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RESEARCH

Flying against the clock – risk management and resilience in Arctic search and rescue and casualty evacuation flights

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Abstract

Despite the successful conclusion of the 2011 Arctic Search and Rescue Agreement, the resources available for search and rescue operations in the High North remain limited. Rescue flights are time critical. Survival times – especially in the Arctic – are severely curtailed by the environment. At the same time, clinical evidence supports the need to provide critical casualty care within the first, or 'golden' hour following injury. The selection, training and management of personnel lies at the heart of addressing the risks attendant upon both flying and rendering appropriate casualty care under such circumstances. Despite technological advances, human decisions remain pivotal. This paper examines recent advances in decision enhancement techniques and their application in improving the safety and resilience of future Arctic rescue flight operations.

Keywords Arctic · Airborne · Casualty evacuation · Medical · Risk management · Search and rescue

Introduction

All biomes may be defined to at least some extent by time,[1] but in the case of the Arctic, temporal restrictions are extreme. In this time-dominated environment, the demand for emergency air transport in the Arctic is increasing.[2] However, by combining air travel and medical care, the *risks* associated with both are added to those innate in the Arctic environment, and it is expected that some of them will increase as the climate changes.[3] As in much rescue work, decisions will have to be made in a time-constrained context (Flin and Arbuthnot 2002 211–214 260; HM Fire Services Inspectorate 1998). This paper considers the management of those risks, and in particular, how decision quality with respect to them can be upheld. The central question addressed is:

> "In what respects is risk likely to increase in Arctic aeromedical evacuation and search and rescue flight operations, and what measures can be applied to improve decision quality in the management of those risks?"

While it is acknowledged that aeromedical transport and search and rescue operations are qualitatively different, for simplicity, this paper will refer to both as 'aeromedical flights', with the understanding that in many search and rescue operations, casualties will require prompt medical attention. The risk decisions under consideration here are principally those undertaken by personnel working in air ambulance services in the Arctic. They are not simply medical judgements per se, although they may be made in consultation with medical personnel, including in-flight carers. The decisions of interest relate in many cases to those risks classified as dynamic, having potentially fatal outcomes on eventuation, and being strongly influenced by time in manifestation

[1] For an early attempt at the classification of biomes generally, see Holdridge (1947). Olson et al (2001) provide a recent and much more detailed treatment, predicated on facilitating conservation. Stonehouse (1990 13, 15) describes attempts to define the Arctic.

[2] See Glomseth et al (2016) for an analysis of search and rescue operations in northern Norway with particular reference to ambulance helicopters in the search and rescue role.

[3] For climate change related risks to polar regions generally, which include issues affecting airborne medical evacuation operations, see Meredith et al (2019). More specific issues and citations are addressed below.

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(Tissington and Flin 2005).[4] For the purposes of this paper, the approach taken by the UK Fire and Rescue Services[5] will be adopted in defining dynamic risk assessment as:

> "The continuous assessment of risk in the rapidly changing circumstances of an operational incident, in order to implement the control measures necessary to ensure an acceptable level of safety."
> (HM Fire Service Inspectorate 1998)

Exemplars are drawn from the helicopter rescue service at Svalbard, which provides emergency response in both the maritime and terrestrial (including mountain) environments.

The Arctic environment and time factors in aviation

In the Arctic, patient care decisions may be influenced strongly by environmental conditions. The remoteness of some locations, and the difficulty, inherent time delays or outright impossibility of road or river transport may necessitate the air movement of casualties. These problems are historic and well known (World Health Organisation 1963 11). However, the resources available for aeromedical evacuation may be modest.[6] Definitive medical procedures may only be available at a relatively limited number of treatment centres. At the same time, Arctic weather, particularly with respect to visibility, can reduce the opportunities for safe takeoff, landing and air transit.[7] The relative lack of infrastructure impacts flight planning, restricting the availability of diversions. Further impediments result from polar daylight conditions, which impose long periods of limited visibility during the winter – in some cases, 24 hour nights and the requirement for compensating navigation measures, and 24 hour days during summer. Disruption to circadian rhythms can have deleterious effects on sleep and consequently, alertness and performance.[8] Upon this environmental backdrop of time-related factors we may superimpose the strictures of time in medical care. Medical practitioners favour prompt treatment, in the case of traumatic injury, preferably in the first or 'golden' hour[9] as a correlate with beneficial patient sequelae.

Time and patient survival factors

While some countries actually recommend aeromedical transport between hospitals for specific patient needs (Varon et al. 1997), more generally, Johnson-Joseph and Kelso (1985), state that there are no absolute medical contraindications to air evacuations. However, extreme care is required with some cases. Examples include anaemia, pneumothorax, uncontrollable cardiac arrhythmias or ischaemic pain, certain head injuries and patients with mandible or maxillary fracture fixation (ibid.). For other conditions, such as gas gangrene, recent abdominal surgery, decompression sickness or hypoxia where the latter is not correctable by oxygen therapy, careful delay may be the most appropriate course of action (ibid.). Aeromedical transport is best considered as part of a system that operates from the moment of injury or presentation of symptoms. It is one option amongst others in minimising delay, but not the only one. For example, in remote industrial installations on the North Slope of Alaska, an alternative is to move the initial assessment and care provision forward, by locating a Physician's Assistant on site. This provides the option of stabilising most patients, buying them time even if weather or a lack of infrastructure precludes prompt evacuation (Ash 2007).

This paper adopts a systemic approach to the risk management decisions in aeromedical evacuation, with emphasis on two contexts: acute cases with potentially life-threatening outcomes, and second, cases moved by air for reasons of logistical efficiency, but which develop acute problems during flight. Both are time critical.

Climate change and risk increment

Climate change is already having a greater effect in the Polar Regions than at other latitudes (Meredith et al. 2019), and has direct impact on aeromedical evacuation. It has been

[4] The academic literature abounds with definitions of risk; see for example Newsome (2013 25–49). Traditionally, the operational risks being managed by pilots, firefighters and police officers are *static risks* – those resulting from nature and human wickedness—whereas *dynamic risks* derive from changes in economic conditions (Vaughan and Elliott 1978 10). However, the usage is changing. While formally, this paper addresses static risks manifesting in a dynamic situation, these will also be referred to as 'dynamic risks'.

[5] Authorities differ in their definitions. For an alternative view, see the UK Ministry of Defence (2022).

[6] The Agreement on Cooperation on Aeronautical and Maritime Search and Rescue in the Arctic, concluded at Nuuk in 2011, describes jurisdictional and administrative arrangements for search and rescue operations. In practice, the resources available in the Arctic may be minimal (See for example Birkland et al 2019; Solberg et al 2020).

[7] For an overview of Arctic weather effects on flying, see FAA (1975 Ch 14) and NATO (2007 Ch 13).

[8] See Arendt (2012) for a comprehensive overview of this problem, and mitigating measures.

[9] For the initial exposition on urgency in trauma care, see Cowley (1975).

evident for some time that cyclone frequency and intensity has increased in northern latitudes (McCabe et al. 2001). There may also be an increase in the number of potential patients requiring rescue as more vessels navigate trans-Arctic shipping routes, conduct high latitude commercial fishing or engage in polar tourism (AECO 2019; PAME 2020). It is worth noting that of the passenger demographic on board cruise vessels, it tends to be those over 65 who require emergency treatment (Johannsdottir et al. 2021), and while cruise ships may well be equipped with their own medical facilities, airborne casualty evacuation (casevac) may still be required for some cases.[10] Ting (2011) has objected to an inference by Norum and Elsbak (2011) that an increment in expedition ship tourist traffic to Arctic Norway could lead to an increased requirement for aeromedical evacuation. In this regard, Ting notes the availability of on-board physicians, pre-departure screening of passengers and the comparative rarity of events requiring emergency evacuation. However, while only a small percentage of a given population may need evacuation, increasing the total population size increases the number of potential evacuees by proportion, unless on-board care or the screening process increase in effectiveness.

PAME (2020) report that fishing vessels constitute the largest element in Arctic maritime traffic: a presence of shipping that has increased by some 25% in the Polar Code area during the period 2013–2019. An increment in fisheries catches is being observed in some species as fish locations are deflected towards the poles by climate change (Norwegian Ministry of Climate and Environment 2021). This process is predicted to continue, substantially favouring the catch potential of Arctic nations (Cheung et al. 2010). Commercial fishing remains one of the most hazardous occupations (Cabeças and Nunes 2005), and the consequent demand for aeromedical services may be expected to increase.

One aspect of climate change that is receiving serious attention is the potential for an increase in violence, including conflict at the societal level. The work of Solomon Hsaing and his colleagues indicates a statistically defensible correlation between environmental conditions and violent behaviour (Hsiang et al. 2013).[11] Inevitably, conflict between nations may spill over to civilian emergency response activities. Recent incidents have included Russian jamming of GPS signals (Depledge et al. 2019; Mikkola 2019). As air navigation in the Arctic can be challenging in itself,[12] such interference constitutes a significant addition to flight risk.

Climate change may also harm the physical infrastructure that supports Arctic air operations. The cost of repairing runways or reconstructing them to resist permafrost melt damage may be high (Hjort et al. 2022). As these factors lead to a potential increase in risk to patients and aeromedical crews, it is prudent to consider measures for managing that increment.

Technology to the rescue?

Robot-assisted remote surgery ('telesurgery') was demonstrated in 2001, when a medical team conducted a trans-Atlantic cholecystectomy procedure using a Zeus surgical robot; an event dubbed the "Lindbergh operation" (Yu 2007). Despite development since then, telesurgery has a number of drawbacks. Significant amongst these are the latency in the communications link[13] and the lack of haptic feedback (Choi et al. 2018; Yu 2007). Non-technical, but nonetheless critical considerations include the cost of the robotic systems and potential legal issues (Choi et al. 2018; Yu 2007).

Unmanned airborne vehicles (UAVs) might be remotely operated, or pre-programmed to fly a given route with a patient on board. Examples of current drone ambulance[14] projects include Dragonfly Pictures' DP-14 Hawk (DPI UAV Systems 2014; Wang 2017) and the Tactical Robotics Ltd Cormorant (Tactical Robotics Ltd undated; Whittaker 2018). If security of link cannot be guaranteed, the machine must be capable of autonomous operation, routing itself in an environment in which ordinary navigation aids including GPS may be compromised, avoiding other air traffic and selecting options appropriate to marginal weather conditions. Despatching a patient in a drone obviates the

[10] For context, in a study from Oct 1999 to May 2000 of cruise passenger aeromedical evacuations in non-Arctic waters, Prina et al. (2001) report a mean patient age of 68.7 years, with conditions falling mainly into into three categories: cardiac (34.6%), neurological (20.2%), and digestive (14%). Carron et al.'s 2018 report of cruise ship pathologies in remote regions identify a median passenger age of 68. Over a 205 day period (19 cruises and 2 positioning voyages), with a total of 3698 passengers and 2942 crewmembers embarked, they note evacuations for 3 cases: one stroke, a duodenal ulcer in a crewmember, and a pneumonia with heart failure.

[11] The work of Hsaing and his colleagues is rigorous. Their defence of the analysis against criticism (Buhaug et al. 2014) was a robust one (Hsiang et al. 2014).

[12] For a background in challenges to Arctic magnetic compass and astronavigation see Hagger (1950). Kirkko-Jaakkola et al (2020) report problems with satellite navigation at high latitudes, while Bachtel et al (2001) describe navigation issues for aircraft on trans-polar flights.

[13] At time of writing, broadband coverage north of 78^0 north reduces significantly as Inmarsat is no longer available, leaving Iridium as the only system in public use. HF links are impractical. New satellite links may address this problem.

[14] The term 'drone ambulance' in this paper refers to a UAV capable of transporting a patient, and not a machine that delivers a defibrillator or medical supplies to the scene of an emergency.

risk of losing the crew with the patient if the flight ends in catastrophic failure. However, neither of the aforementioned systems appears currently to have the capacity to carry a flight nurse with the patient, and it is difficult to see how a full spectrum of in-flight treatment could be administered.[15] Even if future developments include the capability to carry a medical attendant, use of a drone would reduce, rather than eliminate risk to crew.

Telemedicine – the use of telecommunications to provide medical advice, diagnostic support and in some cases direct guidance in a procedure – is valuable in reducing the number of unnecessary medevac referrals (Tsai et al. 2007). However, it does not eliminate the requirement for an aeromedical evacuation facility. Nor is the approach entirely reliable. In an experiment by Nikolić et al. (2006) a group of merchant marine officers were instructed in the use of ultrasound equipment to create diagnostically useful images. The resulting data gave rise to a large number of false negatives and in some cases diagnosis was impossible because the affected organ was not imaged (ibid). In fact, some of the most significant technological aids with regard to risk management reside in the realm of simulators, which have been available for some time (Allerton 2010). These enhance the skill sets of aircrews, and are making increasing contributions in the realm of medical training (De Visser et al. 2011; Ruthenbeck and Reynolds 2015; Teteris et al. 2012). Thus, human judgement remains at the heart of addressing any increment in risk in Arctic aeromedical operations.

A need to recruit more courageous aeromedical flight teams?

> "Unhappy the land that needs a hero."
> (Bertolt Brecht, "Life of Galileo")

It is tempting to think that as circumstances become more challenging, so human courage will increase to meet the need, with an increment in the risk associated with Arctic aeromedical operations conditioning an adjustment in the tolerability levels applied in risk management. Such a process of adjustment may be seen in catastrophic interludes such as war.[16] Expecting such an adjustment is a fundamental misconception of aeromedical operations and indeed, rescue work in general. A senior helicopter rescue pilot interviewed for this study put it succinctly: "We don't have heroes". Calculation saves the need for courage. Risks are managed on the basis of assessment, and human beings can be ingenious in creating solutions to seemingly insurmountable problems. Consider the case of a helicopter flight to airlift a crew member of a fishing boat to treatment. On arrival at the scene, the area was discovered to be blanketed in fog. The onboard system for measuring height accurately was ineffective, as the sea state was flat calm and provided no Doppler return.[17] A solution was found by making a radio call to another craft in the area to determine the edge of the fog bank. The fishing vessel was able to steer for the zone of better visibility, meet the helicopter and have the casualty winched aboard.[18]

However, if technological aids are an adjunct to, rather than a replacement for human judgement in Arctic aeromedical operations, the problem of decision quality in risk management becomes pivotal.

Identifying decision quality

There will be times when a patient dies during an operational incident despite the best efforts of the crew. It may be of limited comfort to the personnel involved that they 'did the right thing'. Indeed, the risks in aeromedical flights include possible psychological harms to aircrew and in-flight carers, and these risks have to be managed.[19] However, how is doing the 'right thing' to be determined in this context?

According to ISO 9000:2015(en) paragraph 3.6.2, quality is defined as the:

> "degree to which a set of inherent characteristics (3.10.1) of an object (3.6.1) fulfils requirements (3.6.4)."
> International Organization for Standardization (2015)

In this case, 'object' includes a process or service, and for an aeromedical evacuation, would include the risk management judgements made in relation to a given flight operation. The quality of these judgements is determined by how closely they align with senior management choices, and

[15] Whittaker (2018) reports that in the Cormorant, the patient communicates via a camera and that infusion bags may be hung inside the vehicle.

[16] For a classic examination of the nature of courage in war, see Lord Moran (1945). Rachman (1984) offers a more scientific treatment of the phenomenon.

[17] This example relates to the instrument fit for the AS332L1 Superpuma which employs Doppler sensing for autohover and transitional flight. A replacement, the Attitude and Heading Reference System (AHRS) utilises inertial data and is unaffected by negligible sea states (Hagen pers comm).

[18] Case reported during interview.

[19] Reid et al (2022) report a higher than average incidence of post traumatic stress symptoms in Norwegian male – but not female—ambulance crews and recommend future studies to include air ambulance personnel. A study by Luftman et al. (2017) of carers of trauma victims, reports a 43% 'at risk for PTSD development' positive screening for flight nurses.

these in turn will be informed – although not dictated – by societal preferences.

A systemic overview of aeromedical risk management[20]

To understand the full complexity of risk management judgements associated with aeromedical evacuation, it is helpful to view the pertinent decisions as a system of interrelated elements (Fig. 1). In the first element, two decisions are made; whether the clinical needs are sufficient to warrant aeromedical evacuation, and whether the patient's condition is such as to permit such action without significantly increasing the medical risk.[21] In some cases, advances in medical technology such as telemedicine may prove valuable in informing such choices (Tsai et al. 2007). Ultimately, these judgements fall to qualified medical practitioners, within whose purview resides the authority to raise the evacuation task.

The second element of the process rests with personnel of the aeromedical service, who must decide whether to accept the task. In general, this is the stage of the process over which senior management may exercise the most direct influence. Standard Operating Procedures (SOPs) form the basis of risk decisions, and are used in connection with briefing and debriefing for every mission. The briefing procedure in itself constitutes a risk assessment, and includes a list of factors to be considered if the flight is to be undertaken. In practice, it is not simply a 'tick box' exercise, and human issues associated with individual crew members, including their level of training and experience, and their fitness to fly will be incorporated into the judgement. If the task is declined, it is then the responsibility of clinicians to determine an alternative. Such issues will often have been considered in advance. Returning to the example of remote industrial installations on the North Slope of Alaska, for some cases, medical evacuation may be accomplished in whiteout conditions by transporting the patient in a vehicle following a bulldozer or wheeled loader – providing that there is road connectivity, or that permafrost conditions permit (Ash 2007).

The third element is concerned with those risks that manifest themselves during the flight itself, including any significant change in a patient's condition. In many cases, the task will be a routine one (Element 3(a)), requiring only adherence to standard operating procedures to complete successfully. This does not mean that there is no element of dynamic risk involved, but rather that those risks are managed without undue difficulty. For flights that present unanticipated risks or dilemmatic problems in which patient survival must be balanced against the potential loss of the aircraft and everyone on board (Element 3(b)), the crew will need to respond with a solution appropriate to the specific circumstances (Element 3(c). Innovation may be required in a situation that is outside those described in SOPs and checklists. In effect, a novel procedure is created, such as moderating height by a modest value to obtain good visibility, despite the guidance of SOPs. Such a decision, based on experience and circumstance specific, is undertaken with the consent of the whole crew. It should be noted in this regard that the onboard management gradient is almost flat, and conditioned by expertise, rather than rank. In such cases it is necessary to have a backup plan – a means of escape if the non-standard procedure fails.

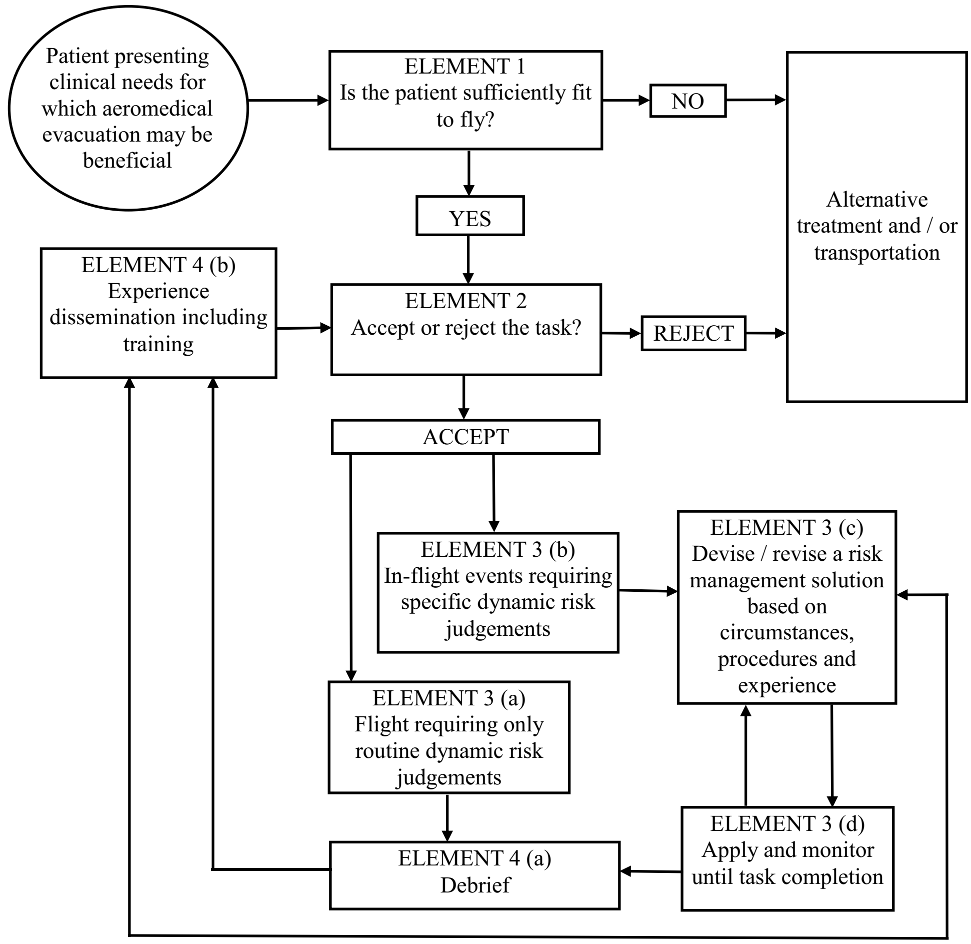
The interpretation of SOPs is grounded in a safety culture, and it is this set of shared standards that informs the choices made at Element 3(c) – in particular, the decision to say: "no, we will not do this". In the case of the helicopter service at Svalbard, the choice to abandon an airborne search operation is made by the Police Service, but for other operational impediments outwith SOPs, the rescue service culture favours waiting and attempting to devise an alternative procedure with appropriately mitigated risk. For this reason, aircrew recruitment is a key element in the risk management process. There are pilots with good skills and experience, perhaps in the merchant air service, who are unsuitable for aeromedical evacuation duties, because their ethos is too tightly bound by adherence to SOPs.

Recent research indicates that dynamic risk management decisions are made to a great extent using Recognition Primed Decision-making (RPD) processes (Klein 1998). Individuals search for cues – both visual and other—in the situation that confronts them. These cues prime a mental model of the incident type and prospective solutions, which are revised as the incident unfolds. The experience base of the decision maker(s) is enhanced and developed during the debrief (Element 4(a)) and information dissemination process (Element 4(b)), entailing the analysis of individual missions. Element 4 is a feedback system, informing the decisions in both Elements 2 and 3. The sharing of experience can be of critical benefit in solving problems in aeromedical operations. Returning to the exemplar in which a helicopter sought the assistance of another vessel in finding a boundary to the fog when trying to winch a casualty, when the incident was discussed, another airman reported that his crew had used the casualty vessel's own wake to generate sufficient Doppler for their instruments to work.

[20] Unless otherwise indicated by citation, information for this section is drawn from interview data.

[21] Varon et al. (1997 op cit.) address the issue of contraindications to the transportation of patients by air. Prina et al. (2001) report in a study of emergency air evacuations from cruise ships that physicians' assessments of patients was correct in over 90% of the cases examined.

Fig. 1 Overview of the aeromedical risk management process



In terms of decision quality, the work of Karl Weick and others is of relevance here in exploring highly reliable organisations (Weick 1987; Roberts 1990). High reliability as a concept in the field of risk science grew in response to Charles Perrow's influential Normal Accident Theory (Perrow 1984/1999). Perrow's basic concept was that human activities could be measured along two axes: complexity, and the degree to which their constituent processes were tightly bound (ibid). He argued that the more tightly bound the processes in an activity are, the greater the need for centralisation of control (ibid). By contrast, the more complex an activity, the greater the requirement for delegation (ibid). Perrow concluded that if an activity was simultaneously tightly bound in its component elements and complex, it should be avoided if the potential outcomes were catastrophic, because its management could not simultaneously be centralised and delegated (ibid).

Weick and others have questioned the validity of this view, citing cases of organisations that undertake activities that are both complex and tightly bound, yet do not evidence high rates of catastrophic accidents (Roberts 1990). Such companies and groups may be referred to as highly reliable, and at their heart there is an organisational culture in which individuals work under relatively centralised control in normal circumstances, but in emergencies know when they may act on their own judgement, informing their decisions by a set of procedures and standards promulgated from the centre.[22] In effect, this defines the 'quality' of the service being performed, because in an emergency, members of an organisation are expected to behave as senior management would, had they been present.

Application of the concept of quality to aeromedical evacuation raises a serious question. As Danielsson and Ohlsson (1999) observe in the context of emergency incidents, there are no normative solutions to dynamic risk problems. While many would agree in retrospect that certain choices in the management of an incident were wrong or harmful to a desired outcome, there may be several courses of action that give rise to a successful conclusion, or at least a conclusion that most parties would find tolerable. It is also possible

[22] It should be noted that the description of both normal accident theory and high reliability has been condensed in this account to simplify the argument line. The debate between the two positions continues.

that the application of management preferred methodologies do not bring about the survival of the patient, but the safe return of the ambulance aircraft and crew at least minimises the number of deaths and preserves the personnel and their machine as assets that may be applied to the care of other patients. Certainly, a disparity in risk tolerability levels may exist between operational personnel and management involved in rescue processes.[23] The creation of a highly reliable organisation involves an exercise in cultural permutation, the aim of which is to ensure that behaviours conform to a clearly described and promulgated set of maxims.

Informing aeromedical flight decisions for dynamic risk management

From the perspective of the service providers, perhaps the most significant aspect of the aeromedical risk decision chain is Element 2: the choice to fly the mission or not, since it entails a move from a zero flight risk scenario to managed flight risk, in circumstances in which critical hazards may not yet be evident. The medical condition of the patient may also bring challenging dynamic risk management problems at Element 3. In some cases, a decision is made to change the flight plan during a mission and transport the patient to a different destination, where it is known that more definitive care is available.[24] Such circumstances lead naturally to consideration of a relatively recent practice in informing in-flight decisions: the application of Crew Resource Management (CRM[25]). This is defined as:

> "…the effective utilisation of all available resources (e.g. crewmembers, aeroplane systems, supporting facilities and persons) to achieve a safe and efficient operation"
> UK CAA CAP 737 (2016)

CRM eschews previous, more hierarchical crew status relationships in favour of a system in which information is provided by all crew members to ensure comprehensive engagement with a given problem. The approach has also been applied with some success in the medical world (Moffatt-Bruce et al. 2017). CRM empowers all crew members to raise observations involving any aspect of safety as a broad variety of perceptions may be beneficial in activating the sensory cues that catalyse the cognitive models of emergency situations internalised by decision makers and used for RPD. Such cues may include complex combinations of information from the cockpit instruments, visual information observed through the windscreen, advice from air traffic control and sounds evident in the aircraft such as engine noise. It is for senior management to align the cue responses of crew members during Element 4 activities with preferred risk tolerance levels.

Simulation is a valuable adjunct to a training programme and has also been proposed as an aid in aircrew selection (Nergård and Ash 2019). While much thought will have to be given to establishing risk tolerability levels for the management of specific incident types, the selection, training and performance audit of personnel for aeromedical evacuation duties can be facilitated by the imaginative use of simulators. It is stressed that simulation is only one aspect of training, and in creating a highly reliable organisation, management will need to adopt a holistic approach to fully informing in-flight decisions. Such an approach may benefit from adopting a time-based perspective.

Risk management in Arctic aeromedical evacuation flights – a time-based model[26]

> "Pilots may treat with disdain the laws of man and even those of God, but without fail they all pay the greatest respect to the fuel gauge."
> Prest (1979 30)

When a helicopter takes off from Svalbard for aeromedical duties, onboard fuel allows an endurance of approximately 5 hours.[27] The clock is ticking from the moment the turbines spin up, and has probably already begun to tick for the patient. Figure 2 summarises the principal activities in the risk management process as viewed from the perspective of time, identifying three temporal domains – past, present and future. Within these are nested four generic activity types: learning, vigilance, innovation and future plans. The time phases form a continuum, with current practice informed by the past, and plans for future operations continuously revised and evolving. Flight experience underlies the creation and periodic updating of SOPs. This process is augmented by a transparent system in which innovative practice is shared, supplementing organisational learning arising from legally mandated reports of deviations from standard procedure. An assessment of the fitness of personnel to fly at the point of pre-flight briefing accounts for the continuous fluctuations in performance levels to which all human beings are subject.

[23] The author has conducted research on just such a situation in the UK Fire and Rescue Service (Ash 2003).

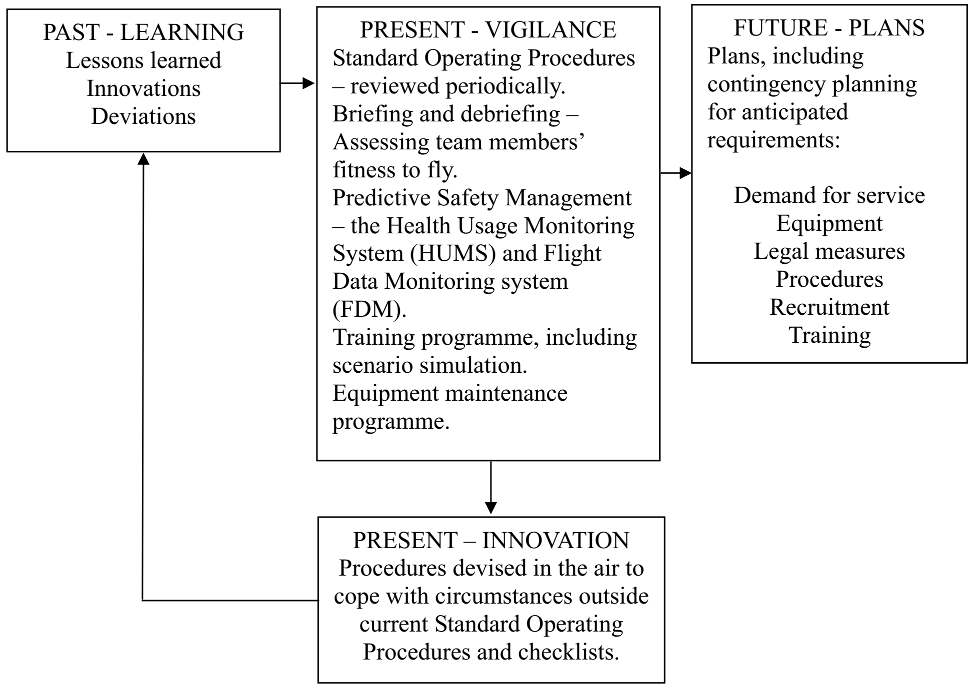
[24] Reported to the author during interview.

[25] Formerly referred to as 'cockpit resource management'.

[26] Unless otherwise indicated by citation, information for this section is drawn from interview data.

[27] At time of writing, the type of helicopter deployed at Svalbard is the Eurocopter AS332L Super Puma (helis.com 2022). Internal fuel for this aircraft provides an operational radius of some 250 miles (practical operational range from interview).

Fig. 2 A temporally predicated depiction of the aeromedical risk management process



Events occurring during flight (Fig. 1 Element 3(b) also have a strong time related component. In the case of a patient's condition deteriorating and a medical specialist on board recommending an alternative destination, the risk to the patient is reduced by collapsing the delay in the application of care. When other Element 3(b) situations obstruct the prosecution of the mission, there are well practised measures to mitigate the risks. In the case of Svalbard for example, fuel caches deployed at various points on the island increase the available endurance, while repositioning a vessel from which a casualty is to be winched may close the range – and thereby reduce flight time.

The present is also the temporal phase in which audit of risk related behaviour and processes occurs. This includes the periodic revision of SOPs, and the use of the Health Usage Monitoring System (HUMS)[28] and FDM (Flight Data Monitoring). These systems collect real time information from the sensors on the helicopter. The HUMS provides data on the aircraft itself, for maintenance planning. The FDM identifies when performance standards are exceeded, and to what extent. For example, if prescribed rates of descent or hover heights are transgressed. An independent human moderator examines and forwards information to flight management in order to identify undesirable trends. Such behaviours may indicate the development of elements in trajectories of opportunity, potentially resulting in serious incidents (Reason 1997).

The management of future risk is largely a matter of studying the interaction of present socio-economic, technological and environmental trends. In the case of Svalbard, a significant increase in maritime traffic includes large capacity cruise ships, which present a challenging rescue problem in any waters (Button and Gorgol 2019). The Arctic environment intensifies this risk, while increased visitor numbers brings a cumulative risk increment. A strategy proposed to mitigate this risk is to match potential casualties to an anticipated *rate* of rescue capability. Once again, a time related process. This recommendation, by a committee appointed by the Norwegian government, limits the number of persons a cruise ship may have on board in the territorial waters of Svalbard (Cruise Committee 2022). In a Mass Rescue Operation, casualties would be accommodated in inflatable shelters while waiting to be flown to places of safety. The shelters can be loaded in the helicopters in a matter of minutes and deployed to provide temporary refuge.

Time as a measure for managing risk – application in practice

The following proposals derive naturally from the above analysis and are offered both as prospective solutions for extant problems, and also as areas of potential future research. They are not exhaustive, nor are they intended to be.

1. Risk mitigation by gaining additional flight time. By definition, increased flight hours bring an increase in risk, as this may be predicted on the basis of failure *per unit time*. However, additional endurance provides addi-

[28] For a technical description of the HUMS system, see Romero et al. (1996).

tional *time on task*, potentially reducing crew pressure, and bringing some distant casualties within range.

2. Risk mitigation through enhanced casualty time efficiency. Re-routing a mission directly to a facility able to provide definitive care *sooner* is an obvious exemplar.
3. Risk mitigation through constant vigilance. *Continuous* audit of both aircrew performance and the in-flight condition of casualties potentially reduces risk.
4. Risk mitigation through anticipated future service demand. A strategy of clear benefit is to restrict service demand to available supply; that is, apply measures to reduce the number of potential casualties to the *rate* at which assistance can be provided.

Conclusions

This paper has addressed the question:

> "In what respects is risk likely to increase in Arctic aeromedical evacuation and search and rescue flight operations, and what measures can be applied to improve decision quality in the management of those risks?"

The Arctic environment may be characterised by a combination of time-related limitations, which increase the risk involved in aeromedical flights and compound the time related medical risk to the casualty. Climate change is increasing the risk, and while some technological advances may provide some mitigation, human judgement is central to the management of the problem. Decision quality as a concept stems from a shared perception of risk tolerability in specific situations. The promulgation by senior management of clear standards and limits of acceptable behaviour is key to the development of a highly reliable organisational safety culture. In nurturing that culture, an aeromedical risk management decision system predicated on time matches the time-pressured challenges of the Arctic environment.

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Author contributions The author conducted the data collection, analysis and composition for this paper.

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Data availability The dataset generated during and/or analysed during the current study is not publicly available for reasons of respondent confidentiality but is available from the corresponding author on reasonable request.

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