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Examining the most accident-prone sector within commercial aviation: Why do accidents with light inland helicopters occur, and how can we improve safety?

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ABSTRACT

Light inland helicopter has for several years been the most accident-prone sector within commercial aviation, with a more than 10 times higher accident risk than offshore helicopters. The main aims of this article are to: 1) Examine why accidents with light inland helicopters occur, focusing especially on the situation in Norway, but also internationally and 2) discuss how these accidents can be prevented. These questions are examined based on three data sources: 1) Analysis of reports from the Accident Investigation Board Norway (AIBN), 2) Qualitative expert interviews, and 3) Systematic literature review. Most of the reviewed studies point to combinations of human errors and technical failures as the major risk factors contributing to helicopter accidents. Our analysis contributes to existing research by also indicating the critical importance of work-related factors like inadequate safety management systems, poor safety culture and challenging framework conditions for pilot behaviour and safety. The literature review indicates a lack of robustly evaluated helicopter safety interventions to address the identified risk factors. Our analysis of the AIBN reports and the interviews indicates a need for measures aiming to improve the safety culture in a sector with challenging framework conditions. Measures focusing on the development of self-imposed and commonly accepted operational limits and guidelines in the sector are discussed.

1. Introduction

1.1. Background and aims

Light inland helicopter has for several years been considered to be the most accident-prone sector within commercial aviation internationally (Iseler and De Maio, 2001 and in Norway (Bye et al., 2013). A quantitative risk analysis conducted in 2013 on Norwegian public and commercial inland helicopter operations showed that one could expect two light inland helicopter crashes per year, with a probability of more than 50% of at least one fatality during the course of the year (Bye et al., 2013).

The Norwegian records from 2010 to 2019, show that there were 5 fatal accidents involving public and commercial operators, with a total of 19 fatalities. In addition, there were two fatal accidents (10 fatalities) involving foreign companies operating in Norway and one accident related to private flights (2 fatalities).

Although these absolute numbers are low compared with other transport sectors, they reflect an accident risk which is high compared with other forms of air transport. Research from the US indicates that helicopters are ten times more likely to have accidents than airliners (Iseler and De Maio, 2001). Subagia et al. (2020) notes that the fatal accident rate of civilian helicopters in the U.S. is about 17 times higher than the fatal accident rates of passenger cars, and that it has shown little or no progress from 2010 to 2020. Moreover, they also conclude that helicopter accidents have not received the same level of attention, or thoroughness in the safety literature as accidents in other high-risk sectors, such as chemical plants, the oil and gas sector, or airline industries.

There are also considerable differences between the risk levels of

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different types of helicopter transport. Inland helicopters have for instance more than 10 times higher risk than that of offshore helicopters operating to and from installations on the continental shelf, when we compare the number of fatal accidents per flight-hour (Bye et al., 2013, 2018). Previous research on light inland helicopters in Norway has shown that ambulance operators have the lowest accident risk, with 1.2 accidents per 100 000 flight hours compared to 3.3 for all inland helicopter operators (Nævestad et al., 2015). These differences in risk indicates that it is possible to reduce the risk in inland helicopter operations substantially, by examining practices in other subsectors and research about effective measures to improve safety.

The main aims of the article are therefore to: 1) Examine why accidents with light inland helicopters occur, focusing especially on the situation in Norway, but also internationally and 2) discuss how these accidents can be prevented. In the present article, we fulfil these aims by examining three different data sources: 1) Detailed reports from the Accident Investigation Board Norway (AIBN), 2) Qualitative interviews with sector experts and a 3) Systematic literature review of international research.

To improve the safety level within inland helicopters, it is important to develop a clear understanding of the safety challenges in the sector, and the potential measures that can be implemented to mitigate these challenges. Our study is important, as studies of helicopter safety often seem to focus on helicopter emergency services (HEMS) and offshore helicopters, which have a far lower risk than light inland helicopters (Bye et al., 2018). With some important exceptions (e.g. Manwaring et al., 1998; De Voogt et al., 2009), there are few other studies focusing specifically on light inland helicopter, even though this is the subsector with the highest accident risk.

1.2. Domestic helicopter operations in Norway

Domestic helicopter activities in Norway are run by 18 different operators with the approval of the Norwegian Civil Aviation Authority (NCAA). Three of these operators primarily perform ambulance missions and police helicopter service. The rest are commercial companies performing aerial work (AW) and passenger transportation (PAX) related to a wide range of activities. In addition to the 15 Norwegian AW/PAX companies, some foreign companies (mainly Swedish) operate in Norway. The total Norwegian fleet among the AOC holders in 2012 was 131 helicopters (Bye et al., 2013). The most used types of helicopter among AW/PAX companies are the Eurocopter AS 350 (51%) and the Robinson R44 (20%). Domestic helicopter operations are conducted with single pilots. With the exception of ambulance operations, the flights are carried out without the use of instruments.

Among the 18 accidents involving AW/PAX companies during the last 10 years, 13 of them are classified as Loss of control (LOC-I), external load events (EXTL) or turbulence related (TURB). Only two of them are classified as power plant failure or malfunctions.

2. Methodological approach

We employ three methods to answer our research questions on why light inland helicopter accidents occur, and how they can be prevented.

2.1. Analysis of accident reports

2.1.1. Analyses of accidents

The AIBN is a public committee of inquiry. The purpose of AIBN investigations is to clarify the sequence of events and factors which are assumed to be of importance for the prevention of transport accidents, and it shall not apportion blame or liability. The AIBN investigates all accidents and incidents in aviation in accordance with ICAO Annex 13, and was established in 1989.

Our review is based on published reports from the Accident Investigation Board Norway. All reports concerning accidents and incidents taking place between 01.01.2009 and 01.01.2018 published by January 2018 have been included in the analysis. The total number of included reports is twenty-nine. Private flights are excluded, as these do not involve organisations. Offshore helicopters are also excluded, as these have 10 times lower risk, and are subject to stricter regulation when it comes to motors, equipment and pilot training.

AIBN reports are generally comprised of the following sections: 1) One-page summary with information (key words) about the helicopter, the location, the weather, light conditions, the pilot etc., 2) Factual information (e.g. three pages), with a neutral description of the incident, including the events leading up to it, with maps, pictures etc. 3) "Assessment of the AIBN" (e.g. one to four pages), where the AIBN provides their view of why the accident or the incident happened and often hints about how it could have been prevented, 4) Recommendations provided as bullet points (not always provided). 5) Annexes with technical information, rules etc. (not always provided). For all reports, we reviewed the discussions, conclusions, and recommendations.

To avoid assuming causal relationships between factors, we use the term "risk factor", rather than the term "cause" to describe why accidents occur. Thus, risk factors denote correlations, or factors that often are related to actors involved in accidents. Analysing the AIBN reports, we separate between five analytical categories (cf. Table 1).

Risk factors are divided into factors associated with: 1) pilots, e.g. risky behaviour, training, experience, age, 2) technology/helicopter, 3) work-related risk factors, 4) risk factors related to framework conditions and 5) situational risk factors.

Work-related risk factors refer to all factors that are influenced by the work-related context surrounding the transport operators, and which may in turn influence transport safety. These can be traced back to management and organization (e.g. safety management systems and safety culture), but also more general factors which are usually not associated with HSE, e.g. pay systems, work scheduling systems, type of contact with transport buyers and customers. Safety culture refers to the informal aspects of safety, denoting shared and safety relevant ways of thinking and acting in organisations. Safety management systems refers to formal aspects of safety, represented by e.g. formal risk assessments, training, procedures etc. We also refer to framework conditions, which are factors external to the organization, e.g. rules and regulation, competition in the sector, type of (sub)sector etc. (cf. Bjørnskau and Longva, 2009). We use the term situational risk factors to refer to common characteristics of the situations in which the accidents or the injuries occurred, e.g. activities, work, accident type. The analytical framework used for the identification of risk factors at different analytical level is based on, and develops further analytical models of relationships from Bjørnskau and Longva (2009) and Nævestad et al. (2015).

The information in the reports is not coded; the language is relatively straightforward, and the reports are short, to make the reports easily accessible to the public and the involved parties. The wording of conclusions and recommendations varies between reports, so that frequently a "factor" in our analysis, is constructed out of what we deem to be sufficiently similar cases that are referred to under different names in the individual reports. Also, in some cases, a number of different factors are grouped together under a single heading in this study, so that, for instance, lack of seatbelts and lack of helmets will both be "lack of safety equipment". Whether two different problems discussed in

Table 1
The risk factors we have used when analysing the AIBN reports.

Risk factors	Examples
1) Pilots	Risky behaviour, lacking experience
2) Helicopter/technology	Engine failure, insufficient power, design
3) Work related risk factors	Stress, lacking risk assessments
4) Framework conditions	Strong competition, inadequate regulation
5) Situational risk factors	Type of operation, weather.

separate reports are in fact two different instances of the "same" factor, is thus a judgment made by the authors during the analysis. As the information in the reports is not coded (i.e. using standardized concepts to refer to risk factors), the authors did this coding based on analytical categories and definitions developed for the purpose of this project. Three researchers were involved in this process, and each categorization involved at least two researchers. The researchers worked independently, and later checked for agreement and discussed discrepancies.

2.1.2. Analysis of recommendations

Based on the analyses of the accidents, several AIBN reports issue official recommendations, focusing on preventing the relevant risk factor(s). If relevant preventative measures have not been mentioned in previous reports, they are often mentioned in a separate section termed "Recommendations of the AIBN". However, far from all of the reports include official recommended measures. If the AIBN has suggested measures against the risk factor(s) in previous reports, they will generally not repeat their recommendations. Most reports nevertheless discuss relevant measures informally, in the final section "The assessments of the AIBN". Here, the AIBN sums up their view on the different factors that contributed to the accident/incident, and they often suggest preventive measures that could have prevented the accident. We take the analytical categories in Table 1 as out point of departure in our classifications of measures.

2.2. Qualitative research interviews

We have conducted qualitative interviews with five sector experts to gain knowledge on the aims of the study. The interviews were conducted as part of a larger project focusing on work related accidents in transport, which also focused on light inland helicopters (cf. Nævestad et al., 2015). Interviewees were selected from key agencies working with safety in light inland helicopter operations.

The interviews were generally conducted by telephone and lasted between one and one and a half hours. We used a semi structured interview guide, which focused on the following themes:

(1) Background information about the interviewees' work
(2) Registration of, and overview of helicopter accidents
(3) Registration of, and overview of risk factors in the accidents
(4) Views on responsibilities related to the occurrence and prevention of accidents
(5) Current, past (and potential future) measures aiming to prevent accidents
(6) Views on efforts to prevent work-related accidents in companies

Two of the researchers conducted the interviews, which were not recorded. Instead both researchers took notes during the interviews. Afterwards, they discussed the main points and impressions and developed a summary of the interviews, based on the notes. These summaries were analysed using a thematic analysis looking for common views and/or individual opinions on point 2–6 above (Miles and Huberman, 1994). Presenting the data in the present paper, we focus more generally on the interviewees' views on why accidents occur and how they should be prevented. This analysis was both deductive, as it was based on the themes in the interview guide (point 2–6) and inductive, as several new themes came up (Welsh, 2002).

2.3. Literature review

The purpose of the review was to identify and analyse empirical studies focusing on why helicopter accidents occur and studies discussing how these accidents can be prevented. The results of the review are recorded according to the guidelines of the Preferred Reporting Items for Systematic reviews and Meta-Analyses (Moher et al., 2009).

2.3.1. Search strategy and search words

The searches were conducted in November 2018, in Science Direct (SD) and ISI web of science (ISI). In the first search, aiming to identify studies to help us examine why accidents with light inland helicopters occur, we used the following combinations of search words: "Helicopter AND (accident* OR incident* OR risk*)". In the second search, focusing on how these accidents can be prevented, we used the following combinations of search words: "safety AND (intervention OR training OR program OR effect OR prevent) AND helicopter". In ScienceDirect, the search words were applied for keyword, title and abstracts. In ISI the searches are based on topic, and our first search resulted in 850 hits. We therefore applied several exclusion criteria to remove irrelevant topics, e.g. acoustics, biotechnology, applied biotechnology, cardiovascular systems.

2.3.2. Selection criteria

When selecting publications to include we used the following criteria:

- Written between 1996 and 2018.
- Written in English or Norwegian.
- Studies identified according to the first aim should be:
  - o Empirical studies of all inland helicopter accidents (of a certain type) occurring in a given place in a given time.
  - o Provide empirically based discussions of risk factors in these accidents.
  - o Provide systematic discussion of risk factors in all the accidents, estimating the general importance of different risk factors.
- Studies identified according to the second aim should be:
  - o Studies describing the results of safety interventions in light inland helicopters (or helicopters in general), or
  - o Well-founded, empirically based recommendation of measures (i.e. not "proto-types").
  - o Not primarily focusing on improving other safety related aspects of the helicopter missions (e.g. improving fire fighters' ability to combat wildfires when operating from helicopters, reducing HEMS medicals' time on the scene).

2.3.3. Screening of studies

Studies fitting these criteria were identified in a two-stage screen. In the first screen of studies relevant to the first aim, we mainly focused on identifying titles of empirical studies of helicopter accidents. In several cases, we also had to read abstracts to collect additional information. A main concern in the second screening of studies relevant to the first aim was to find studies systematically analysing all helicopter accidents occurring in an area within a given period to provide a systematic overview of the risk factors involved.

For the second aim, we first examined titles to find studies generally focusing on measures aimed at improving helicopter safety. A main concern in the second screening of these studies was to find studies providing robust evaluations of relevant measures, e.g. studies with pre and post measurements and control groups. As there were few such studies, the focus was rather on identifying studies providing some kind of empirical test or assessment of relevant measures. We thereby excluded studies merely suggesting, or developing measures.

Results of the screening of the studies are presented in Fig. 1.

2.4. Criteria for comparing the reviewed studies

Reviewing the studies, we used the following points as a checklist:

(I) Name of the authors, year and country.
(II) Method and sample, e.g. studies examining accidents; how many accidents, with what types of helicopters? In what country? For studies of interventions; what kind of design, e.g. pre-post study with control groups?

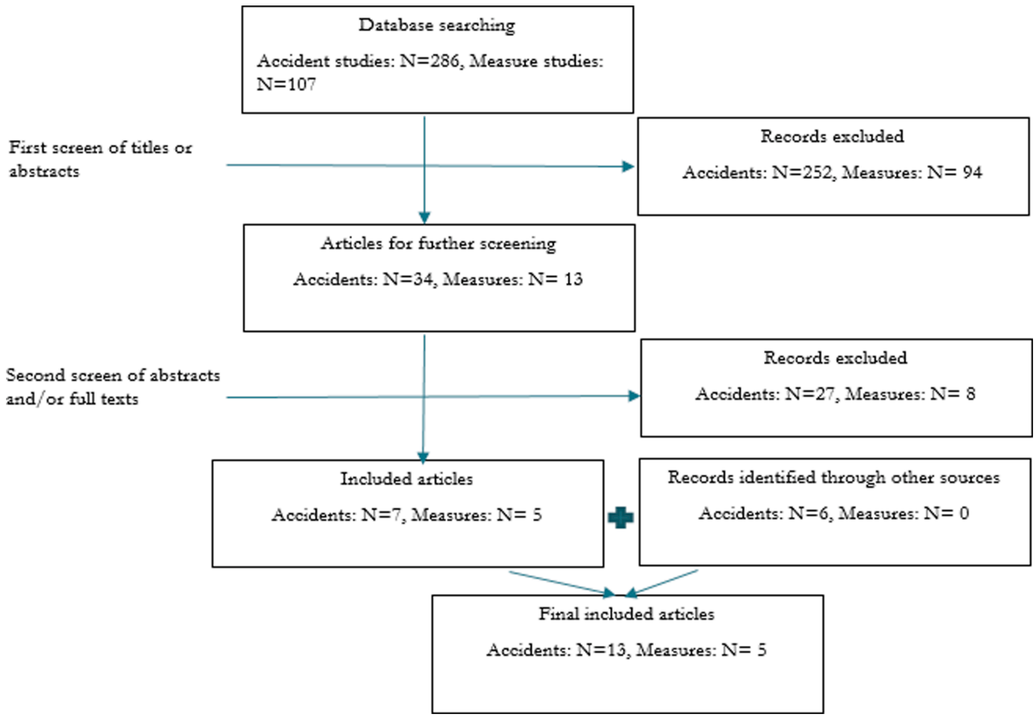

Fig. 1. The numbers of search results and studies screened, assessed and included in the review.

(III) Identified risk factors or measures
(IV) Strengths/weaknesses

3. Results

3.1. Why do accidents happen?

3.1.1. Analysis of accident reports

The analysis of accident reports based on our analysis of the AIBN data is presented in Table 2. The analysis is based on and extends a previous analysis conducted in Nævestad et al. (2015), where the main purpose was to compare the helicopter sector with road and the maritime sector. The present study extends the analysis of AIBN reports with four years, as it also includes 2015–2018, and it includes additional sources of data: qualitative interviews and a literature study.

Although the table includes accidents taking place since 01.01.2009, the first year in the table is 2011, as this is first the year when reports on accidents from these years were published by the AIBN. Thus, the table focuses on the AIBN report year, and not the year the accident occurred.

3.1.1.1. Risk factors related to operators. Risk factors related to operators are identified 25 times in the reports.

Lacking use of /lack of safety equipment. Six reports conclude that the use of various kinds of safety equipment might have prevented or mitigated the effects of accidents or incidents, e.g. shoulder belts or helmets, flight recorders and radio altimeters.

Risky behaviours. Five reports describe accidents involving some kind of risky pilot behaviours. This refers to voluntary risks taken by pilots, such as aggressive manoeuvring, flying too low or too close to physical obstacles. Generally, these are situations in which the physical limits of

Table 2
Published reports from the AIBN, concerning accidents and incidents taking place between 01.01.2009 and 01.01.2018, reports published by January 2018.

	Risk factors	2011	2012	2013	2014	2015	2016	2017	2018	Total
1. Pilot	1.1 Lacking use of/ lack of safety equipment	2	1		2	1				6
	1.2 Risky behaviours		2	1	1		1			5
	1.3 Procedure violations		1	1	1	1	2		1	7
	1.4 Assignment completed in spite of unfavourable conditions	1		1	2					4
	1.5 Lack of experience			2		1				3
2. Helicopter/Technology	2.1 Insufficient engine power under the circumstances	1			1					2
	2.2 Technical failure	1		1	1	1	1			5
3. Work-related factors	3.1 Insufficient risk analysis		1	2	1		1	1		6
	3.2 Insufficient procedures	1	1	3	1	1	2		1	10
	3.3. Insufficient training			1	1	1			1	4
	3.4 Underdeveloped organisational structure			2	1					3
	3.5 Stress/fatigue/workload			2		1				3
	3.6 Communication problems		1	1		3	1	2		8
4. Framework conditions	4.1 Safety culture in the sector	1		1	1					3
	4.2 Poor aviation authority follow-up			1			1			2
	4.3 Insufficient rules	1								1
	4.4 Missing elements in helicopter pilot education	1			1					2
5. Situational factors	5.1 Low altitude		1	2	2	1				6
	5.2 Wind/weather/ darkness		1	2	2					5
	5.3 Reindeer herding		1	1	1					3
	5.4 Errors of others involved	2				1				3

the helicopter are challenged.

Procedure violations are identified as risk factors in seven reports. This applies to situations where the pilots violate principles in the procedures and formal routines of the helicopter operator.

Assignment completed in spite of unfavourable conditions is a risk factor found in four reports. These refer to cases when, in the view of the AIBN, an assignment should have been cancelled as a safety precaution, but was still carried out. This risk factor is sometimes related to reindeer herding, which to some extent require continuous operations. It may also refer to other forms of helicopter operations involving time pressure, or certain expectations from customers, often in combination with bad weather.

Lacking experience. Three reports refer to the pilots' general or situation specific lack of experience as a risk factor, inducing an unreasonably high workload on the pilot, which was not compensated for, e.g. by training. changing pilot, or shortening the work period.

3.1.1.2. Helicopter/Technology. Insufficient engine power under the circumstances. Two reports refer to the risk factor insufficient engine power under the circumstances, which e.g. refers to situations where the pilot has conducted manoeuvres where the power of the engine was insufficient to uphold control over the helicopter, given its mass.

Technical failure. In three reports, technical failure is an important risk factor. This may e.g. be related to errors in the hydraulic system, wear and tear of critical parts, or design issues involving missing bolt-nut fasteners in critical steering equipment.

3.1.1.3. Work-related risk factors. Work-related risk factors are identified 34 times in the reports. A total of 20 of these risk factors are components of what we may refer to as safety management systems, i.e. related to risk assessments, procedures and training.

Insufficient risk assessment. Six AIBN-reports indicate how proper risk assessments could have prevented accidents. This could either refer to the quality of risk assessments or lacking risk assessments. AIBN-reports repeatedly underline the negative safety implications of the fact that helicopter operators were not obliged by law to carry out risk assessments of their operations. Such a requirement was introduced with the implementation of new EASA regulations (EASA Ops) in 2016.

Insufficient procedures. Vague or missing procedures/guidelines are an important factor related to safety management systems that are referred to as a risk factor in 10 reports. For instance, clear - and clearly enforced – guidelines specifying when assignments should be aborted for safety reasons, could counteract the tendency to "push the weather", and complete assignments in spite of unfavourable conditions. Many of the cases of "risky behaviour", for instance cases of aggressive manoeuvring or low flying for the enjoyment of passengers, seem to be reflecting such an underlying lack of strict organisational guidelines, and enforcement.

Insufficient training. There are also examples of lacking training of helicopter pilots in companies that have been involved in crashes. This is especially the case with "freelance pilots" that have a weak relationship with the company. This risk factor is referred to four times in the reports.

Underdeveloped organisational structure. The organisation of the company in question is mentioned as a possible risk factor in three of the reports, referring to a lack of a proper organisational structure.

Stress, fatigue and high workload is mentioned as a risk factor in three reports. This may for instance refer to situations where the pilots fly under challenging conditions for long periods, presumably inducing a high workload, stress and/or fatigue, increasing the probability of errors and mishaps.

Communication problems. Eight reports identify communication problems as a risk factor, often referring to the communication between the pilots and people on the ground, or other involved parties.

3.1.1.4. Framework conditions. What we refer to as framework conditions are identified eight times in the reports.

Safety culture in the sector is addressed in 3 reports.

Report 2014/06 states that organisational safety culture is a general challenge in the inland helicopter business:

> *"It is the opinion of the AIBN that this accident is a reminder of how challenging it can be for inland helicopter companies to create a safety culture that influences pilots to avoid risky behaviour when they are alone on an assignment, and "nobody" see what they do. The AIBN find that these challenges previously have been treated thoroughly in our reports.…" (2014/06).*

In accordance with this, several reports recommend flight recorders to be installed in the helicopters, to monitor helicopter operations and "discipline pilots". AIBN report 2013/20 notes for instance that:

> "(…) *the business "inland helicopter" has a considerable way to go before it can be said to have reached a level of maturity where professional safety knowledge permeates the operations*." *(2013/20)*.

Report 2011/14 emphasizes that the inland helicopter pilots' rate of reporting incidents of which there is no obvious requirement to report is too low to allow for fruitful learning from dangerous incidents.

Poor aviation authority follow-up is mentioned in two reports. This refers e.g. to a situation where the CAA several times had found weaknesses in the operators' safety management system and in the competence of the pilots, but failed to ensure that these weaknesses were corrected.

Insufficient rules refer, for instance, to insufficient (inter)national rules regulating the business, including the fact that there were no rules requiring operators to conduct risk assessments of operations (before 2016).

Missing elements in helicopter pilot education, refers for instance to a case where there were missing elements in the helicopter pilot education related to how pilots should avoid pilot induced oscillation (PIO). This is mentioned in two reports.

3.1.1.5. Situational risk factors. Situational risk factors are referred to 17 times in the reports.

Low altitude is mentioned in six reports. Flying low increases the risk of loss of control of the helicopter, because of variations in the terrain (e.g. hills) and surprising and unpredictable winds that may affect the stability of the helicopter. Additionally, when flying low, it may be difficult for the pilot to uphold a correct sense of the terrain and maintain reference points. Thus, safety margins are small when flying close to the terrain. Under these conditions, the AIBN reports sometimes conclude that under the manoeuvre that the pilot was undertaking, or because of a sudden wind, the power of the engine was insufficient to uphold control over the helicopter, given its mass.

Wind/weather/ darkness is mentioned in five reports; e.g. bad weather, darkness, low visibility, and light conditions (flat light).

Reindeer herding is mentioned in three reports. This is a type of operation that involves exposure to several of the risk factors described above. Reindeer herding, which is time critical work, is dependent on how the herd moves in the terrain. The risk factor Low altitude is inherent in the operation. Reindeer herding is often conducted in mountain passes and on mountain plains, often with snow or ice cover. This implies a relatively high exposure to hazards, such as "white out", turbulence, rapid change of wind directions, as well as bad weather and sight conditions in general (e.g. snow, windy, flat light etc.). The time critical aspects of the operation may enhance the risk factor Assignment completed in spite of unfavourable conditions.

Errors of others involved is mentioned in two reports. This includes e.g. errors of people preparing the landing site of the helicopter. In one case, an unsecured trailer rolled onto a helicopter after landing.

3.1.2. Results from qualitative expert interviews

Most of the interviewees referred to the (poor) safety culture in the light inland helicopter sector to explain the relatively higher risk in this sector, compared to e.g. offshore helicopter operations. Interviewees generally found that there was greater acceptance of risk in light inland helicopters than in other parts of aviation. This was related to the more inexperienced pilots, market pressures and the fact that the pilots often perform the operations alone. Without clearly defined company policies and active verification of pilot adherence to company regulations, this can lead to bad and unsafe habits. One interviewee described this as a "cowboy mentality" in this part of the industry. Others also mentioned that the lack of organisational safety culture in the companies had played a role in the past, along with lack of communication, planning and good systems for contact with customers. The situation was contrasted with offshore helicopters, which are subject to stricter regulation when it comes to motors, equipment and pilot training.

Inland helicopter pilots primarily fly based on visual references to the terrain, according to visual flight rules (VFR). In marginal visibility this could lead to loss of control. This is in itself a crucial risk factor. In offshore operations, there are always two persons in the helicopter, and the flights are performed by instrument flight rules (IFR). Offshore helicopters also have computer-based, pre-programmed routes, which the helicopter follows automatically, whereas pilots of inland helicopter operations pilots fly manually all the time.

The interviewees also referred to framework conditions when discussing the higher risk of inland helicopters, and the most frequently mentioned framework condition was finances. A substantial part of the industry runs a deficit, and safety, such as training, requires financial resources. Since customers tend to focus on price, there is a strong incentive to cut costs. This competition could also influence actual flying practices, as the pilots are faced with customer expectations which might jeopardize safety. It may be difficult for inexperienced pilots to fail such expectations.

Customer demands could also cause stress, when they must be weighed against weather, technical conditions and cargo. It was mentioned that safety levels are generally higher in offshore and ambulance helicopter, where customer demands for safety are stricter, and the industry is less pressed on finances.

Several interviewees mentioned that pilots of inland helicopters are frequently young and inexperienced, and use this as a steppingstone for their further career in aviation. In combination with demanding customers and complicated manoeuvring, this could lead to problems. The lack of experience could for instance explain that many accidents are related to bad weather, which might not have been acknowledged.

Aerial work operations are demanding, and there have been cases of loss of load. Pilots performing aerial work without accompanying task specialist are more exposed to accidents and incidents. Surprisingly, passenger flights have been more accident-prone than more complicated flying operations. It was hypothesized that this might be because the awareness of risk is higher in more complicated operations.

Interviewees mentioned that the activities of the companies could explain different risk profiles, as rein herding, for instance, is usually done by small companies operating helicopters with marginal performance. The very fact that these are often "thin" organisations, could also lead to less organisational learning and development. In general, it was claimed that organisations that were less characterised by routines tended to have higher accident rates, and that, at least earlier, there was widespread use of freelance pilots, who were only paid if the flight was carried out. This was believed to have changed.

Various models of employment may still have an influence on safety, however. While all kinds of employees are protected against negative consequences of reporting, for instance, this could be more complicated to enforce in cases where the reporting party is not a permanent employee.

3.1.3. Results from the literature review

The identified studies that are relevant to the first aim: "why do accidents with light helicopter inland occur?" are presented in Table 3.

The risk factors in the studies presented in Table 3 can be classified into five risk factor categories: 1) Pilots, generally pilot error, 2) Helicopter and technology, 3) work-related risk factors, 4) Framework conditions, and 5) Situational risk factors.

Pilot error. A dominant risk factor identified explicitly in 11 of the 13 studies is pilot error (pre- or during flight) or errors of other people involved, e.g. maintenance personnel. Rao and Marais (2015) find that the fourth most prevalent occurrence chain resulting in fatal accidents was related to pilot errors. Galazkowski et al. (2015) conclude that human errors were involved in 21% of the studied accidents. These were almost always procedural errors, typically unintended violations of flight regulations. Van Hijum and Masson (2010) refer to poor pilot judgment as a key issue in the studied accidents and conclude that 56% of the accidents generally were related to "unsafe acts". Couch and Lindell (2010) found that loss of situational awareness and other human factors accounted for more than 79% of all the instances of the losses of airframe and fatalities. De Voogt et al. (2009) report that 44% of the aerial application accidents and 22% of the external load accidents were related to mechanical failure pilot error in flight. They also relate the former accident types to pre-flight errors (21%). The analyses of Bye et al. (2013) also point to unsafe pilot behaviours as one of several risk factors found in 72% of all the studied helicopter incidents, relating it to work related factors (e.g. work pressure) and framework conditions (e.g. market conditions and competition). Majumdar et al. (2009) conclude that operational failures, especially due to unsafe acts, were the major cause of accidents in both UK and New Zealand. Thies et al. (2006) also point to unsafe pilot behaviours as an important risk factor, e.g. flying at low altitude in bad weather conditions. Fox (2005) concludes that human factors (or unknown factors) were given as a cause in 74% of the accidents. Manwaring et al. (1998) identified human error by pilot or other flight crew as a cause in 44% of the studied accidents. Manwaring et al. (1998) point to the interaction between operation type and the prevalence of pilot versus mechanical failure. Similarly, Habib et al. (2014) highlight the interaction between operator type and pilot error, finding that human error more is common among commercial HEMS than public safety HEMS.

Helicopters and technology. A second dominant risk factor in the studies was helicopters and technology. A total of 9 of the 13 studies relate safety outcomes to poor or inadequate equipment or mechanical failure, related to the helicopter type, on-board navigation or other equipment. It is not surprising that Churchwell et al. (2018), and the UK Civil Aviation Authority (2014) identify technical causes as the most important risk factor, as these studies focus especially on technical causes. Nevertheless, seven additional studies point to helicopters and technology as critical risk factors. Rao and Marais (2015) found that three of the top five occurrence chains resulting in serious accidents involved engine failures. Galazkowski et al. (2015) found that technical factors were involved in 59% of the studied accidents. Habib et al. (2014) point to Inadequate equipment as a risk factor. Couch and Lindell (2010) conclude that engine/power train failures were one of the leading causes of US military helicopter accidents. De Voogt et al. (2009) report that 23% of the aerial application accidents and 40% of the external load accidents were related to mechanical failure. Majumdar et al. (2009) found that light single piston helicopters were the major group associated with accidents in both the UK and New Zealand. Finally, Manwaring et al. (1998) found that mechanical failure was a cause in 63% of the heli-logging compared with 28% of other external load accidents. In contrast to these results, Thies et al. (2006) conclude that technical defects played a minor role.

This is more in line with the findings from Bye et al. (2013). When analysing 122 accidents that had resulted in damage to the helicopter and/or personal injuries they find that technical malfunctions were contributing conditions in 16% of the accidents.

Table 3
Identified sudies that are relevant to the first aim: "Why do accidents with light helicopter inland occur?"

Study	Sample/method	Identified risk factors	Strengths/ weaknesses
Churchwell et al. (2018) US	Based on the FAA civil helicopter registration data and the NTSB accident data.	Fewer rotor blades give higher risk (3 vs. 4–6), the same does reciprocating engine, single engine.	Largely examines technical risk factors, and do not relate these to e.g. work-related factors
Rao and Marais (2015) (US)	Analyse 5051 helicopter accidents between 1982 and 2008, to obtain high-risk occurrence chains.	– Identified 366 occurrence chains, resulting in 5051 accidents – The occurrence chain "loss of control-in flight" resulted in most accidents. – Three of the top five occurrence chains resulting in serious accidents involved engine failures. – The fourth occurrence chain resulting in fatal accidents was related to pilot errors	Focuses on a large number of accidents.
Galazkowski et al. (2015)	Analysis of 56 incidents involving Mi-2 helicopters in Poland 2006–2009.	Of 4 groups of contributing factors – human, technical, organizational and environmental – human and technical factors predominate, present in 21%and 59% of incidents, respectively. Human errors almost always procedural errors, typically unintended violations of flight regulations. Only 2 incidents classified as having organizational contributory factors.	The study finds low importance of organisational factors, despite looking actively for it.
Habib et al. (2014)	Retrospective analysis of 2040 crashes in US National Transportation Safety Board database (1998–2012) to determine HEMS-involvement and risk factors.	Pilot and other human error more common among commercial HEMS than public safety HEMS – Challenging trips / inappropriate flight selection – Inadequate training for prevailing conditions – Limited resources – Inadequate equipment	
Civil Aviation Authority (2014) UK	Offshore helicopter study of 100 accident reports	The primary causal factor in 83% of the selected "technical" accidents were related to helicopter design issues.	Focuses especially on accidents with technical causes.
Bye et al. (2013) (Norway);	Methodical triangulation consisting of: – Literature search – Statistical analysis of incident and production data – Statistical analysis of data obtained from the helicopter operators – Document studies – Survey – Interviews – Focus group interviews	Evidence based risk influencing factor model (RIF model) consisting of the following factors: – Education, training, selection – The extent of operators' organizational support functions (structure) – Operational support and leadership – Working condition – Helicopter types – Navigation equipment – Markings (power lines, towers, cables) – Market/ economy – Regulations/ administration/ Supervision	Based on a wide range of different data sources, and a conceptual model covering a wide range of risk factors at different analytical levels.
Van Hijum and Masson (2010) European countries.	311 helicopter accidents occurring in the period 2000–2005 in European countries that have 90% of the helicopters in Europe.	Poor pilot judgment identified as a key issue. Generally, 56% of the accidents were related to "unsafe acts". The report also indicates the importance of: – Safety culture and management, and – Ground duties	Provides an overview of helicopter accidents in European countries that are members of the European Aviation Safety Agency (EASA).
Couch and Lindell (2010) US Military.		The majority of US military helicopter losses was attributed to mishaps, not to combat hostile actions, with human factors and engine/ power train failures being the leading causes.	Focuses on a military context, but indicates however that 81% of the losses were not due to hostile combat actions.
De Voogt et al. (2009)	Analysis of high-risk helicopter operations. (i) 142 serious personal or material injury accidents involving aerial application flights 1998–2005; (ii) 120 serious personal or material injury accidents with external load operations 1995–2005 (cf. Manwaring et al., 1998). From US NTSB database.	Aerial application accidents: 44% due to pilot error in flight 23% mechanical failure (caused by company/ maintenance personnel) 21% pre-flight error (mostly pilot) Most accidents occur on departure from refuelling/loading platform; poor fuel management is implicated in 37% of accidents. External load accident: 22% due to pilot error in flight 40% mechanical failure 29% pre-flight error Most accidents occur during challenging hover phase	It is important to note that the study only focuses on accidents related to two types of helicopter operations.

(continued on next page)

Table 3 (*continued*)

Study	Sample/method	Identified risk factors	Strengths/ weaknesses
Majumdar et al. (2009)	Helicopter accident data from the United Kingdom between 1986 and 2005 for 566 accidents and from New Zealand between 1996 and 2006 for 230 accidents	– Operational failures, especially due to unsafe acts, were the major cause of accidents in both countries, followed by airworthiness causes. – Light single piston helicopters were major group associated with accidents in both countries. – The majority of accidents were in non-public operations	Compares data from two countries over a long time period.
Thies et al. (2006) (HEMS)	Survey all German HEMS-programs, between 1980 and 2001: data from 42 of the 51 centres covering 844,468 HEMS-missions and 779 operating years. 12 accidents with casualties.	Accident inducing factors: – Contact with obstacles during landing. – Flying at low altitude in bad weather conditions – Lack of discipline in the cockpit-crew. – Technical defects played a minor role.	Examines a low number of accidents.
Fox (2005) (US)	Data from Bell Helicopter, in addition to general accident data from the US.	The dominating and initiating cause factors in the period from 1947 to 1996; and 1994 to 2004 were given as human (or unknown) in 74% of the accidents.	Indicates a need for more detailed cockpit information recordings.
Manwaring et al. (1998)	Descriptive analysis of NTSB reports of 230 accidents involving external load operations by helicopters, with serious material or personal injury, 1980–1995. (Fatality rate 25%).	Analysis of "probable cause": – Human error by pilot or other flight crew – 44% of accidents – Mechanical failure of all types – 38% Improper or inadequate maintenance – 10% (also listed as contributory in an additional 9% of accidents where human error was cause). Large differences in cause with different types of external load operation e.g. pilot error probable cause in 29% heli-logging accidents versus 50% of other types of external load accidents. Mechanical failure cause in 63% heli-logging versus 28% of other external load accidents. Fuel starvation a main cause of pilot error in all types of external load accident.	Only focuses on one type of accidents: external load accidents. This provides, however a detailed overview of these operations.

Work-related risk factors. Work-related risk factors are less often identified in the reviewed studies than e.g. factors related to pilot error and helicopter/technology. Five of the 13 studies indicate the importance of work-related risk factors. These studies generally contextualise the incidence of human errors, concluding that poor working conditions (e.g. time pressure) and poor SMS and organisational safety culture increases the likelihood of human errors. Comparing commercial and public HEMS, Habib et al. (2014) conclude that pilot errors and errors of other people involved were significantly more common in the former because of poorer training conditions, limited resources etc. Bye et al. (2013) also find that work-related risk factors, e.g. the extent of operators' organizational support functions, education, training, selection, operational support and leadership, are critical for pilot behaviours and helicopter safety. One of the main conclusions of Van Hijum and Masson (2010) is related to the importance of safety culture and management. Thies et al. (2006) refer to "lack of discipline" among cockpit crew as a cause of accidents, which seems to concern safety culture, and De Voogt et al. (2009) focus on the role of extra crew for safety, which comprises an important working condition. Finally, it should be noted that Galazkowski et al. (2015) look actively for organisational factors, but only identify it as a risk factor in two of the 56 instances (technical service).

Framework conditions. Only three of the thirteen studies focus explicitly on framework conditions, mostly by relating more or less challenging working conditions to the more general framework conditions in the sector. This is especially evident in Habib et al. (2014), who compare working conditions and the incidence of human error in public and commercial HEMS, concluding that framework conditions are more challenging in the latter. Van Hijum and Masson (2010) refer to inadequate government and industry standards and regulations as one of the top issues for commercial helicopter transport operations. Bye et al. (2013) highlights that both authority's inspection activities and the regulations influence safety. They also indicate that market pressures may represent an important risk factor. For instance, Bye et al. (2013) report that 26% of the pilots employed by the AW/PAX operators in Norwegian light inland helicopter operations claim that competition with other helicopter companies make it necessary to violate safety routines. As many as 42% of the respondents working for commercial operators agreed that consideration regarding accomplishing the mission means that the they sometimes violate safety routines, and 75% claimed that it they sometimes thought of rejecting a flight due to fatigue but chose to fly anyway. According to Bye et al. (2013), 47% of the AW/PAX in Norwegian light inland helicopter pilots claim that they weekly or daily have to decide whether to fly into weather condition that may deteriorate below Visual Flight Rules minimum. Bye et al. (2013) also find several important and safety relevant differences related to subsectors (ambulance/police vs. AW/PAX), related to pilots' experience and training, to compliance with rest time regulations, and to flying when fatigued etc. These conditions were generally far better among ambulance and police helicopter pilots than among AW/PAX.

Situational risk factors. This may be viewed as a very broad risk factor, as it relates to the observation that some types of operations are more accident prone than others, due to e.g. the type of flights involved (external versus aerial load operations) (Manwaring et al., 1998; De Voogt et al., 2009; Bye et al., 2013), the flying and landing environment, factors related to challenging weather and environment (Thies et al., 2006; Habib et al., 2014; Rao and Marais, 2015) and the risk of different phases involved in particular operations. This factor is generally given less explicit attention in the reviewed studies. Moreover, when it is given explicit attention, it is generally found to be a less important risk factor in accidents than human error and technology.

3.2. How can accidents with light inland helicopters be prevented?

3.2.1. Results from the AIBN reports

Only five of the twenty-nine investigation reports included in this study issue formal safety recommendations. The AIBN seldom repeats previously mentioned formal recommendations. However, when including potential preventative measures mentioned in the final report sections, we found 21 mentions or suggestions of relevant preventative measures. Thus, most of the recommendations presented here are not formulated as formal recommendations issued by the AIBN. Instead they are often mentioned in the final assessment section, when the AIBN points to measures that potentially could have prevented the accident, or which helicopter operators could implement to avoid similar accidents in the future.

On a general level, the AIBN comments on the safety level in the sector, asserting that:

> *"It is the opinion of the AIBN that the many helicopter operators can attain considerable safety benefits by implementing measures that not necessarily are complicated or expensive. This requires, however, a basic will and endurance to continuously work systematic with mapping the safety challenges that your own organisation face, and the ability to see which concrete solutions that will work best in practice. This applies both to the organisational and the individual level." (2014/06)*

This comment points both to the safety potential of conducting risk analyses, or implementing safety management systems. The comment also relates to the safety culture in the sector, referring to a presumably lacking will and endurance to work systematically with safety.

Several more specific measures are also mentioned in the reports. Measures related to technology are suggested 13 times in the reports, e.g. the instalment and use of flight registration technology during flight, both to (supposedly) "discipline" the pilot during flight and to increase the information available in accident investigations, new technology to compensate for lacking visual cues during flights (e.g. radio altimeter), and the use of (improved) communication equipment, e.g. between pilot and the cargo handler. Four measures are directed to helicopter producers, focusing on changing technology, design or to issue warnings or information about technology or design. Two other suggested measures concern obstacles: database/map of obstacles and obstacle warning. This measure is suggested in accidents/incidents were helicopters have struck e.g. power lines or other obstacles.

Measures related to work related factors are suggested in 8 times in the reports, e.g. risk assessments that helicopter operators should conduct prior to helicopter operations, routines and practices related to securing of landing site, simulator emergency training, emergency releaser procedure, reporting systems.

3.2.2. Results from the qualitative expert interviews

Discussing risk factors, the interviewees especially mentioned the safety culture in the sector. Importantly, they pointed to the sector's safety culture not only as a factor influencing risk, but also as a product of other framework conditions. In particular, they linked it to market conditions, customers, young and inexperienced pilots, unstandardized missions with pilots often flying alone etc. Interviewees asserted that there was greater acceptance of risk in light inland helicopters than in other parts of aviation, and the most important safety measures that they highlighted was related to strengthening the safety culture in the sector.

Discussing this, most of the interviewees underlined the importance of the Flight safety forum for light inland helicopters. This was mentioned as one of the main preventive measures in recent years, aiming to improve the safety culture in the industry. The Safety forum is publicly financed, and consists of managers (accountable manager, flight manager etc.) in all companies operating inland. Everyone has a duty of attendance. One of the interviewees said that, before the Safety Forum, there was 1 accident per every 8000 flight hours, while there were 1 accident per 35–40.000 h at the time of the interviews, attributing this risk reduction to the work of the Safety Forum.

Interviewees stated that the Forum has created awareness of risk, and led to a professionalization of the industry, applying to both the companies and the customers. A first crucial aspect of the work of the Safety Forum is the development of commonly accepted standards and guidelines for helicopter operations. The purpose of the development of the commonly accepted standards is to contribute to the development of clear and clearly enforced guidelines for when to abort/avoid operations. The guidelines relate e.g. to weather conditions, maximum heeling requirements, maximum pitch up with helicopter, with passengers on board, that one cannot lift cargo with 100% engine power, but must have a certain reserve available. This would fill a gap in the companies' safety management systems, as illustrated by the study of Bye et al. (2013) showing that only 31% of the AW/PAX pilots stated that the company they worked for had a standard procedure for handling bad weather conditions.

If all helicopter operators follow the same voluntary safety standards, it could involve a heightening of the safety level of the sector, and a way of creating a shared buffer toward the negative effects of framework conditions related to the fierce competition in the industry (e.g. compromising on safety requirements to win bids). It was mentioned that the guidelines are enforced through self-policing in the industry.

A second crucial aspect of the work of the Safety Forum is information and education targeting customers. For instance, the Forum has made recommended guidelines for the power industry's use of helicopters, with requirements on how to set requirements for helicopters. The effects of establishing the Safety Forum, described as a key to changing the sector's safety culture, was thus primarily a mechanism for targeting other framework conditions.

Another important measure that was mentioned by the interviewees was related to day payment instead of hours, thereby reducing financial motivation to fly under challenging conditions. Interviewees also mentioned risk assessments, training, development of a reporting culture, installation of flight-recording systems to impede pilots from violating rules and self-imposed limits and standards while flying. It was mentioned that it is important that companies actively use such technologies for them to be efficient means of regulating pilot behaviours.

3.2.3. Results from the literature review

The identified studies that are relevant to the second aim: "how can accidents with light helicopter inland be prevented?" are presented in Table 4.

As seen in Table 4, relatively few studies evaluate the outcomes of interventions or measures in the helicopter sector. Our literature review did not identify any robust evaluations of measures aiming to improve the safety of inland helicopter operations, i.e. pre-post measurements with control groups. Pietsch et al. (2016) includes pre and post measurements of self-assessed competence, but this study does not include control groups.

Additionally, the five studies in Table 4 focus on different types of measures: a working group aiming to analyse risk factors and develop counter measures (Manwaring et al., 1998), optimization of transport to reduce exposure (Menezes et al., 2010), rules on flight duty periods (Simons et al., 2011), training (Pietsch et al., 2016) and a weather warning system (Kanemaru, et al., 2017). Moreover, it should also be noted that few of the studies in Table 4 focus on inland helicopter: two studies are from the offshore sector (Menezes et al., 2010; Simons et al., 2011), and two are from HEMS (Pietsch et al., 2016; Kanemaru, et al., 2017). Manwaring et al. (1998) concern inland helicopter, focusing specifically on logging operations.

Table 4
Identified studies that are relevant to the second aim: "How can accidents with light helicopter inland be prevented?"

Study	Sample/method	Measure	Results	Strengths/weaknesses
Kanemaru et al. (2017). HEMS Japan.	Comparison of assessments of the probability of a flight based on 1) conventional data, weather chart and meteorological reports), and 2) information obtained from the WWS and the conventional data.	Weather webcam system (WWS) was established to observe the meteorological conditions in 29 locations in a mountainous area.	Results indicate that the WWS may prevent flights in unfavourable weather conditions.	The technology and the methods need to be assessed further.
Pietsch et al. (2016). HEMS. Mountain rescue.	Pre- and post-training self-assessment of 40 HEMS crewmembers.	Simulation-based training, dedicated to mountain helicopter emergency medicine.	Significant increase in self-assessed competence in safety-related items of human factors and team resource management.	No control group. Uncertain to which extent the increased self-assessed competence is correlated with safety performance.
Simons et al. (2011) (Dutch offshore helicopters)	Data of 24 pilots comprising 224 duty days were analysed. Assess effects of pre-duty sleep, pre-duty travel time, and workload factors on the alertness and vigilance of pilots.	Fatigue management. Results of the tests indicated safe levels of alertness and vigilance, because of the flight duty period scheduling and regulations.	During the flight duty periods, pilots maintained safe alertness and vigilance levels. Attributed to reasonable length of flight duty periods (FDP)s and several other factors.	Only a cross-sectional study, thus results must be interpreted with caution. No before-after, or control groups.
Menezes et al. (2010). Offshore. Brazil.	Development of a network flow model to optimally assign passengers to selected routes, and reduce helicopter transport.	Reduce exposure. By reducing the helicopter transport, the probability of accidents is generally lower. Optimize the activities of flight planners' selection of routes.	By using the system, Petrobras reduced the number of offshore landings by 18% and total flight time by 8%.	Potential negative side effects for safety are not evaluated.
Manwaring et al. (1998)	Descriptive analysis of NTSB reports of 230 external load operation accidents. Also includes experiences from specific measures aimed at reducing accidents.	Reports experiences from an interorganisational working group to prevent helicopter accidents in Alaska in 1993–1994, including two helicopter safety workshops (1995) aiming to conduct systematic risk analyses of the sector and develop measures. Guidelines were developed. Increased inspections from the authorities.	Reductions of helicopter logging accidents in Alaska; from 6 in 1992–93, none in 94–95 and 1 in 1996	Uncertain results, because of small numbers, and two companies with poor safety record quit their operations in Alaska.

4. Concluding discussion

4.1. *Why do accidents with inland helicopter occur?*

The first aim of the study was to examine why accidents with light inland helicopters occur, focusing especially on the situation in Norway.

The relationships between pilot errors, work-related risk factors, framework conditions and situational risk factors are illustrated in Fig. 2, which primarily are based on our analyses of AIBN reports and the qualitative research interviews. We have assigned numbers to the

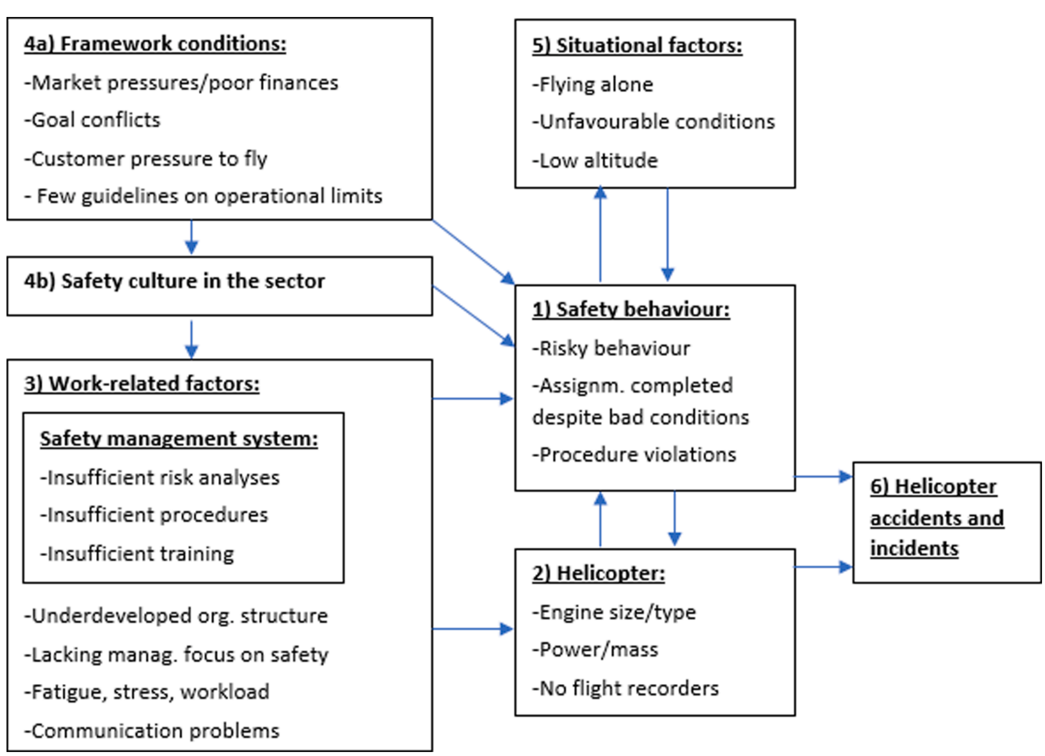

Fig. 2. Illustration of hypothesized relationships between typical risk factors related to framework conditions, work-related factors, and risk factors related to pilots and helicopters. Based on analysis of AIBN data, interviews and literature reviews.

risk factors, to alleviate the discussion of relationship between the risk factors.

Risk factors related to the pilots were identified 22 times in the AIBN reports. The AIBN analyses did, however, generally not stop at the analytical level of the pilot: they also described the context in which the risky pilot behaviour occurred, to explain why and how it could happen. This is indicated by the fact that the organizational level that we label work-related factors were the most commonly identified risk factors. The importance of this for pilot behaviour is illustrated by the relationship between box 3 and 1 in Fig. 2.

The analyses of the accident reports from the AIBN seem to indicate that work-related factors comprise the most important risk factor in the helicopter accidents. This especially applies to factors related to the quality of safety management systems in the helicopter companies; facilitating risk analysis of operations, procedures describing the risks and training of pilots. The importance of the organisational level was also highlighted in the interviews. We elaborate on this below.

The AIBN reports and the interviews also indicate a relationship between the general framework conditions (box 4a) and the safety culture in the sector (box 4b). In addition, these data sources also linked the work-related factors in the helicopter companies to more general framework conditions in the light helicopter inland sector, e.g. the safety culture in the sector, poor aviation authority follow up. This is indicated by the depicted relationships between box 4a, 4b and box 3. Additionally, the reports and the interview also indicate direct relationships between framework conditions (box 4a-b) and pilot safety behaviours (box 1), e.g. when the pilots experience customer pressure to fly, goal conflicts, are influenced by the safety culture in the sector etc.

The data from the AIBN reports and the interviews indicate that it is especially challenging for pilots to deal with such goal conflicts, as they often are young and inexperienced, as they generally tend to operate alone, and when they are members of “thin organisations”, i.e. without clearly defined company policies and active verification of pilot adherence to company regulations (cf. the relationship between box 3 and 6). Interviewees suggested that it may be relatively challenging for relatively inexperienced pilots to fail the expectations of pilots in a challenging market.

Results from the interviews and the reports also indicate the importance of “situational risk factors”, e.g. reindeer herding operations, wind/weather/darkness. These denote situations in which pilots’ handling of goal conflicts between safety and completing assignments seem to have been difficult, and where the safety margins have been “pushed too far”. These might lead to pilot violations, like “assignments completed in spite of unfavourable conditions”, as indicated by the relationship between box 1 and 5 in Fig. 2.

In contrast to the data from the AIBN reports and the qualitative interviews, the most frequent risk factor identified in the studies from the literature review was a combination of human error and technical factors (Churchwell et al., 2018; Rao and Marais, 2015; Galazkowski et al., 2015; Civil Aviation Authority, 2014; Couch and Lindell, 2010; De Voogt et al., 2009; Majumdar et al., 2009; Fox, 2005; Manwaring et al., 1998). In accordance with this, Gonçalves et al. (2019) note that there is a lack of studies that relate human and organisational factors, affecting the safety of helicopter operations.

It is, however, important to note that the studies in the literature review also generally focused on how combinations of risk factors contributed to the accidents. Situational risk factors were the third most frequently identified risk factor, and five of the reviewed studies also indicated the importance of work-related factors and framework conditions (Bye et al., 2013; Van Hijum and Masson, 2010; Thies et al., 2006; De Voogt et al., 2009; Habib et al., 2014).

Nevertheless, weighing the importance of different causes involved in the accidents, most of the reviewed studies viewed pilot error and technical failure as the most important risk factors (e.g. Churchwell et al., 2018; Rao and Marais, 2015; Galazkowski et al., 2015; Civil Aviation Authority, 2014; Van Hijum and Masson, 2010; Couch and Lindell, 2010; De Voogt et al., 2009; Majumdar et al., 2009; Fox, 2005; Manwaring et al., 1998). This seems to indicate a certain discrepancy between the risk factors identified in the literature review and the AIBN data and the qualitative interviews. In the latter data, human error tends to be viewed more as a result of work-related factors and framework conditions (cf. Fig. 2).

This potential discrepancy in the data sources may be due to at least two different explanations. First, work-related risk factors and framework conditions may be less important risk factors in the accidents examined in the reviewed studies from other countries and sectors, as these may have more favourable framework conditions and more well-developed safety management systems than light inland helicopter in Norway in the study period. It is difficult to assess the importance of this, but we may note that some of the reviewed studies focus on HEMS (e.g. Galazkowski et al., 2015; Habib et al., 2014; Thies et al., 2006), and offshore helicopters (e.g. Civil Aviation Authority, 2014), which have lower risk and supposedly better framework conditions (cf. Bye et al., 2013).

Second, the contextualization of pilot error, focusing on work-related risk factors, situational risk factors and framework conditions can also be viewed as the result of the analytical frameworks implicitly or explicitly chosen in the analyses. Lundberg et al. (2009) underline that studies and investigations of accidents generally employ implicit accident models, involving a set of assumptions about how accidents happen and what the important factors are. Such models influence what investigators and researchers studying accidents look for, and hence their conclusions. This has been called the “What-You-Look-For-Is-What-You-Find”, or WYLFIWYF tendency (Lundberg et al., 2009).

A minority of the studies in the literature review indicate that work-related factors and framework conditions can help explain pilot error (e.g. Habib et al., 2014; Bye et al., 2013; Van Hijum and Masson, 2010). It is not unlikely that the lacking focus on work-related factors and framework conditions in the majority of the studies could be due to their (lacking) operationalization of such factors, or lacking data about them.

If present, such conceptual limitations may be problematic, as they may limit the scope of potential measures. The WYLFIWYF tendency may also limit our learning and our ability to implement safeguards after accidents, as the identified causes typically became specific problems to be fixed during an implementation of solutions, following that they refer to as the “What-You-Find-Is-What-You-Fix” or WYFIWYF tendency (Lundberg et al., 2009). Below, we discuss how accidents with inland helicopters can be prevented.

4.2. How can accidents with inland helicopter be prevented?

The second aim of the study was to discuss how accidents with light inland helicopters can be prevented, focusing especially on the situation in Norway. On a specific level, the most frequently mentioned measure in the AIBN reports was related to technology.

On a general level, the AIBN reports indicate that the most basic factor that needs to be improved in the sector is the safety culture. The safety culture in the sector was also a major challenge discussed in the qualitative interviews. The most important measure mentioned in this respect was the Flight safety forum for light inland helicopters, as it aimed to develop clear and clearly enforced guidelines for when to abort/avoid operations. This could reduce the influence of negative framework conditions in the sector (e.g. competition, market pressure) on safety. One of the reviewed studies also documented experiences from a similar process, with designated work groups aiming to develop operational guidelines (Manwaring et al., 1998).

The studies identified in the literature review indicated a major research gap, as we did not identify any robust evaluations (i.e. pre-post measurements with control groups) of interventions aiming to improve (inland) helicopter safety. The lack of robust intervention studies is probably related to the fact that it may be difficult to conduct such experiments in the sector. Moreover, most of the studies suggesting measures focused on emergency or offshore helicopter transport.

4.3. Methodological limitations

When discussing the safety level and safety culture in light inland helicopters in Norway, based on the AIBN reports and qualitative interviews, it is important to note that our analysis of these data describe a situation at a specific period in time where involved parties seemed to agree that the safety culture level was low, and that measures had to be implemented. The inland helicopter Flight Safety Forum (FsF) was initiated in 2009, and its mandate was to work to improve flight safety with inland helicopters, with the "zero vision" as the target for accidents. The FsF initiated the helicopter safety study (Bye et al., 2013), which issued 41 safety recommendations when it was published in 2013. In the spring of 2019, the Civil Aviation Authority Norway concluded that the last of these recommendations were "closed" and that the work with implementing the 41 recommendations was finished. The majority of the studied AIBN reports were published in the early FsF period (2011–2015), while most of the qualitative interviews were conducted in 2016–2017. Thus, our qualitative data describe a specific historical period in the sector. As noted above, one of the interviewees asserted that the safety level has improved substantially from 2010 to 2019, e.g. due to the work of the FsF. This is also indicated in Fig. 3.

Fig. 3 shows that the number of fatalities per million flight hours was at its highest in the early FsF period (2010–2014), while it was nearly reduced to the half in the subsequent period.

Discussing methodological limitations of our study, it should be mentioned that both the number of AIBN reports studied and the number of qualitative interviews are low. However, the reports' level of detail still allows for analyses of e.g. work-related factors and framework conditions, and the interviews were conducted with key personnel. Together, and combined with the literature reviews, these data sources provide a rich description of the sector.

It should also be noted that the results of the literature reviews are contingent on the criteria for inclusion. For instance, some studies examining helicopter accidents were excluded due to a focusing on comparing accidents with incidents and/or examining factors influencing the severity of accidents, e.g. studies providing quantitative comparisons of crashes and/or fatal accidents and less critical incidents (e.g. O'Hare et al., 2006; Groff, & Price, 2006; Baker et al., 2006; Bensyl et al., 2001). Moreover, some studies have also been published after our review. The study of Rao and Marais (2018) has for instance been updated in Rao and Marais (2018). Other important and more recent studies are e.g. Saleh et al (2019), Gonçalves et al. (2019), Subagia et al (2020), Moon and Yakovlev (2020). These were not included, as they were published after our review.

There might also be a bias in the included/excluded studies describing helicopter safety measures. The point of departure for including studies was to include robust descriptions of interventions, but we did not find any such studies. Thus, our focus changed to including studies describing the empirical experiences with safety measures. Several accident studies suggest measures based on analyses of accidents. We did, however, not include these, as we focused on studies describing empirical experiences with measures and not merely suggestions, based on analyses of accidents. It could, however, be argued that the latter may also provide valuable lessons.

4.4. Implications for policy and research

The study indicates how analytical conceptualisations may influence the conclusions of accident analyses, cf. What-You-Look-For-Is-What-You-Find" (Lundberg et al., 2009). Implicit/explicit analytical conceptualisations may also influence the choices of preventative strategies, cf. "What-You-Find-Is-What-You-Fix" (Lundberg et al., 2009). Our study could indicate that a better focus on and conceptualisation of work-related factors and framework conditions in helicopter accidents could enable more effective preventative efforts.

5. Conclusion

Most of the existing studies from the literature review point to combinations of human errors and technical failures as the major risk factor contributing to helicopter accidents. Based on our analyses of the AIBN reports and the interviews, our analysis contributes to existing research by also relating pilot behaviour to work-related factors and framework conditions. The accident data and interviews indicate challenges related to framework conditions like the safety culture in the sector, poor finances/competition, and few operational guidelines for pilots when dealing with competing demands. Our analyses seem to indicate that accidents are more likely to occur when such poor framework conditions are combined with insufficient safety management systems and poor work-related factors like fatigue, stress, high workload

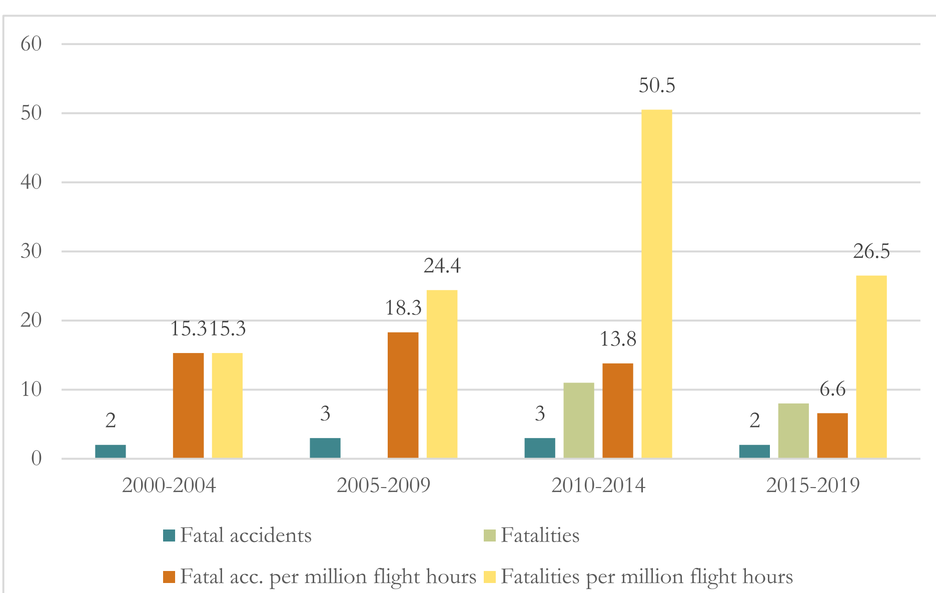

Fig. 3. Accident records and flight hours, including PAX/AW and HEMS (Scheduled flights not included.)

and lacking management focus on safety. Under such conditions, it seems more likely that risky pilot behaviour may occur, as the pilots will lack a "protective buffer" between themselves and challenging framework conditions. Based on this, we discuss measures that may prevent inland helicopter accidents, focusing especially on the Flight Safety Forum's development of self-imposed and commonly accepted operational limits and guidelines in the sector. We argue that this could provide a viable approach to improving the safety culture in the sector, underlining that this has to be examined in future studies.

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