million flight hours as the denominator.

3. Exploratory Study of International Helicopter Accidents Offshore and Onshore

In the following section, we have documented our findings from our review of previous research related to accident levels, causes and suggested measures.

3.1. Accident Levels

In [19], it was argued that the helicopter industry had a poor safety record, which was documented in several studies. When exploring research related to helicopter safety, there has been a perception that safety can be improved and that the number of accidents has been too high in relation to the aviation industry in general, i.e., related to fixed-wing transportation, as mentioned in [20]. In the presidential report on aviation safety [21], the goal of the United States was to reduce the number of fatal accidents by 80% in the helicopter transportation area to be no more than 2.8 fatalities per million flight hours by 2007, as described by [19]. The European Aviation Safety Agency (EASA) publishes an annual safety review, comparing fatal accidents in different domains on a broad level, [22]. The Advisory Council for Aeronautics Research in Europe (ACARE) has set an overall and general safety goal of less than one accident per ten million commercial aircraft flights, [23].

The oil and gas industry is a safety oriented industry and has been working to improve safety in helicopter transport. The IOGP goal was to reduce the fatal accident rate to less than one per million flight hours by 2013. In the Norwegian white paper [24] the goal from 2002 was less than one fatality per million-person flight hours. In [25] the goal is suggested to be 0.7 fatalities per million-person flight hours, based on mitigating actions already carried out in Norway.

3.1.1. Accident Levels in the Emergency Services (EMS)

Baker et al. [26] performed a review of US helicopter EMS accidents in the period 1983 to 2005, documenting a fatal accident rate of 17 per million flight hours.

Hinkelbein et al. [27] presented a review of German helicopter EMS, based on 40 years of data from 1970 to 2009. The fatal accident rate in the period was 47 per million missions, showing a reduction in the last period. There was no compulsory reporting of flight hours, thus it was difficult to normalize the results. The Human Factors Analysis and Classification System (HFACS) from [7] was used and it was reported that accidents often occurred during landing. Hinkelbein et al. [27], see Table 1, compared fatal crash rates of helicopter EMS based on seven studies, where the fatal crash rates ranged between 9.1 and 47 per million flight hours. It was difficult to gather and compare relevant data due to differences in reporting. In this data-set, there has been a reduction of fatal accidents per million flight hours from the period 1982–1987 (level of fatal accidents: from 41 to 47) to the period 1987–2004 (level of fatal accidents: from 9.1 to 18).

Table 1. Fatal Crash Rate Helicopter EMS (per million flight hours) [27].

Country	Period	Fatal Accidents	Ref.
US	1982–1987	47	[28]
Germany	1982–1987	41	[28]
US	1987–1993	16.1	[29]
Australia	1992–2002	14.6	[30]
US	1992–2001	16.9	[31]
Germany	1999–2004	9.1	[32]
US	2000–2004	18	[33]

Based on our review we have seen a reduction of accidents in the later periods, and that there is a need for more standardized reporting of helicopter accidents to be able to compare results and learn from different countries, in line with the findings from [16].

3.1.2. Accident Levels in the International Oil and Gas Industry

IOGP [3] has compared the safety level associated with the offshore helicopter operations in the North Sea, the Gulf of Mexico and helicopter operations in the rest of the world. In addition, they have compared the risk of using fixed wing transportation. Table 2 presents their estimated risk of fatalities per million-person flight hours within the defined offshore transport groups. Their analysis shows that the fatality rate in the Gulf of Mexico was three times as high as the fatality rate in the North Sea area, (the North Sea had flights predominately from the UK and Norway). The IOGP data also show that fixed wing transport has approximately a 10 times better safety level than the safest helicopter services. That is in line with the discussion in [1] who pointed out that fixed wing transportation had a fatal accident rate 10 times lower than North Sea helicopter transportation.

Table 2. Risk of fatalities from [3], per million-person flight hours).

Offshore Transport	Fatal Accidents
- Helicopter North Sea	1.44
- Helicopter Gulf of Mexico	4.54
- Helicopter Rest of the World	8.15
Fixed wing transport	0.23

A comparison between the United Kingdom (UK) and Norway has been conducted by the UK Civil Aviation Authority (UK-CAA) in CAP1145 [34]. This study shows that the number of fatal accident per million flight hours was 3.42 in the UK and 1.08 in Norway in the period 1992 to 2012. In [11], the number of fatalities per million-person flight hours in the period 1990 to 2009 was 0.9 for the Norwegian sector while the UK sector had 5.6 fatalities per million-person flight hours. We cannot conclude that the Norwegian sector has a statistically significant lower accident rate than UK. However, we argue that relevant practices used in Norway have led to fewer accidents, and that this practice can help improve safety. Thus, our argument is based on a qualitative assessment. The credibility of our argument is based on member checks and support from the authorities. Based on the Norwegian model of collaboration between actors, UK CAA will establish a new offshore helicopter safety forum in the UK to drive forward the recommendations and actions identified, CAP1145 [34]. UK CAA will also liaise with Norway further to share experience and best practice.

The IOGP goal for helicopter safety was that it should be in line with "the average global airline" [19] (meaning an airline based on commercial fixed-wing flights). Helicopter safety level in the North Sea was identified as best practice operations [19], and it was suggested that the global oil and gas industry could save more than 20 fatalities each year by exploring best practice from the North Sea. This can only be done by collaboration between customers (oil companies and IOGP), regulators, helicopter operators and original equipment manufacturers (OEM). Improvements must be carried out by influencing the whole socio-technical system.

3.2. Causes

A review of helicopter accidents was conducted by the European Helicopter Safety Team (EHEST) [35], among the members of the European Aviation Safety Agency (EASA). It identified a complex set of causes based on human factors, technology and organizational issues, identifying poor pilot judgment as a key issue. Overall, 56% of the accidents were related to "unsafe acts" [35].

In [36], there is a broad review of helicopter safety based on detailed data from a supplier, Bell Helicopter, in addition to general accident data from the US. One of the key issues was the poor data collection methodology, such as the lack of both accurate flight-hour exposure data and documented information about what happened in the cockpit during the accident sequence. The dominating and initiating cause factors in the period from 1947 to 1996; and 1994 to 2004 are given as human (or unknown) in 74% of the accidents, thus there is a need to have more detailed cockpit information recordings.

The Manwaring et al. study [37] of external load accidents in Alaska found that human error by pilot or other flight crew accounted for 44% of accidents, whereas 38% of the accidents could be attributed to mechanical failures.

The De Voogt [38] comparison of aerial application flights and external load flights shows that 44% of the aerial application flights were caused by human error, and that prefight conditions, mostly pilot errors, caused 21% of the accidents. 23% of the accidents were caused by mechanical failure, mainly caused by maintenance personnel. 40% accidents during external loads occurred due to mechanical failure

A study of helicopter operation in Poland by Gałązkowski et al. [39], gives a different distribution between "technical" and "human" conditions. Gałązkowski et al. [39] found that that 59% of the accidents were caused by technical conditions. This is more in line with an offshore helicopter study of 100 accident reports, CAP1145 [34]. The first step was to focus on offshore (i.e., 50 accidents) and then focus on technical events (in 30 accidents). They found that the primary causal factor in 83% of these selected "technical" accidents were related to helicopter design issues. It was also pointed out that the root cause of three of the five most recent UK North Sea helicopter accidents has been the failure of critical parts in the gearbox.

As a special case from the US military at the 2010 International Helicopter Safety Symposium [40], stated that both the rotorcraft loss rates and fatality rates are far too high. The majority of US military helicopter losses can be attributed to mishaps, not to combat hostile actions, with human factors and engine/power train failures being the leading causes.

Rao and Marais [20] identified 366 occurrence chains, resulting in 5051 accidents between 1982 and 2008. The occurrence chain "loss of control-inflight" resulted in most accidents and the highest cost impact. Three of the top five occurrence chains that resulted in serious accidents involved engine failures, thus supporting the focus on critical components.

Several international analyses of onshore helicopter operations have been conducted to identify contributing causes for helicopter crashes. Among these there are some studies that address external factors such as flight conditions [26,38,41,42], and the location/area of the accident [41,43,44].

Studies show that helicopter crashes also are associated with a broad set of organizational conditions such as the age of the pilot [41], pilot experience [41,43], pre-flight error [38], including improper or inadequate maintenance [37], lack of information regarding weather [8] and equipment and resources [43,45].

In a study from Alaska [41] found that the age of the pilot, pilot experience, use of seat belts, weather conditions, fire following the accidents, and the residential address of the pilot (pilot with local knowledge or not) influence whether an accident will result in fatalities or not.

Baker et al. [26] review US helicopter EMS accidents in the period 1983 to 2005 and found that 68% of all fatal crashes occurred during darkness. Severe weather also increased the probability of fatalities.

An analysis of both helicopter and fixed wing accidents in Alaska [42], shows that severe weather increases the probability of fatalities by a factor of 5.3. Adverse weather and darkness were found to be factors that increase the probability of a fatal accident.

Iseler and Maio [43] found that reduced situational awareness, and the skill level of the pilot are associated with accidents, together with flights in uncontrolled airspace. They also found that more accidents occur with cheaper helicopter types than with more expensive types. This finding is interpreted as a consequence of a relationship between price and the quality/extent of equipment.

In a study conducted in New Zealand [8], show that deficient weather briefing, conditions at the accident site, and type of operations (passenger-PAX operations, or not) influence the probability of personal injuries.

A similar study [45] found that inappropriate flight selection, inadequate equipment and limited resources are dominating contributory causes in helicopter accidents.

In summary, we have seen a broad set of causes, technical, organizational and human factors in accidents. The following key issues have been highlighted: flight conditions (weather, darkness); "unsafe acts" by pilots; competence level of pilots (age and experience); extent of equipment and resources (navigation instruments, monitoring systems), and technical conditions (helicopter design and mechanical failures of critical components).

3.3. Measures

In [36], the main safety protections levels are:

(1) Certification of the equipment and the pilot; the pilot should be certified through systematic training;

(2) Redundancy of equipment, auto-rotational capacity or other resilient capabilities (or if this is not possible—preventive maintenance such as health and usage monitoring systems (HUMS);

(3) Protection of occupants through crash survival features (airbags; fire inhabitancies; better seats and belts, protective clothing).

Baker et al. [26] presented mitigations, such as improvement of crashworthiness of helicopters (crash resistant fuel systems) and improved standards for the certification of helicopters. Within the oil and gas industry the operators from the industry have improved safety by several measures [19]. One is improved operational standards i.e., helicopter operations monitoring program (HOMP). Airframe system failures have been identified as key causes. There is a need to continuously monitor the quality of safety critical components, avoid single point of failures (such as failure of the engine, power train or gearbox) and build resilience (i.e., build redundancy, error tolerance, ability to recover and advance notification of impending problems). By exploring known accidents and assessing mitigating measures improvements could be achieved through: (1) Improved design requirements and enhanced handling qualities; (2) Enhanced training; (3) Operational control and quality assurance; (4) HUMS; (5) HOMP; (6) Enhanced ground proximity warning system (EGPWS), ref [19].

HUMS could prevent 65% of all rotor/train drive failures, [19]. According to [46], HUMS has generated significant safety benefits. However, the reliability of HUMS is dependent on organizational factors. In an initial phase of HUMS usage, there were 200 false positives [47], thus the systems were difficult to trust and use. The ability to improve the system in use will need a combination of operational experience and research knowledge. The HUMS effort (i.e., design, implementation, regulation/rules, and use/procedures) needs considerable effort to improve the reliability and diagnostic ability [47]. This challenges several bodies: the regulator, the customer, the helicopter operator and the equipment manufacturer.

The study of accidents reported in CAP1145 [34], identified that the primary causal factor in 83% of the selected accidents (30 accidents of the 50 accidents offshore) was related to helicopter design. The poor safety of helicopters vs. fixed wing has been a recurring theme in some of the reports and articles discussing helicopter safety (i.e. [19,34,36]). The design of fixed wing airplanes has been continuously improved in comparison with helicopters.

Based on their study of US civil rotorcraft accidents from 1990 to 1996, Iseler and De Maio [43] recommend that pilot training should be improved. De Voogt et al. [38] argue that the training of pilots should include all actors (i.e., crew and maintenance) involved in high-risk helicopter operations. Manwaring et al. [37] use experience from Alaska to claim that compliance with existing regulations and recommendations from helicopter manufacturers, enhanced training programs and frequent maintenance has resulted in fewer casualties and damage.

The industry could also use modern technology to avoid or mitigate risks. As an example—by using lightweight unmanned drones in some of the aerial operations, (i.e., surveillance, line inspection, livestock/reindeer counting ref. [48]), the risk of causalities will be reduced.

To get the benefits of measures and achieve risk reduction, pilot training and certification must be improved in addition to the improvement of technical reliability of key components. New technology such as HUMS must be implemented by continuous learning and the evolvement of rules, regulations and practice. Thus, measures and mitigating actions must be developed in the context of the socio-technical system, which involves stakeholders, technology, rules and the procedures to reduce the risks.

4. Comparisons of Norwegian Offshore and Onshore Helicopter Transportation

In the following section, we have documented the findings from our comparative analysis of offshore and onshore helicopter transportation in Norway based on the structure of the socio-technical perspective presented earlier:

(1) Types of operations offshore and onshore
(2) Accident frequencies and description of two fatal accidents
(3) Regulators

(4) Companies, training and employment conditions
(5) Work organization and support related to technology, pilots and crew
(6) Implementation of risk-reducing measures

4.1. Type of Operations Offshore and Onshore

Offshore helicopter transportation is divided into three areas: (1) Transport service between onshore bases and offshore installations; (2) Shuttle traffic between installations; and (3) Search and rescue (SAR) operations.

Onshore helicopter operations in Norway are diverse; the main segments are: (1) Ambulance and police operations (Amb/Pol); and (2) Aerial work (AW), passenger transportation (PAX) and non-commercial activity. Military helicopter operations are not included. The AW/PAX operations are divided into a variety of operations. NCCA operate with 9 subcategories:

(1) Charter (Passenger flight from A to B)
(2) Taxi-flight (Passenger flight from A to B)
(3) Other passenger flight (Passenger flight from A to A)
(4) Ambulance/Helicopter Emergency Medical Service (HEMS)
(5) Educational and training flights
(6) Surveillance (Line inspection/top control/ . . . , etc.
(7) Aerial Work—AW (including all flights with external loads)
(8) Cargo transportation (Cargo inside the helicopter)
(9) Transfer/technical flights

The total number of flight hours is presented in Figure 2, showing that the flight hours offshore and onshore are of the same order of magnitude. The annual number of flight hours offshore has increased from 42,753 h in 1999 to 56,747 h in 2012. The shuttle traffic between the installations accounts for 12% of the total flight hours. Thus, the flight hours of offshore and onshore transportation dominate. Flight hours in AW/PAX have increased since 2000.

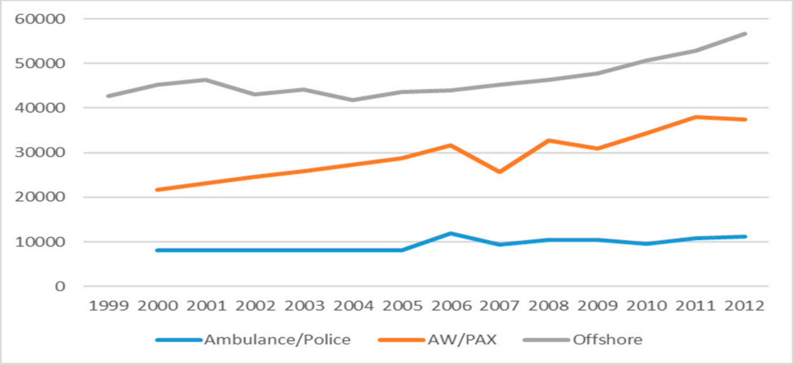

Figure 2. Yearly flight hours—offshore and onshore.

4.2. Accident Frequencies and Description of Two Fatal Accidents

The number of accidents per million flight hours in offshore helicopter transportation dropped from 11.2 in 1990–1998 to 2.8 in 1999–2008. The number of fatal accidents per million flight hours for offshore helicopters from 1990 through 1998 was 2.8, and 0 from 1998 until 2008.

Onshore, there were 39 accidents in AW/PAX operations from 2000 through 2012 (Table 3), giving an accident rate of 101.9 accidents per million flight hours. Seven of these accidents were fatal, resulting in 18.3 fatal accidents per million flight hours for AW/PAX.

Table 3. Accident records and flight hours.

Description	Offshore 1990–1998	Offshore 1999–2008	Amb./Police 2000–2012	AW/PAX 2000–2012
Number of accidents	4	1	2	39
Helicopter crash	1	0	0	23
Accidents with personal injuries	1	0	1	20
Fatal accidents	1	0	0	7
Fatalities	12	0	0	16
Flight hours	355760	442764	122052	382452
Fatal acc. rate per million flight hours	2.8	0	0	18.3

When calculating accident frequencies, it is apparent that the PAX operations and other flights (technical transfers etc.) are accident-prone activities. The offshore accident rate has been significantly lower.

During the same period, there were two accidents in ambulance and police operations (Table 3), giving an accident rate of 16.3. None of the accidents was fatal.

4.2.1. Characteristics of the Accidents

In the 20 years from 1997 to 2016 there have been two fatal accidents in offshore helicopter transportation: one in November 1997 (the Norne accident) with 12 fatalities, and one in April 2016 (the Turøya accident) with 13 fatalities.

The Norne accident occurred with a Super Puma AS332L-1; see the Aircraft Accident Investigation Board Norway [49]. The accident was due to fatigue cracking in the right-hand input shaft pin in the main gearbox of the helicopter. This component transfers power from the right-hand engine to the rotor-head. The Turøya accident occurred with a Eurocopter EC225 Super Puma, and preliminary findings from AIBN were that the accident was most likely a result of a fatigue fracture in one of the eight second-stage planet gears in the gearbox, [50].

Thus, the two latest significant offshore accidents were due to mechanical failures of the gearbox. CAP1145 [34] pointed out that the root cause of three of the last five UK North Sea helicopter accidents were failure of critical parts in the gearbox. The focus on technical reliability (especially of the gearbox) was highlighted in [1]. Additional factors were increased focus on the collection and utilization of performance data and further development of HUMS. In 2016, which is 26 years after this focus on technical reliability in [1], it is relevant to ask if the design of the gearbox and operational procedures (as HUMS) has increased the resilience and reliability of the helicopter fleet? Technical reliability needs to be improved by focusing more on the design of technical components, and increase research on preventive maintenance of critical component such as the gearbox.

Analysis of the accidents in onshore helicopter transportation from 2000 through 2012, shows that 30.8% ($N = 12$) of the accidents occurred in relation to departure or landing. The rest, 69.2% ($N = 27$), occurred en-route [51]. A review of the historical accidents by use of Human Factors Analysis and Classification System (HFACS) [7] found that in 67% of all accidents, one or several “unsafe acts” contributed to the accident [51].

A binary logistic regression analysis and correspondence analysis of incident data has been performed to identify causes of helicopter crashes [51]. The results are that helicopter crashes, compared to other accident types, were associated with: PAX operations; severe weather conditions; loss of control in the air (“loss of control in flight” LOC-I); inadequate planning; pilot’s age (younger pilots were more involved in crashes); pilot’s total number of flight hours (i.e., fewer than 1000 flight hours), and types of operators (small aerial work/PAX, foreign operators, and private pilots).

4.3. Regulators

The Norwegian regulator of helicopter transportation is the Civil Aviation Authority Norway (NCAA). The NCCA has a dedicated section for helicopters with responsibility for case management, regulations and supervision. The regulations are based on the adaptation of standards from the European Union. In the European Economic Area agreement (EEA), Norway is in principle obliged to implement all EU regulations for the aviation sector and have regulations that comply with EU standards as if the country were an EU member state.

The regulation of offshore helicopter transportation is dominated by four main stakeholders: Civil Aviation Authority Norway (NCAA), the Petroleum Safety Authority, Norway (PSA), the Norwegian Oil and Gas Association (NOG), and the Committee for Helicopter Safety (CHS).

Oil and gas production on the Norwegian Continental Shelf is not covered by the EEA agreement. This has led to greater latitude for the Norwegian authorities with regard to regulating offshore helicopter transportation. To have access to the offshore market, each helicopter company must be a Norwegian registered company and have an AOC (air operator certificate) issued by the NCAA. The NCAA conducts supervision of all helicopter operators, since supervisory responsibility belongs to the state that issues the AOC.

(The European Aviation Safety Agency—EASA has developed a set of new common European regulations for helicopter offshore operations—HOFO. However, the Norwegian government will not implement a strict HOFO in Norway [52], but will continue to control regulations based on experience and Norwegian conditions).

The Petroleum Safety Authority, Norway (PSA) has responsibility for the regulation of safety management of helicopter transport used by the oil and gas companies offshore. The Norwegian regulations are mainly function-based and contain few detailed prescriptive requirements; thus, the oil companies have the responsibility to establish detailed guidelines.

A major part of the requirements for Norwegian offshore helicopter operation is the industry standard—NOG 066 [53]—issued by the Norwegian Oil and Gas Association. The standard is used in the formulation of contract requirements between the oil and gas companies (customers) and the helicopter operators (suppliers), and includes both technical and operational requirements. The normal contracts imply long-term agreements (several years), including fixed day rate plus hourly compensation. The contracts set requirements for the technology in use, as well as the qualifications of the crew and the extent of training.

Based on discussions with key stakeholders, the oil and gas industry in Norway perceives itself as the driving force behind helicopter safety. However, there is poor regulatory support.

The development of customer's requirements and regulations has been coordinated though a formalized cooperative safety forum for offshore helicopters, the Committee for Helicopter Safety (CHS). The forum involves representatives from the oil and gas industry (customers), the helicopter operator's employer's associations (suppliers), trade unions (both the union for pilots and unions for employees on offshore installations) and several governmental bodies, such as NCAA, PSA, and Avinor—air traffic control and air navigation services. CHS is responsible for following up the developments in offshore helicopter safety and works to ensure continuous improvement of helicopter transport safety. The participation in the forum is voluntary. However, by not participating, actors may risk a negative reputation. CHS checks that the contracts between customers and suppliers are standardized to ensure that safety standards are not compromised.

The main regulatory stakeholders in onshore helicopter operations are the NCAA, the customers and the Flight Safety Forum inland helicopter (FSF).

Onshore cargo and passenger transportation was until 2014 regulated by European regulations JAR OPS 3, which was replaced by EASA-OPS from 2014. The onshore aerial work was until 2016 based on Norwegian regulations, and was replaced by annex VIII Part-SPO, of the EASA-OPS. One change is that new operators do not have to be approved by the national authorities, it is sufficient to have a declaration from the company, and the national authority of that company then has the responsibility to supervise. Another change was that the organizational requirements were reduced for operators of the transportation of passengers. The onshore helicopter market has not been limited to Norwegian operators. The permit is based on applications where the company demonstrates compliance with the regulations used in Norway. With the new EASA regulations foreign operators will not need to be authorized in the country where operations will take place. Except for "high risk specialized operations", the new EASA-OPS has reduced the NCAA's possibilities to preauthorize foreign operators.

The onshore AW/PAX companies have a wide range of customers, ranging from enterprises to private individuals. The services are predominately based on single assignments, and price is often the most important criterion [2]. Most suppliers, the lowest fee, and lowest margins, are characteristics of where most of the accidents occur, i.e., AW/PAX. The small companies are relatively more dependent on customers in tourism advertising and events, compared to the medium and large helicopter companies.

The ambulance/police segment is special in terms of customers. The police operator is an integrated part of the police agency. The ambulance helicopter has only one customer, a public company responsible for contracting air transportation on behalf of the national public health enterprises. The normal contracts imply long-term agreements (several years) and fixed day rates. Additional requirements include the level of training among crew members.

Inspired by success of CHS within offshore helicopter transportation, a similar formalized forum has been established for onshore helicopter transportation. This forum, the Flight Safety Forum inland helicopter (FSF), does not involve customers and trade unions but only the helicopter companies and the NCAA. So far, until 2017 this forum has been unable to develop measures that are regarded as compulsory requirements by all operators. They have however developed guidelines for electric power companies to improve their knowledge regarding helicopter safety and promote certain requirements that the customers should include in their contracts. This includes requirements regarding helicopter and equipment, pilot qualifications, employment conditions for crew members, training and the organization of the operator.

When we consider other possible stakeholders that may influence the safety standards within the individual helicopter suppliers (i.e., labor unions, politicians, media and the public), there is also a difference between the helicopter operations offshore and onshore. In the offshore helicopter industry, the labor unions (organizing the pilots and organizing the offshore workers) are influential in impacting safety, regulations and guidelines. The onshore AW/PAX helicopter is an industry in which unions are virtually non-existent. When we consider the extent of media attention and coverage, ambulance and offshore helicopter transport has traditionally received a higher media attention than the AW/PAX helicopter operations.

4.4. Companies, Training and Employment Conditions

In the following section, we describe the companies, the training given and employee conditions in Norway based on the organizational components from Figure 1.

4.4.1. Companies (the Suppliers)

Two major companies conduct most of the offshore helicopter transportation on the Norwegian Continental Shelf. These two operators are the largest helicopter companies in Scandinavia. In 2015, one of them had approximately 200 pilots, while the other had about 150. Two other helicopter operators have entered the area, but their activities have been marginal.

Two companies supply the ambulance services. One of them is owned by a non-profit foundation. The commercial ambulance supplier is also a provider of AW/PAX, scheduled flights with helicopters, and offshore transportation of pilots. The police operator is an integrated part of the police agency.

In 2013, onshore AW/PAX operations consisted of 15 companies. These companies must compete with foreign competitors and private non-commercial certified pilots that conduct AW/PAX operations illegally. These private pilots compete especially within film/photo and reindeer herding. Most of the aerial work/PAX companies have had a negative operating profit over the past five years [54]. The competition is significant and the margins are small. PAX operations and reindeer herding are the operations with the lowest hourly rates [54] and with the most helicopter providers.

The accident frequencies are higher among the small AW/PAX companies (less than six helicopters), compared to the medium-sized companies (six to 14 helicopters) and large companies (more than 14 helicopters, i.e., 15 and upwards). (The categorization into three groups was done in collaboration with the onshore safety forum in Norway, based on what they considered to be relevant divisions).

Between 2005 and 2012, the accidents and accidents with personal injuries per million flight hours were twice as high for small vs. large companies (Table 4).

Table 4. Accident frequency with personal injuries per 100 000 flight hours among aerial work/PAX operators of different company size, 2005–2012 (*N* = 17).

Onshore Operations	Accident Frequency
AW/PAX-Large Company	3.44
AW/PAX-Medium Company	4.56
AW/PAX-Small Company	8.22
Ambulance/Police	2.45

4.4.2. Training

Pilots working in offshore transportation receive 12 h of simulator training per year [11]. Requirements regarding training have been introduced by customers and are included in the contracts. The extent of training among ambulance pilots is described and included in the contract. The training has special focus on the interactions among crew members and on non-technical skills, i.e., Crew Resource Management training (CRM) as performed in aviation including teamwork, communication and stress management.

Survey results [55] show that 91% of the ambulance/police pilots say that they receive retraining in the operations they conduct (*N* = 48). (Except for one respondent, all ambulance/police pilots agreed that they have received sufficient training in handling critical situations) (*N* = 45). In comparison, 48% of the AW/PAX pilots agree that they receive retraining if they have not conducted a specific operation for a while (*N* = 97), and 62% of the AW/PAX pilots claimed that they have received sufficient training in handling critical situations (*N* = 95).

Very few of the AW/PAX pilots receive systematic training initiated by the company, or the customer. Pilot training is included by some operators as a part of transfer operations. However, most of the operators have training facilities that make it possible to conduct training on external load operations that imply interaction with personnel outside the helicopter. The quality of this facility varies. The extent of the training, measured in hours is generally limited, and in some companies, the pilots must pay for the use of the helicopters when conducting re-certification [2].

4.4.3. Employment Conditions

Pilots in offshore and police/ambulance operations are generally employed full time. The conditions are quite different in onshore AW/PAX operations. Survey results [55] show that 22% of the pilots employed by the AW/PAX operators work part time. These proportions vary between large, medium and small operators. Only 2% of the pilots employed by the large companies work part time, in small companies 46% have part-time employment.

There is extensive use of freelance pilots in some companies, based on so-called "fly for food" agreements. The helicopter pilots do unpaid work in the company to accumulate flight hours to keep their certificates and document experience towards potential companies offering employment. Further, 27% of the AW/PAX pilots have been temporarily laid off once or several times, and 40% of the pilots employed by AW/PAX have additional employment outside the helicopter company (freelance pilots not included). There is a general view among pilots that the employment conditions are best among the larger operators [2].

4.5. Work Organization and Support Related to Technology, Pilots and Crew

In the following section, we have documented the part of the work organization and support related to technology, pilots and crew.

4.5.1. Work Organization and Support

The offshore operations are based on a two-pilot system, whereas the onshore operations are performed with a single pilot system. The ambulance helicopter consists of 3 people; a pilot, a rescuer and a physician. The rescuer is a trained pilot, and the whole crew undergoes CRM training. Regarding aerial work operations, the crew consists of a pilot and his tow-master. The tow-master is often an inexperienced pilot, who accumulates experience and flight time by conducting the unpaid transfers back and forth from the assignments.

The offshore operations are limited to permanent bases; i.e., onshore heliports with controlled airspace, and helidecks on the offshore installations. Ambulance helicopters and the police helicopters operate from permanent bases, but conduct landings on unprepared landing places. Onshore PAX and AW operations are often operated from temporary bases without administrative service, and with limited standards in terms of landing conditions.

4.5.2. Technology

Twin-engine turbine craft are required for offshore operations. The helicopter fleet is standardized and consists of Sikorsky S-92A and Airbus Helicopters H225 (Eurocopter EC225 Super Puma). The helicopters are equipped for instrument flights, and have extra safety equipment such as flight monitoring systems, HUMS, and Terrain Alert Warning Systems. In 2015, the total fleet of offshore helicopters was 51 craft [56].

The twin-engine turbine is the required helicopter in the police and ambulance services. They are equipped for instrument flights. The total number of craft was 21 in 2012. Five different helicopter types were used. The most common type was Eurocopter 135 (now known as Airbus Helicopters H135)—12 craft, and AgustaWestland AW 139—five craft. The remaining types were Airbus Helicopters AS365 Dauphin, AgustaWestland AW109, and Eurocopter EC145, now known as Airbus Helicopters H145.

Within AW/PAX, twin-engine helicopters are relatively rare. The total helicopter fleet of the 15 AW/PAX companies was 110 craft in 2012. 16 different types were in use. However, 51% of the fleet consisted of different versions of Airbus/Eurocopter 350 single engine. 27% of the fleet were piston engine helicopters, consisting mainly of Robinson 44 and Robinson 22. The AW/PAX helicopters are not equipped for instrument flight, relying on meteorological conditions that permit visual-based flights. Furthermore, the helicopters have less protective equipment (such as floats and/or impact absorption/protection). The average age of the fleet (nine years) is a little higher than within the A/P segment (seven years).

The frequency of accidents with piston engine helicopters—resulting in personal injuries per 100,000 flight hours—is four times as high as the corresponding frequency related to single engine turbine helicopters (Table 5).

Table 5. Frequency of accidents ($N = 39$) and accidents with personal injuries ($N = 18$) per million flight hour by motor type among aerial work/PAX operators, 2000–2012.

Description	Piston Engine	Single Engine	Twin Engine
Accidents	353.5 ($N = 7$)	89.8 ($N = 29$)	75.2 ($N = 3$)
Accidents with personal injuries	101.0 ($N = 2$)	43.4 ($N = 14$)	50.1 ($N = 2$)

4.5.3. Pilots and Crew

The educational background of the helicopter pilots in Norway varies, from the military or civilian flight school in Norway, or civilian flight school abroad (predominately the USA). The military education is considered the most comprehensive and 28% of the pilots in ambulance/police are educated in the military [54]. One pilot among the AW/PAX pilots has a military education. The recruitment process involves use of standardized tests of the candidates.

Working as a pilot in offshore transportation requires a set of EASA certificates:

- CPL H (Commercial Pilot License—to act as a pilot of a commercial aircraft);
- IR (Instrument Rating—to perform instrument-based flight, without visual references);
- ATPL H (Air Transport Pilot License—to act as pilot in command within a two-pilot system).

The companies require a minimum of accumulated flight hours, in Norway this is between 800 and 1000 flight hours. The customers (oil companies) require that the pilot in command has at least 2500 flight hours.

Working as an AW/PAX pilots requires only CPL H.

Ambulance and police pilots are in addition required to have IR and the theory part of ATPL H. The latter is an essential part for improving the interactions between crew members. A survey (with $N = 47$) shows that 55% of the ambulance and police pilots hold a full ATPL H certificate [54]. Minimum flight hours required to be employed as an ambulance pilot is 2000 h of relevant experience as helicopter commander, 200 h of night flying, 100 h of instrument flying and 50 h flying supported by night vision goggles (NVG). For police pilots, the requirements are 1500 h of helicopter flying, 1200 h as commander, 200 h of night flying, 25 h of NVG (with approval). No requirements are set for IR.

In 2012, the average number of total flight hours among ambulance and police pilots was 5647, and the average years of experience was 19. The survey results ($N = 97$) show that 27% of the AW/PAX pilots have IR certificate, and 13% had an ATPL. The average number of flight hours was 3230 h, i.e., 2417 h less than the average among pilots working with Ambulance/Police operations.

The average years of experience among AW/PAX pilots was 10 years. 57% of the AW/PAX pilots had less than eight years of experience. The corresponding percentage among ambulance and police pilots was 8%.

Employment within different sectors of the helicopter industry is closely linked to the career path of the individual pilot. For many pilots, onshore AW/PAX work is an intermediary period to accumulate enough flight hours to get a job in the offshore transportation or ambulance operations.

4.6. Implementation of Risk-Reducing Measures

The oil and gas industry internationally has focused on helicopter transport safety and published normalized accident data in addition to working systematically to understand and reduce the number of accidents in collaboration with the helicopter industry [3]. Several large oil companies have been the driving forces in this effort. Thus, the industry has created arenas and the possibility for continuous learning and improvement. It has been seen that improvement in safety needs engagement from significant actors such as equipment manufacturers, regulators, operators and customers.

In Norway, there are some differences related to identifying risks and implementing risk—reducing measures. The oil and gas industry has focused on technical issues whereas the onshore industry has focused on organizational issues. Measures have been implemented in the oil and gas industry, while the onshore industry lags behind in terms of implementation.

The *Helicopter Safety Study 2* [10], pointed out that the risks were significantly reduced since the first study, with a 50% reduction from period 1 (1966–1990) to period 2 (1990–1998). The risk estimate for Norway and the UK was 1.9 fatalities per million passenger flight hours. The main contributing factors suggested were: implementation of systems to improve technical reliability (implementation of HUMS), improved radar and radio coverage and the separation of flight routes, implementation of quality management standards, implementation of new helicopter types, and improved aircraft crashworthiness.

The *Helicopter Safety Study 3* [11] listed one minor helicopter accident with no fatalities in the Norwegian sector in the period 1999 to 2009. The risk reduction was estimated to be approx. 16% in period 3 (1999–2009) compared to period 2. The main contributing factors were: new helicopter types, use of HUMS, increased pilot skills, improved flight operating procedures, improved helideck design and operation, improved emergency preparedness, introduction of safety management system, establishment of the CHS. The system model used in the safety studies 1, 2 and 3, Hokstad et al. [57], is in line with the system models developed by Nascimento et al. [58]

In the *Safety study onshore helicopters* [2], 41 safety-improvement measures have been evaluated. The measures that are considered to have the greatest effect are those that strengthen the regulation and supervision of the industry and those that aim to increase the professionalism and the accountability of the customers. Other measures that have been assessed to have a significant impact on the safety level deal with organizational matters such as better documentation of competence, more training and wage systems that are independent of day-to-day production.

The differences between offshore and onshore helicopter safety in Norway challenge the importance and effect of regulations versus the focus of the customers and operators on safety. The specific risk-based focus from the oil and gas industry is supported by a risk-based regulation regime in Norway. The same regulations impact both offshore and onshore. Based on discussions with key stakeholders, the oil and gas industry in Norway perceives itself as the driving force behind helicopter safety. As mentioned, there is poor regulatory support.

5. Discussion, Lessons Learned and Conclusions

5.1. Discussion

There have been few peer-reviewed papers discussing helicopter safety based on normalized accident data. However, there has been a clear perception in papers and governmental white papers that helicopter safety can be improved. Thus, it is important to discuss and explore the development of helicopter safety in an international perspective and explore best practice.

The differences in accident rates across the different segments of Norwegian helicopter transportation indicate differences in the safety levels. When we compare the characteristics of the accidents within these different segments, some variations are seen in terms of contributing causes, and in what situations accidents usually occur.

Studies of offshore helicopter operations in Norway conclude that the primary cause for accidents have been related to technical design [1,10,11], whereas studies of onshore helicopter operations show that most of the accidents could be attributed to “human actions” [51]. A trace of this difference between offshore and onshore operations is found by comparing international studies (CAP1145 [34] versus EHEST [35]; Manwaring et al. [37]).

Even though technical reliability has been in focus in offshore helicopter transportation from 1990, the two-latest fatal offshore accidents in Norway (1997 and 2016) were due to mechanical failures of the gearbox. Technical reliability of the gearbox seems a significant root cause of accidents, which indicates a need for increased research and understanding of robust design of these key components and improved preventive maintenance these mechanical components (such as the gearbox). The focus on improvement in design and establishment of more resilient technical equipment seems an under-researched area, and should be explored more thoroughly (i.e., [19,34,36]). The analysis should include an analysis of contributing factors based on a task analytical approach. As an example, an optimal operation of HUMS is dependent on design, organizational issues and human factors. We must obtain a better understanding of how HUMS has supported helicopter safety in the past and how it can improve helicopter safety in the future. Thus, preventive maintenance, i.e., HUMS, should be researched from design through operations.

A common feature of both offshore operations and onshore PAX/AW operations, is that most accidents occur en route and in the work phase [25,51]. Previous studies carried out internationally reveal that these findings are in accordance with some studies [34–36], but also deviate with others. A study of HEMS [27] indicates that most accidents occur during landing; however, this should be expected since HEMS must adapt to many different landing conditions based on emergencies and is a high hazard area.

The finding that helicopter accidents within Norwegian onshore are associated with severe weather conditions [51] is in line with several similar studies [26,38,41].

When we consider the task/operation in Norwegian offshore, onshore police/ambulance, and onshore PAX/AW, the differences in accident rates and causes may be attributed to the varying operations that have different levels of hazards. However, the operation type with the highest accident rate in onshore PAX/AW is PAX, i.e., the operations that are most similar to operations in the other two segments in terms of task and hazards. This indicates that the differences associated with the type of operation are not an adequate explanation.

The differences in accident frequencies and the characteristics of the accidents may reflect the variation in work organization/operative support, including technology and crew. The observation that “unsafe acts” by crew members seems to dominate in onshore PAX/AW segment and that technological failure seems to be the typical for offshore accidents, could be related to the single pilot and two pilot systems. The differences in accident rates between onshore ambulance and AW/PAX, which both operate with a single pilot system, indicate that this explanation is not sufficient.

When we include the differences, such as type of airspace (controlled or non-controlled), permanent vs. temporary bases, extent of administrative support, and instrument flight vs. visual flight, this may contribute to explain the variation in accident rates. Further, the differences in terms of the pilot experience, combined with technological differences related to available navigational equipment and monitoring system (such as use of HUMS within offshore helicopter transportation) may contribute to explain the difference in both accident rates and primary causes related to the accidents. These findings are congruent with some of the findings of [41,43,45,59].

A comparison on the company level reveals differences between the segments in terms of training, and employment conditions. Pilot training is limited within the onshore PAX AW segment, compared to offshore and ambulance/police. This variation may contribute to differences in the probability of “unsafe acts”. A hallmark of the employment condition in onshore PAX/AW is a rather extensive use of temporary or single mission contracts, which link pilot revenues (salaries and accumulated flight hours) to the mission accomplishment. This condition may influence a pilot’s self-evaluation about whether he or she is fit for flight. Within the offshore segment, permanent employment contacts have been the standard. Further, the employment conditions within onshore PAX/AW implies cases of rather a “tight coupling” between pilot revenues (salary and flight hours) and mission accomplishment, which one may assume can influence both pilot’s decision-making and fatigue management, enhancing the probability of unsafe acts.

There is variation between small and large onshore PAX/AW companies when it comes to working conditions, type of operations and the extent of administrative support. These differences may explain the observed variation in accident rates between small and large operators. The arrangement where the salary is dependent on the pilot’s decisions regarding the carry out the assigned flights or not, and so-called “fly for food” agreements, may function as an incentive to increase the risk willingness.

In general, the profitability in onshore PAX/AW is low compared to the other segments. Fewer financial resources are available to areas and conditions that influence safety (extent of training, employment conditions, administrative support, technology in use etc.). These findings may be congruent with those of Iseler and De Maio [43], and Habib et al. [45].

The variations we observe on the company level, across the segments, may partly be a response to the variation in regulatory stakeholders.

There is a difference between the customers in AW PAX, A/P and offshore helicopter transportation in both ability and willingness to pay. Another difference is the duration of the contracts, and the extent of customers' additional safety requirements. These variations may contribute to differences between the segments in terms of willingness to pay for safety-improving measures. Customers of offshore helicopter transportations have financial resources, and have been more willing to follow up on mitigating actions and to pay for improved flying conditions that are assumed to influence the safety level. The formalized cooperative safety forum for offshore helicopters (CHS) seems to have functioned as a binding agency for learning, improvement and alignment among the oil and gas companies.

PAX/AW onshore helicopter suppliers do not have the same demanding customers as offshore, or market conditions that support such customers. They compete on price, and use cost-cutting strategies that may influence the safety level in their operations. The Safety Committee for Onshore Helicopter operations in Norway so far has not been as efficient in improving the safety levels within their segment of the industry as the CHS. One explanation for this might be that the Safety Committee for Onshore Helicopter operations only includes the suppliers and authorities. The interests of the customers, the pilots and the passengers are not represented as stakeholders in this forum, as they are in the CHS. The limited involvement of the customers, may contribute to less willingness to implement cost-driving safety measures among the suppliers.

The variation in the extent of safety requirements set by the customers may also be related to the degree in which the customers are made accountable for helicopter operations. This accountability may function as an incentive to increase the willingness to pay for safer helicopter services.

The same extent of accountability enhancing conditions is not present in the onshore AW and PAX segment of the helicopter industry. Imposing requirements increases the costs for the customer, and it is reasonable to assume that their willingness and ability to pay will have an impact on the extent of requirements suggested and implemented.

The regulations set by the NCAA have not been specific, neither in onshore nor offshore helicopter transportation, and it has largely been left to the industry itself to find solutions to promote safety. When we look at the CHS, it seems that the offshore industry has been oriented towards continuous improvement and learning. The strong focus on safety, the responsibility/accountability combined with few detailed regulations from the authorities, seems to have had a stimulating effect on learning and improvement.

In onshore helicopter transportation, where the actors have fewer resources than offshore and the accountability of the customers is weak, more detailed (minimum prescriptive) regulations from the authorities and more proactive focus/inspections/learning focus from the regulatory authorities seems to be needed. An alternative strategy is making the major customers more accountable for the safety results through intervention from the regulatory authorities. This could be supported by a formalized arena for learning and improvement, such as that established in Norway and the UK for offshore helicopter transport, where equipment manufacturers, pilots, regulators, trade unions and customers work together.

5.2. Conclusions and Lesson Learned

In this paper, we have conducted a comparative analysis between Norwegian offshore and onshore/onshore helicopter operation, using relevant international research as a reference. In our research, we have used an analytical framework based on the socio-technical model of safety management originally developed by Rasmussen [4]. The overall aim has been to develop some hypotheses regarding contributory factors to fatal helicopter accidents.

The analysis shows that there are significant differences between offshore and onshore helicopter transportation, which may explain the difference in accident rates. Partly in line with previous research, our comparative analysis indicates that pertinent factors include flight conditions (weather), type of airspace, type of flight (visual or instrument), "unsafe acts" by pilots (including inadequate planning), competence level among pilots (instrument rating, age and experience), and technical conditions (helicopter design and mechanical failures of critical components). Further, our analysis indicates that these conditions may be influenced by more "blunt end" conditions such as wage systems, working conditions, administrative support, size of the helicopter company, profitability within the industry, safety requirements in contracts, safety focus and accountability of the customers.

Systematic work on offshore helicopter safety in Norway has been conducted since 1990. This has had a significant impact on the organization, guidelines, technology and awareness of safety in offshore helicopter transportation. The offshore customers have knowledge, focus on the major risks, financial resources and willingness to pay to move the industry in a direction that has increased safety significantly. Similar collaboration and improvement processes have not been undertaken in the onshore helicopter industry, which is characterized by different customer groups with varying financial resources, less willingness to pay and less knowledge of helicopter operations than offshore.

Learning from the oil and gas industry and the North Sea, one of the main issues is to focus on helicopter safety and work together with industry operators, equipment manufacturers, regulators and the customer base. Despite a lack of detailed regulations by the authorities, operators, equipment manufacturers, regulators, trade unions and customers have systematically documented causes and implemented mitigating actions. The combination of a lack of detailed regulations and the safety focus of the customers has contributed to continuous safety improvements rather than just being in compliance with regulations set by the authorities. Significant improvements in safety can be achieved by working more proactively with helicopter safety research and studies. Building safety and resilience from the design stage through operations is an under-researched area that should be prioritized in the future.

5.3. Recommendations

In our view, there is an opportunity to improve helicopter safety through organizational issues, design, maintenance of critical components and key operational factors. To focus on safety, we suggest that the government and industry establish goals for the accident levels. (A reasonable goal is that the industry could reduce the accident level to less than one fatal accident per million flight hours, a goal that should be attainable by the right incentives and regulation).

In the following we have summarized our recommendations:

- Improve reporting of normalized accident and incident data, and get a richer set of data to understand accidents (through recording of more sensor data, and extended data such as video recordings of pilots in the cockpit in collaboration/agreement with the pilots).
- More focus on improved design of critical components in helicopters, supporting resilience and ability to identify necessary maintenance before breakdown. New technology such as HUMS must be implemented by continuous learning and the evolvement of rules, regulation and practice. (This can be done in the offshore helicopter segment; however, the cost outside this segment may be prohibitive).
- Use of modern technology to avoid or mitigate risks (such as lightweight unmanned drones to conduct relevant aerial operations).
- Improvement of pilot training and certification.
- Avoid employment conditions that imply that pilot revenues (salaries and accumulated flight hours) are dependent on their decisions to accomplish assigned flights.

- Customers should be made more accountable for helicopter operations. This may function as an incentive to increase their willingness contribute to develop safer helicopter services.
- Focus on helicopter safety through organizational structures, such as the Committee for Helicopter Safety (CHS). We have seen that helicopter safety has been improved through collaboration between industry operators, equipment manufacturers, regulators and the customer base, based on systematic documentation of causes and agreement to implement mitigating actions.

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