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AN ANALYSIS OF HELICOPTER EMS ACCIDENTS USING HFACS: 2000-2012

By  
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B.Eng., Royal Military College of Canada, 2005

A Thesis Submitted to the  
Department of Human Factors & Systems  
in Partial Fulfillment of the Requirements for the Degree of  
Master of Science in Human Factors and Systems

Embry-Riddle Aeronautical University  
Daytona Beach, Florida  
Spring, 2014

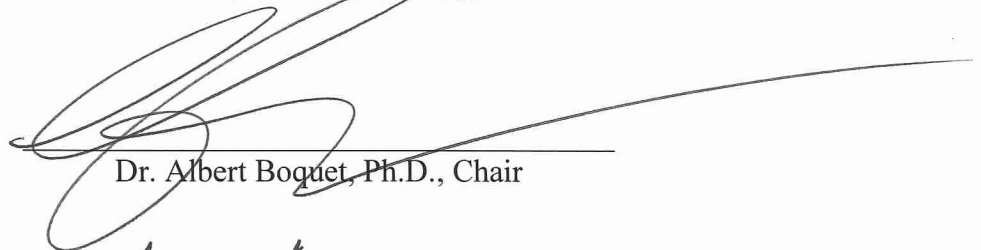
AN ANALYSIS OF HELICOPTER EMS ACCIDENTS USING HFACS: 2000-2012

by

Christopher G. Bryan

This thesis was prepared under the direction of the candidate's thesis committee chair, Dr. Albert Boquet, Ph.D., Department of Human Factors & Systems, and has been approved by members of the thesis committee. It was submitted to the Department of Human Factors & Systems and has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Human Factors & Systems.

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## Introduction

In 1972, the first hospital based civilian helicopter emergency medical service (HEMS) in the United States began operations. While the use of helicopters to transport medical casualties started decades previously, St. Anthony Flight for Life represented the start of an industry that would grow rapidly in the years to follow, both in the US and around the world (Flight for Life Colorado, n.d.).

Helicopters provide a valuable contribution to the field of medicine. They are faster than ground-based transportation and able to reach areas considered otherwise remote or impassible. They are highly manoeuvrable, unhindered by traffic, and can land in confined spaces. Further advancements, such as the use of advanced life support equipment and flight medical personnel have further improved patient outcomes.

After a decade of growth, a disturbing trend emerged in the air ambulance sector. In the early 1980s, the National Transportation Safety Board (NTSB) observed a marked rise in aviation accidents involving ambulance helicopters. Since then it has been observed that there are a disproportionate number of accidents in HEMS flying compared to other types of flying, including fixed-wing EMS. This phenomenon has been the subject of numerous articles, government reports, and news stories (e.g. NTSB, 1988; Harris, 1994; Wright, 2004; Veillette, 2005; and Negroni, 2009).

By its nature, HEMS operations pose more risks than other types of flying. Unscheduled flights into unfamiliar areas and semi-prepared landing surfaces ostensibly increase the chance of an accident or incident. However, examination of HEMS operations in other countries show that the risk is more pronounced in the US than other countries (Table 1). The US had an accident rate in 2000-09 that was both higher than other countries and the previous decade. It also has the highest fatal accident rate, considering that the Australian rate in 2000-09 was the result of a single HEMS crash in 2003.

Table 1

*Accident and fatal accident rates by decade for select countries*

| Decade  | Accidents per 100K flying hours |                  |                  | Fatal accidents per 100K flying hours |                  |                  |      |
|---------|---------------------------------|------------------|------------------|---------------------------------------|------------------|------------------|------|
|         | US                              | AUS <sup>a</sup> | GER <sup>b</sup> | US                                    | AUS <sup>a</sup> | GER <sup>b</sup> | CAN  |
| 1980-89 | 11.43                           |                  | 5.96             | 4.49                                  |                  | 0.90             | 0.00 |
| 1990-99 | 3.04                            | 5.10             | 4.51             | 1.26                                  | 0.00             | 0.99             | 0.00 |
| 2000-09 | 4.49                            | 3.82             | 2.60             | 1.43                                  | 2.49             | 0.43             | 0.00 |

*Note.* US data compiled from NTSB, 1988, 2011; Blumen et al., 2002; Harris, 1994; Connell and Reyanrd, 1995; and Wright, 2004. Australian data compiled from ATSB, 2012; Holland and Cooksley, 2005; and BITRE (personal communication, March 11, 2013). German data adapted from Hinkelbein, Schwalbe, Neuhaus, Wetsch and Genzwürker, 2011. Canadian data adapted from Seguin, 2009.

<sup>a</sup>Austalian data only available from 1992 onward. <sup>b</sup>Original German accident rates were provided in per missions flown. Data was converted to flight hours using an approximation of 1 mission = 1.4 flight hours.

## Literature Review

As a result of these findings, numerous HEMS operators, commercial aviation associations and industry experts have examined the issue and proposed a variety of causes. Negroni (2009) points to the use of HEMS transportation in non-time critical situations, increasing risk exposure (i.e. flying carries an inherent risk, so the chances of an accident will increase with the amount of hours flown) without a commensurate increase in benefit. This in turn is caused by the competitive pressures being developed by the for-profit nature of many HEMS operators. Additionally, she cites the industries collective failure to embrace optional safety technology such as dual engines, instrument flight rules (IFR) equipment and terrain avoidance warning systems (TAWS). This, coupled with a perceived lack of regulatory oversight, drives the troubles in the industry.

Another position on the reasons for an elevated accident rate is found in Macdonald (2009). In his assessment, the necessary regulations and best practices are well-known; the problem is that they are not being followed. He believes that this failure of pilots and other aircrew to heed rules and experience comes from a lack of a safety culture within most HEMS operations. Similar to Negroni, he cites profit motivations in industry as the ultimate root cause.

A review of a series of articles by Veillette (2005, 2008a, 2008b) provides other causes. Lack of local weather reports, organizational pressure on pilots to fly in marginal conditions, conducting cruise flight at low level, unprepared landing zones, abbreviated planning cycles, fatigue and the large amount of non-routine flying are all proposed as root causes.

The obvious difficulty with all of these analyses is their lack of scientific rigour. Causes are primarily derived from logical argument or personal experience. While these can be valuable sources of insight, the varied nature and geographic location of HEMS operators precludes generalizing these results. According to Flanigan & Blatt (2011), there are HEMS operators in 48 states (Rhode Island and Vermont are the exceptions). Each are affiliated with medical facilities to a varying extent, with some owned and operated by a particular hospital, others that are freelance, and the remainder falling somewhere in between. There are both public and private operators, and the latter can be further broken down into for-profit and non-profit. In short, it is difficult to consider any individual HEMS operation as a representative sample.

A review of academic literature shows that some research has been conducted in the area of HEMS accidents, mostly of the epidemiological variety. Through archival research (primarily the NTSB aviation accident database), salient characteristics of each accident are extracted and aggregated for a time period of interest. The resulting data is then analyzed for trends. This method has yielded several interesting and occasionally counterintuitive conclusions about the nature of HEMS accidents.

One study found that the presence of post-crash fires, inclement weather and darkness significantly increased the odds of an accident being fatal (Baker et al., 2006). Another showed that accidents in general occurred equally during the day and the night (Frazer, 1999). Frazer also revealed that the vast majority of pilots involved in HEMS accidents have over 2000 hours of flight experience yet two-thirds of the accidents were attributed to pilot error.

Numerous other statistics are available, but there are challenges in applying the information. First, some of the statistics shift noticeably depending on the timeframe examined. For example, Veillette (2001) examined a period of 1987 to 2000 and Frazer (1999) looked at 1978 to 1998. In comparing characteristics that were examined by both studies, there were five measures where different results were reported (Blumen et al., 2002). While this suggests that year-to-year variations are a potential confound, the more important lesson is that the selection of

a timeframe for examination should be purposeful rather than arbitrary, given that they cannot be generalized to another period of time.

Another major group of stakeholders making contributions to this area of research are government agencies. The goal of these government reports is to provide actionable recommendations that are likely to address the accident rate in a timely manner. As a result, this body of work represents a hybrid between the academic research and trade articles. The analysis of the accident data is more rigorous than the magazine articles, but less than the refereed papers. Additionally, the recommendations made are specific and directed to particular organizations, as opposed to the general and tentative recommendations made in magazines and journals respectively.

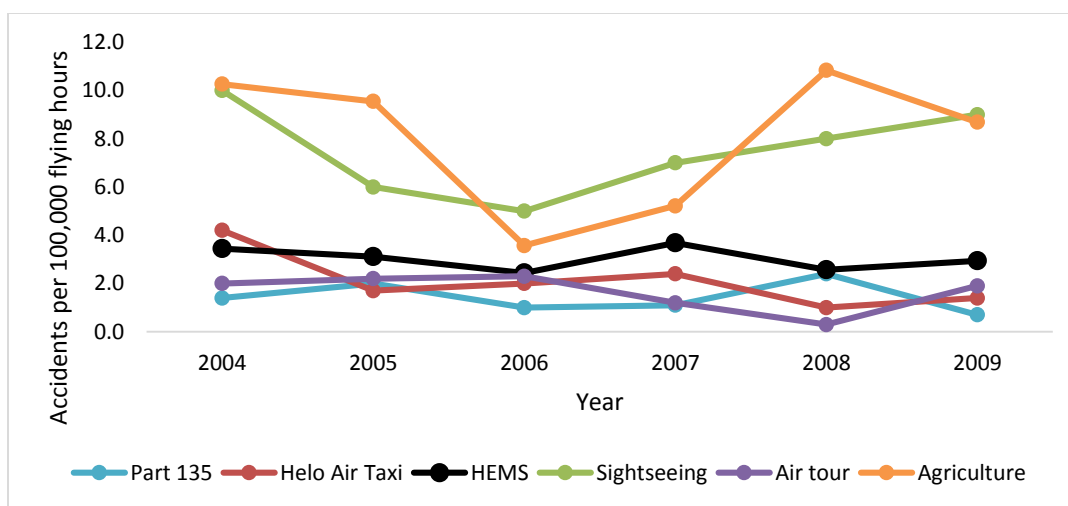
The three government agencies involved with HEMS are the Federal Aviation Administration (FAA), National Transportation Safety Board (NTSB), and the National Aeronautics and Space Administration (NASA). While NASA is normally considered an aerospace organization, they do administer the Aviation Safety Reporting System (ASRS) which allows persons involved with aviation to anonymously submit incident reports to an organization with no regulatory enforcement mandate.

While these agencies share a common interest in reducing the HEMS accident rate, their overall vision for solving the problem varies. The NTSB believes more stringent regulation in several areas such as the reporting of exposure data, installation and use of safety enhancing technologies, and government oversight (NTSB, 1988, 2006, 2009). By contrast, the strategy employed by the FAA is to ensure HEMS operators have access to the knowledge, training and tools required to safely conduct operations through the use of advisory circulars, industry consultations and national airspace system (NAS) infrastructure enhancements (Rigsby, 2005; NTSB, 2006). NASA's role is generally limited to consolidating and summarizing HEMS incidents, but their one analysis of these incidents concluded that HEMS pilots were carrying a disproportionate share of the operational responsibilities relative to the operational support they were receiving. Their solution can be summed thusly: "The acknowledgement of the pilot's role and membership in this [EMS] team is important in order to develop constructive mechanisms that incorporate realistic expectations among all participants of the EMS operation." (Connell & Reynard, 1993, p. 7)

It is clear that there is a diversity of opinions on the causes of and solutions to this problem. One consistently drawn conclusion is that the proximate cause of a majority of HEMS crashes is human error (e.g. Veillette, 2001; Bledsoe, 2003). While mechanical failures have caused some accidents, they are the minority compared to human causes such as obstacle strikes and controlled flight into terrain. Unfortunately, review of the existing literature could find no in-depth and systematic analysis of the particular human errors being committed and if there were any associations between certain errors and external environmental influences (e.g. time of day, weather.)

## History

In viewing the literature as a whole, a narrative emerges. Civilian HEMS operations have been carried out in the United States for forty years, growing from a nascent capability at one hospital to a complex system that provides medical evacuations and transfers throughout the country. Its elevated accident rate, first observed over twenty-five years ago, has been scrutinized by government agencies, medical and aviation organizations, academics and popular media. Interventions have been prescribed and implemented, the number of safety-enhancing technologies available has increased and the collective body of knowledge in the areas of safety and risk management have been greatly expanded. Progress has clearly been made, but as can be seen by Figure 1, it is still one of the riskiest types of commercial helicopter flying in the United States.



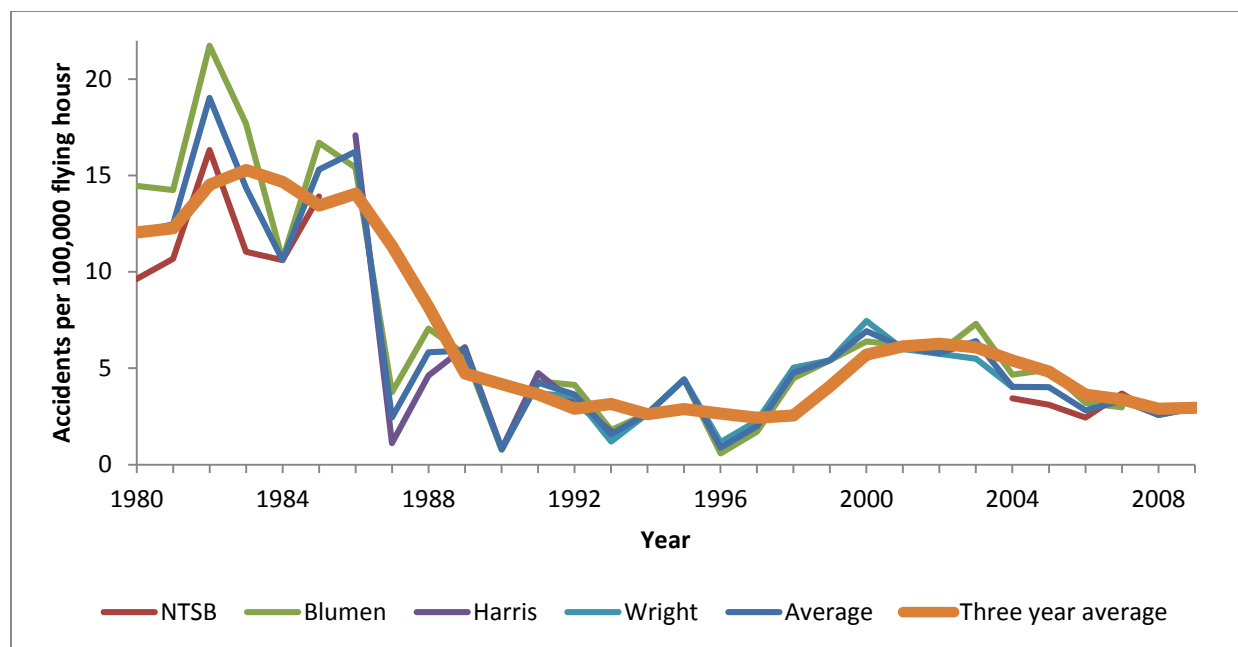
*Figure 1.* Comparison of accident rates between various commercial helicopter roles. The line titled “Part 135” represents the accident rate for all commercial flying less major airline operations. Adapted from NTSB, 2009.



It should be pointed out that although the accident rates of sightseeing and agricultural activities are much higher than the remainder, they are skewed upwards by the relatively low number of hours flown in these roles.

This is not to say that the accident rate for HEMS operations have remained constant over the last forty years. When the accident rate is plotted over the lifetime of the industry (Figure 2), a set of distinct periods appear. The period from 1980-1987 is marked by a double-digit accident rate as well as a rapid expansion in HEMS programs. After relatively modest growth in the 70s (from 1 program in 1972 to approximately 20 in 1978), the number of HEMS operators expanded rapidly. By 1987, there were approximately 155 HEMS operations in the US (NTSB, 1988). The cause of this rapid growth was never exhaustively researched, but Mackenzie et al. (1986) concluded “that financial incentives play a major role in the rapid growth rate of HEMS Programs at UHs [University Hospitals] and other TCHs [Tertiary Care Hospitals]” (p. 37).

The accident rate in the period from 1988 to 1998 began with a precipitous decline and remained both steady and relatively low. This was likely a result of increased attention and scrutiny from the NTSB and other stakeholders in the HEMS industry. For example, the Association of Air Medical Services (AAMS, known at the time as ASHBEAMS), published the results of an aeromedical safety survey they conducted with the express aim of investigating what they deemed as “alarming safety problems” (Moriarty et al., 1987, p.50). Efforts such as these investigations spurred a number of regulatory changes by the FAA, primarily the issuance of advisory circulars for HEMS operations. In parallel, the AAMS created the Commission on Accreditation of Air Medical Services (CAAMS), an organization that developed and maintained accreditation standards for air medical transportation. Additionally, CAAMS (now known as CAMTS) started to provide voluntary accreditation evaluations.



*Figure 2.* Plot of HEMS accident rate from 1980 to 2009. There is no one coherent source for the entire thirty year period, so the average line is a composite of the available data. The three-year average line represents the mean accident rate for that year and the two previous. Data compiled from NTSB, 1988, 2011; Blumen et al., 2002; Harris, 1994; and Wright, 2004.

From 1999 to 2005 there began another rise in the accident rate. Similar to the 1980 to 1986, this rise coincided with a rapid growth in HEMS operations. While the number of helicopter air ambulances doubled in the ten years between 1990 and 2000, it had doubled again by 2005 (Elias, 2006; Flanigan & Blatt, 2011). A number of sources (e.g. Elias, 2006; Dillingham, 2009; and Negroni, 2009) attribute this growth to Medicare fee schedule changes that were mandated in 1997 and implemented beginning in 2002. A thorough explanation of the changes can be found in Dillingham (2009), but the fundamental result was that a for-profit, independent provider operation became an increasingly viable model. Previously, hospital based providers were able to conduct patient transports at a loss because the hospital recovered the costs from increased treatment revenues, something that an independent provider did not have access to. The fee schedule changes in a sense “leveled the playing field”.

Another parallel with the 1980 to 1986 period was the increased popular and governmental scrutiny on HEMS operators. A number of reports, both in media and academic literature were published in 2006. Most notably, the NTSB conducted a special investigation into EMS operations as a result and published a number of recommendations (NTSB, 2006). Starting

in 2006, the accident rate returned to the level seen in the 90s and has remained steady since then.

### **Problem Statement**

Despite this encouraging downwards trend, this accident rate remains quite troubling from an occupational health and safety perspective. Blumen et al. (2002) conducted an analysis of work-related deaths and injuries amongst HEMS personnel (i.e. pilots, flight nurses, etc.). What was discovered was that the odds that aircrew in the HEMS industry in any given year would die of a HEMS accident was 1 in 1,158, which “exceed[s] that of motor-vehicle accidents and all other accidental deaths” (p. 42).

Abernethy, Bledsoe and Carrison (2009) state the problem more bluntly:

Imagine that several times a year (approximately every 50,000 procedures) there was a cardiac catheterization lab accident in which the medical team (cardiologist, nurse and technician) perished along with their patient. There would be an immediate outcry to make the procedure safer (technology, practices, safeguards) and reduce risk for the patient and providers. Second, all cath lab procedures would undergo intense scrutiny to assure appropriate utilization. Although such a scenario may seem outrageous, it is essentially the same risks that helicopter EMS (HEMS) crews face on a daily basis. In fact, HEMS transport is the only medical procedure that holds a much higher morbidity and mortality for the providers than it does for the patient. (para. 1)

The set of interventions that will efficiently and effectively reduce the accident rate to an acceptable level already exists. Unfortunately, it is buried in an even larger set of proposed interventions. Blumen (2002) alone lists almost 70 possible strategies, rated on the two axes of effectiveness and feasibility. Implementing them all is clearly impossible from both a time and money perspective. Further compounding the issue is that there has been little investigation into the relationship between specific interventions and previous accident rate reductions. As well, the interventions are well linked to the problem they intend to solve, but there has been almost no research that scientifically quantifies the contribution of a given deficiency to the overall accident rate.

## Methods

In fairness, accident investigation is resistant to rigorous experimentation. Simulation of situations that may lead to injury or death must paradoxically not allow the possibility of injury or death, severely limiting the generalizability of any findings. As such, research in this field is more focused on archival research, attempting to learn from the accidents that have happened. With such a dataset, control of confounding variables is not possible, forcing researchers to adopt non-experimental techniques.

One such avenue is in the area of human error. As mentioned in the literature review, the cause of most HEMS accidents is human error. This finding is consistent with observations made in other aviation fields, whether it be in commercial, military, or general purpose flying (Wiegmann & Shappell, 2003). Therefore, if specific modes of human error can be systematically extracted from the body of HEMS accidents and associated with environmental and physical factors, specific problems contributing disproportionately to the overall accident rate may be identified. Thus it becomes possible to recommend interventions based on scientific evidence in addition to expert opinion and experience.

The Human Factors Analysis and Classification System (HFACS) is a taxonomy intended for use by accident investigators attempting to classify the human factors that contributed to the accident (Shappell et al, 2007). It is an implementation of Reason's (1990) "Swiss cheese" model, which posits that in addition to an immediate cause (or active failure), all accidents also have a number of latent failures that were pre-conditions necessary for the active failure to finally cause the accident. This system has been repeatedly shown to be an effective tool in civil aviation accident investigation (e.g. Wiegmann & Shappell, 2001; Dambier & Hinkelbein, 2006).

As shown in Figure 3, the taxonomy is divided into four levels: unsafe acts, the proximate causes of the accident; preconditions for unsafe acts, latent failures that precipitated the active causes of the accident; unsafe supervision, failures of leadership and management; and organizational influences, systemic deficiencies that facilitate latent and active failures at the other levels. It is this system that will form the core analytical technique of this retrospective study.

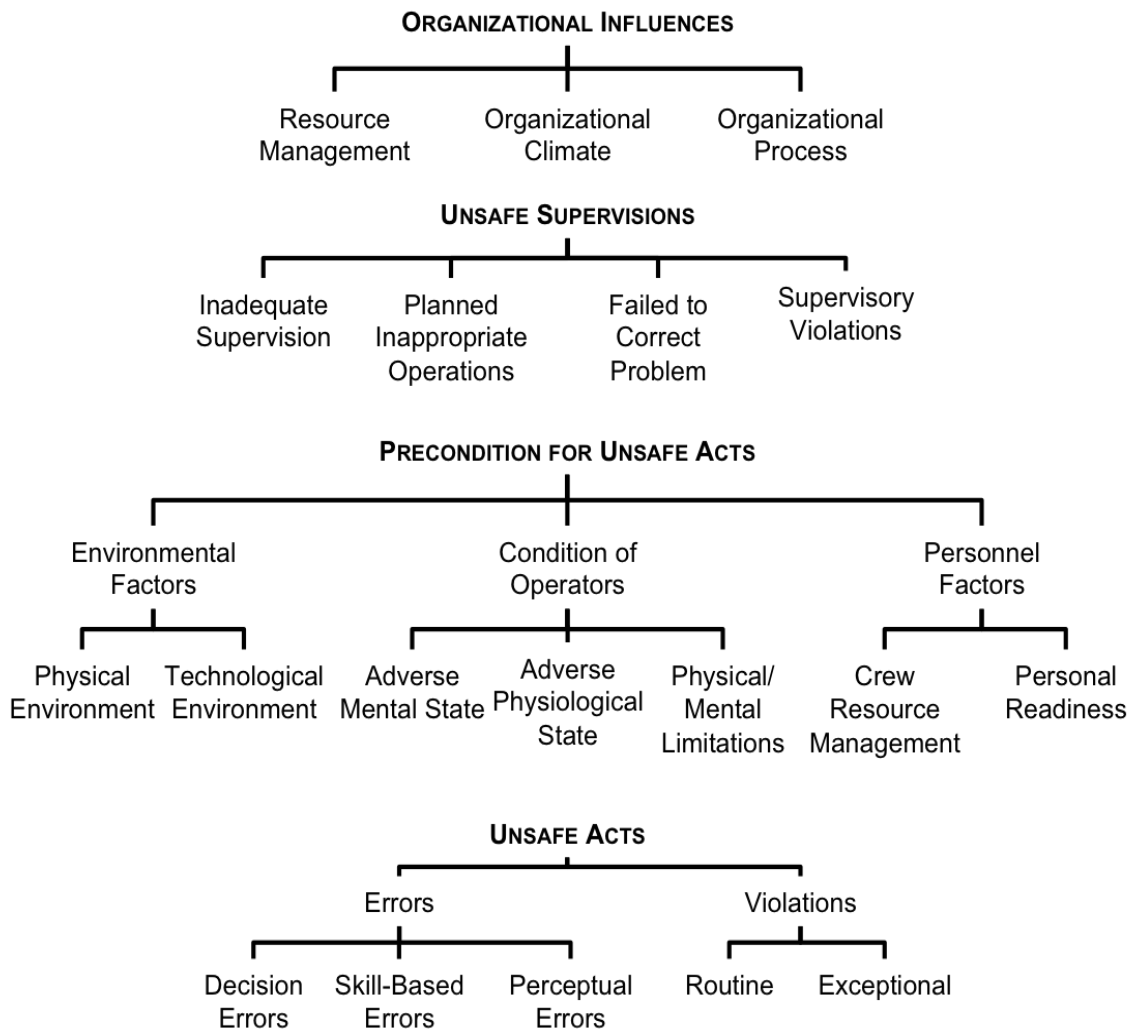


Figure 3. The HFACS framework. Reprinted from “Human Error and Commercial Aviation Accidents: An Analysis Using the Human Factors Analysis and Classification System” by Scott Shappell, Cristy Detwiler, Kali Holcomb, Carla Hackworth, Albert Boquet, and Douglas A. Wiegmann, 2007, *Human Factors*, 49(2), p. 229. Copyright 2007, Human Factors and Ergonomics Society.

### Source data selection

The NTSB has been charged by the US government to be the lead investigative authority for all aviation accidents (49 U.S.C. § 1132). In carrying out their mandate, they have developed a publicly-available database replete with hundreds of details about each investigated accident. Almost all of the literature reviewed used this database to some extent and it will be the primary source of data for this analysis.

Given that the current upward trend in HEMS accidents began at the start of this century, a time frame of 2000-2012 was selected. Relevant cases were extracted through two means.

First, multiple keyword searches were performed on all helicopter accidents in the chosen timeframe. Second, the list of accident file numbers used to determine total helicopter air medical accidents in NTSB (2011) was obtained. The two data sets were merged and the resultant union of 259 cases were read to determine applicability.

The initial exclusion criteria applied was the removal of all accidents that occurred entirely outside the United States (i.e. the accident helicopter did not take-off, land, or intend to take-off or land anywhere in the US, including territories, coastal waters or protectorates). Additionally, any cases that were extracted as a result of a keyword false positive (e.g. when searching on the keyword “hospital”, it was found several accidents contained narratives such as “the pilot was later interviewed at the hospital”). This reduced the number of relevant cases to 174.

In order to capture accidents that reflected the unique nature of HEMS operations, certain accidents involving air ambulance helicopters were excluded. Maintenance, proficiency, check, training and publicity flights were all excluded as none of these flights were a result of a patient needing to (or potentially needing to) be moved. An exception to this criterion was training accidents that were simulating maneuvers and procedures used during HEMS operations. This further reduced the number of accidents of interest to 147.

### **HFACS coding protocol**

The selected case files were analyzed to determine the HFACS cause factors involved in the accident. The analysis was conducted by three graduate-level human factors students, each with approximately 30 to 60 hours of HFACS training and coding experience. The composition of the team did not change over the course of the analysis. The protocol that was followed for the review of each case is as follows:

1. The panel was presented with the case. All three members read the file concurrently. Only the factual report, summary, and probable cause were examined. While some of the accidents have a more thorough accident docket (e.g. serious accidents are normally the subject of a blue-ribbon report), initial assessment of the accidents of interest found that the lowest common denominator was the three data previously mentioned. Conversely, if an accident file did not have these three data fields (e.g.

- only a preliminary report is available), no attempt to determine HFACS cause factors was made.
2. The facts presented by the report were assumed to be true (i.e. no attempts to infer, extrapolate or second guess the information were made). Given that the reports represent the consolidation of a larger body of information that the panel were not privy to, the only consistent and repeatable approach to analyzing the facts was to accept them uncontested.
  3. Any statements made by accidents witnesses in the case file were assumed true unless they are directly refuted by the NTSB investigation. If a witness statement conflicts with NTSB findings but is not explicitly challenged, both the statement and the finding will be considered true, even if it is logically impossible. This is required because it was not possible for the panel to determine which version of events is accurate.
  4. No attempt to differentiate between routine and exceptional violations was made. The timeframe examined in each accident is normally too narrow to establish if a violation was habitual and implicitly accepted by the organization.
  5. When a panel member identified a cause factor, they brought to the attention of the other two members. If the other two concurred, it was recorded. If not, discussion of the cause factor continued until a unanimous agreement was reached.
  6. When it became apparent that continued discussion would not yield a collective decision, the cause factor was temporarily tabled pending discussion with an expert HFACS coder.
  7. After discussion of a discordant factor with the HFACS expert, another attempt at consensus was made. If it wasn't reached, then the decision was made by a simple majority vote by the panel and the expert, with the expert's vote counted twice.

At the conclusion of coding all of the case files, a random 10% sample was recoded blind. That is, the panel was not provided with the factors they previously chose for the particular file. The results of this exercise yielded 80% concurrence between the two rounds of analysis. On the advice of an HFACS expert, the group reviewed all of the cases a second time (this time with access to the previous decisions) to ensure consistency. This exercise yielded a change of approximately 10% of the factors. Causes for the changes varied, but most were due to coding of

cause factors that were not in the probable cause (but were in the narrative) and ambiguity as to whether a cause factor needed to be split into two factors or two factors needed consolidation.

### **Epidemiological data extraction**

As previously mentioned, the NTSB has made its database of aviation accident case files publicly available. In addition to the narrative fields, each accident record contains around 100 different data fields. Some of them were used to determine the cases of interest (e.g. occurrence date and type) but the majority remain unexploited.

Since the database is machine readable, extracting the fields of interest is as simple as creating the necessary database query. The difficulty lies in determining the fields of interest. The approach was to make field selections based on previous research as well as fields likely to support specific areas of inquiry. For example, accident time of day and total flight hours of the accident pilot are fields that may provide insight into the stated problem, either by themselves or associated with HFACS cause factors.

One field that was manually coded was the HEMS phase of flight for each accident. While the NTSB provides the generic phase of flight (takeoff, transit, approach, etc.), the mission profile flown during the HEMS operations under examination is not aligned with the NTSB's taxonomy. For example, a HEMS mission consists of three separate landings: arrival at patient pick-up, patient drop-off, and base of operations.

In order to capture this, the accident HEMS phase of flight was determined concurrent with the HFACS analysis. The HEMS phase of flight was determined by considering the following three aspects:

1. Generic phase of flight (takeoff, transit or landing)
2. Destination at time of accident (patient pick-up, patient drop-off, or base of operations)
3. Type of patient movement (retrieval from accident site or inter-hospital transfer)

If any of these aspects cannot be definitively determined through examination of the accident file, that aspect was declared "unknown".

In addition to the NTSB accident database, supplementary data was needed for some of the avenues of inquiry. For example, exposure data (i.e. yearly flying rates) was required to normalize some of the aggregate accident data.



## **Aim**

The primary task of this study was to attempt to associate specific modes of human error with physical and temporal characteristics present in HEMS accidents. The intent of this epidemiological research was identify commonalities in frequent HEMS accident scenarios and provide evidence-based support for one or more specific intervention strategies.

In addition to conducting an HFACS analysis of the accident set, data was gathered to support investigation into a number of hypotheses and assertions made by literature on this subject. While there were a plethora of such issues to examine, the following were deemed to be the most feasible to address and most likely to yield useful information.

**Are there any geographical association between accident rate and density of HEMS operations?** Ostensibly, there should exist a simple positive association between population density, number of HEMS operations and number HEMS accidents. That is, a greater population would be served by a greater number of HEMS operations flying a greater number of hours resulting in a higher number of accidents. However, cursory examination of the data suggested that this may not be the case, and further investigation was required.

By superimposing the locations of HEMS accidents on a map showing the relative HEMS operation density (e.g. number of HEMS operations per 1000 people), it can be seen if there are any geographical dimensions to this issue. For example, it may be found that mountainous terrain is associated with elevated accident rates or a particular urban area shows a disproportionately low number of accidents.

**Does conducting HEMS operations under part 91 impose a higher risk than part 135?** The federal air regulations (FARs) provide different rules for each category of flying. When an ambulance helicopter is traveling without a patient, it is subject to the rules in FAR part 91 (general aviation). However, once a patient is onboard, they must also follow the rules in FAR part 135 (on-demand and commuter operations). According to NTSB (2011), between 2004 and 2009 the HEMS accident rate during part 91 flying was, on average, 20 times higher than the HEMS accident rate during part 135 flying.

NTSB (2006) posited that requiring EMS flights to operate under part 135 regardless of whether a patient was onboard would reduce the accident rate. Their reasoning was that requiring HEMS operators to follow more stringent guidelines for all phases of HEMS flying would prevent pilots from finding themselves in situations likely to lead to an accident (there are a

number of differences between part 135 and 91, but the major difference is that part 135 has stricter weather minima and imposes restrictions on the length of time that a pilot can be available for flying duties without rest.)

While there is a relationship between higher accident rates and part 91 HEMS flights, the potential efficacy of the NTSB's recommendation has not been established. An alternate explanation is that the phases of flight that don't involve a patient onboard are inherently more risky. One example would be landing at a remote accident site, an inherently riskier scenario given unfamiliar terrain, ad hoc site preparation and a lack of specific wind information. These risks exist whether a pilot flies under part 135 or part 91 regulations. To this end, this study investigated this issue by determining how many part 91 accidents would have been prevented through adherence to part 135 rules.

### Results

The accidents of interest were divided into four broad categories: Investigation incomplete (NTSB had not yet published a probable cause), unforeseeable/unknown (cause was not or could not be attributed to the actions of the accident aircrew), foreseeable mechanical failure (caused by either improper maintenance or manufacturing defect), or human error. The breakdown is presented in Table 2. If an accident was determined to be in one of the first three categories, the panel ceased their analysis. As expected, human error was the predominate cause of HEMS accidents (69%). These accidents were further analyzed by the panel using the previously described procedure.

Table 2

*Number of HEMS accidents by category*

|                                     |            |
|-------------------------------------|------------|
| Human error                         | 101        |
| Unforeseeable/Unknown               | 21         |
| Improper maintenance/Defective part | 12         |
| Investigation incomplete            | 13         |
| <b>Total</b>                        | <b>147</b> |

## Phase of flight

Another piece of data gathered from the HEMS accidents was the phase of flight where it occurred. Table 3 presents the breakdown for all of the accidents, as well as those that were fatal and those that involved human error. In each breakdown, over half of the accidents (three quarters for fatal) are described by only a third of the phases. As a result, the top three human error phases of flight were subjected to further analysis. The breakdown of specific human error is shown in Table 4. Graphs of the breakdown can be found in Figure 4. Errors in the organizational influences and unsafe supervision categories were not graphed as they only represented 3% of the total errors found. This was an expected result as investigation into higher-level root causes are normally not conducted by the NTSB investigations.

Table 3

*Number of HEMS accidents by phase of flight*

| Phase                             | Accident Type |           |             |
|-----------------------------------|---------------|-----------|-------------|
|                                   | All           | Fatal     | Human Error |
| Launch                            | 19            | 1         | 11          |
| Transit to patient                | <b>32</b>     | <b>14</b> | <b>19</b>   |
| Land at patient site <sup>a</sup> | <b>23</b>     | 5         | <b>20</b>   |
| Take-off from patient site        | 12            | 1         | 10          |
| Transit to hospital               | 17            | <b>11</b> | 12          |
| Land at hospital                  | 7             | 2         | 3           |
| Take-off from hospital            | 9             | 1         | 5           |
| Transit to home base              | <b>22</b>     | <b>13</b> | <b>16</b>   |
| Land at home base                 | 6             | 2         | 5           |
| Total                             | 147           | 50        | 101         |

*Note.* The top 3 accident phases of flight for each type are bolded.

<sup>a</sup>Of the accidents that occurred while landing to pick up a patient, 22 were at improvised landing sites and 1 was at a hospital.

Table 4

*Breakdown of human error present in selected types of HEMS accidents*

| Category                  | Sub-category                             | Accident type |       |                      |                    |                      |
|---------------------------|--|---------------|-------|----------------------|--------------------|----------------------|
|                           |  | All           | Fatal | Land at patient site | Transit to patient | Transit to home base |
| Organizational influences | Organizational process                   | 3             | 2     | 1                    | 0                  | 0                    |
|                           | Resource management                      | 1             | 1     | 0                    | 0                  | 1                    |
| Unsafe supervision        | Failure to correct known problem         | 1             | 1     | 0                    | 0                  | 0                    |
|                           | Inadequate supervision                   | 2             | 2     | 0                    | 0                  | 1                    |
|                           | Planned inappropriate operations         | 1             | 0     | 0                    | 0                  | 0                    |
| Preconditions             | Adverse mental state                     | 11            | 6     | 0                    | 2                  | 1                    |
|                           | Adverse physiological state              | 17            | 8     | 2                    | 5                  | 7                    |
|                           | Communication, coordination and planning | 16            | 8     | 3                    | 1                  | 1                    |
|                           | Fitness for duty                         | 1             | 0     | 0                    | 0                  | 0                    |
|                           | Physical environment                     | 49            | 17    | 15                   | 7                  | 7                    |
|                           | Physical/Mental limitations              | 9             | 7     | 1                    | 3                  | 2                    |
|                           | Technological Environment                | 2             | 1     | 0                    | 0                  | 1                    |
| Unsafe Acts               | Decision error                           | 20            | 8     | 3                    | 4                  | 4                    |
|                           | Perceptual error                         | 34            | 17    | 8                    | 4                  | 11                   |
|                           | Skill-based error                        | 53            | 11    | 12                   | 9                  | 4                    |
|                           | Violation                                | 14            | 10    | 0                    | 5                  | 4                    |
| Total                     |  | 234           | 99    | 45                   | 40                 | 44                   |

*Note.* Only the first instance of a specific sub-category is counted per accident.

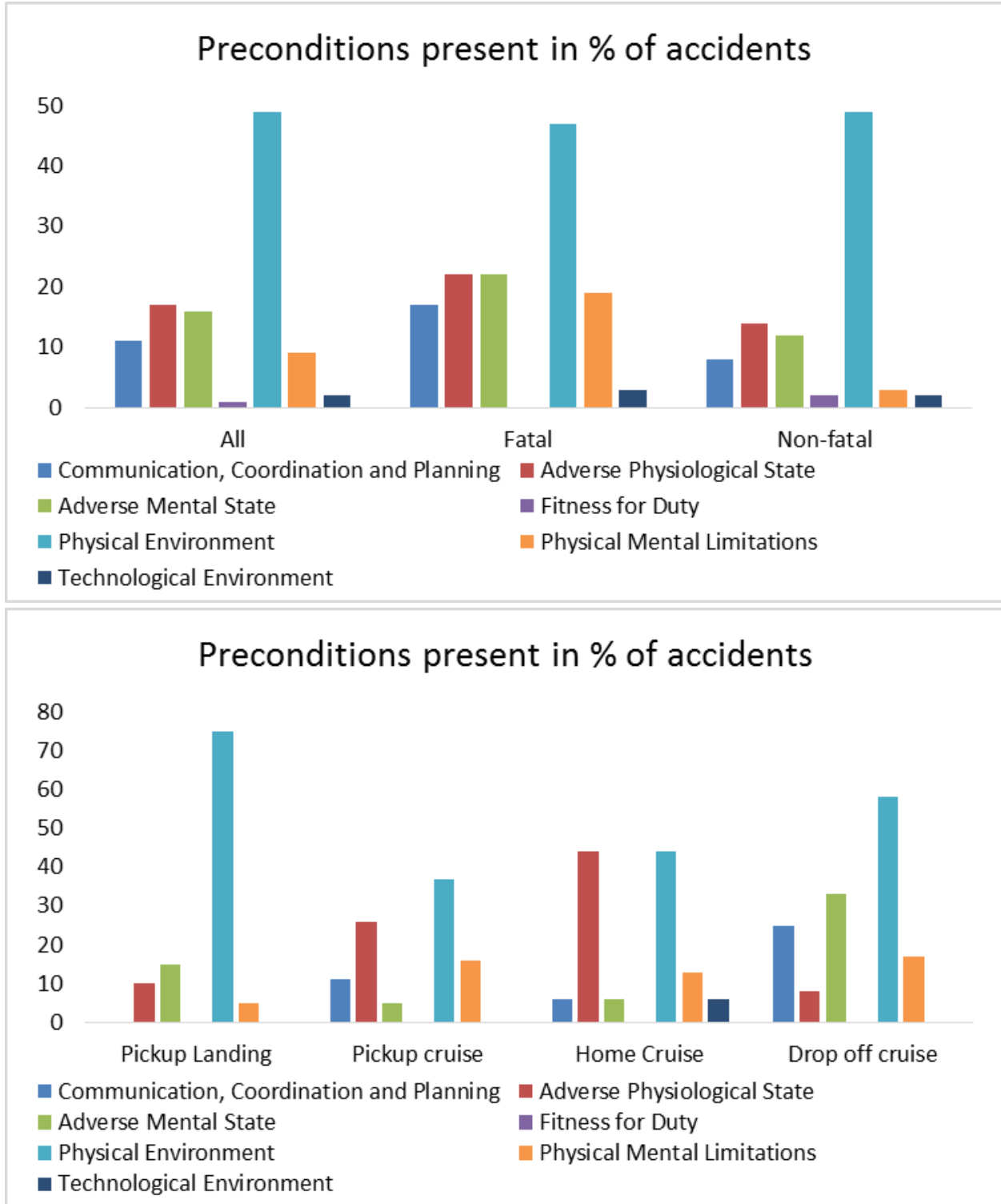


Figure 4a. Preconditions present in percentage of human error involved accidents.

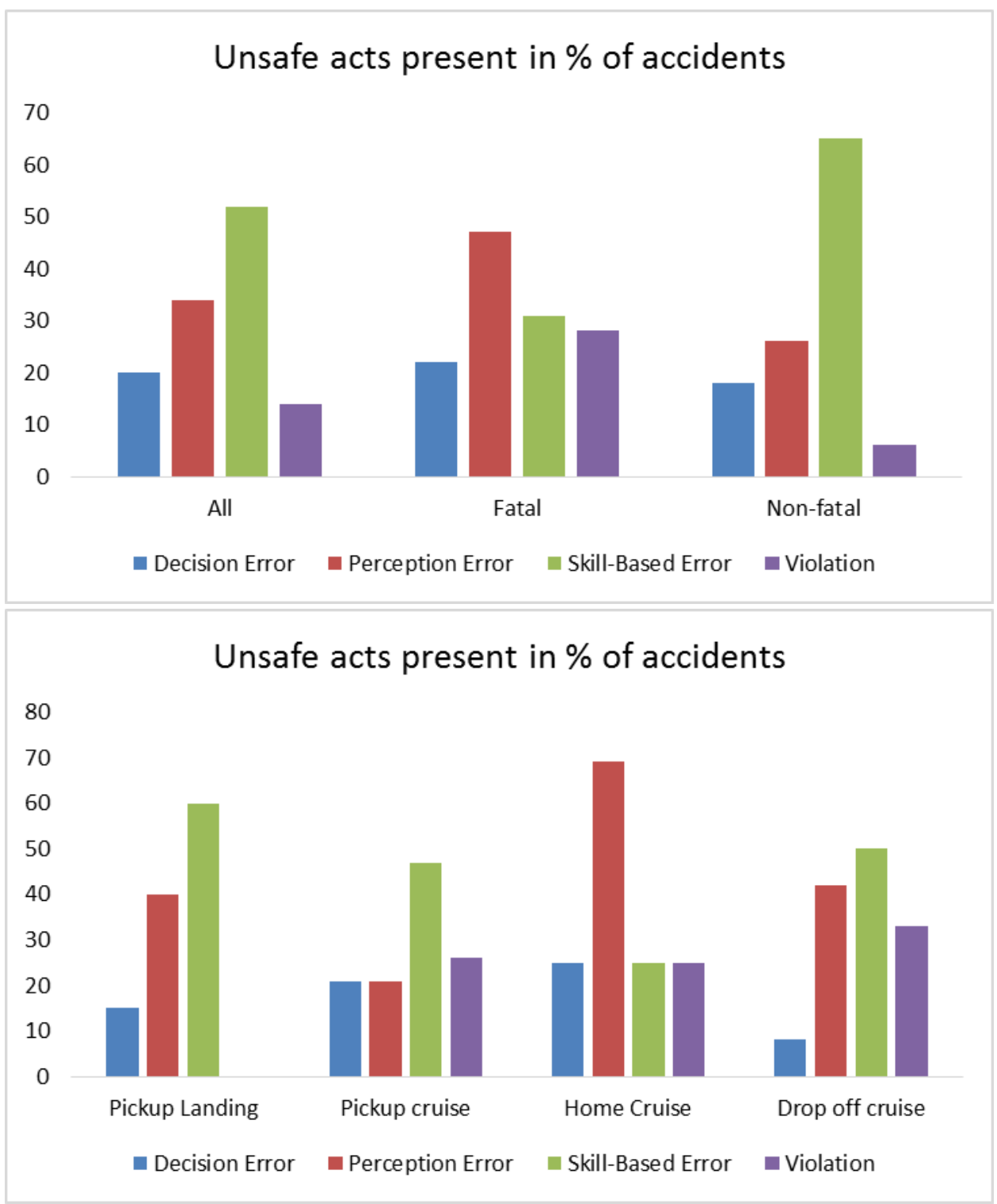
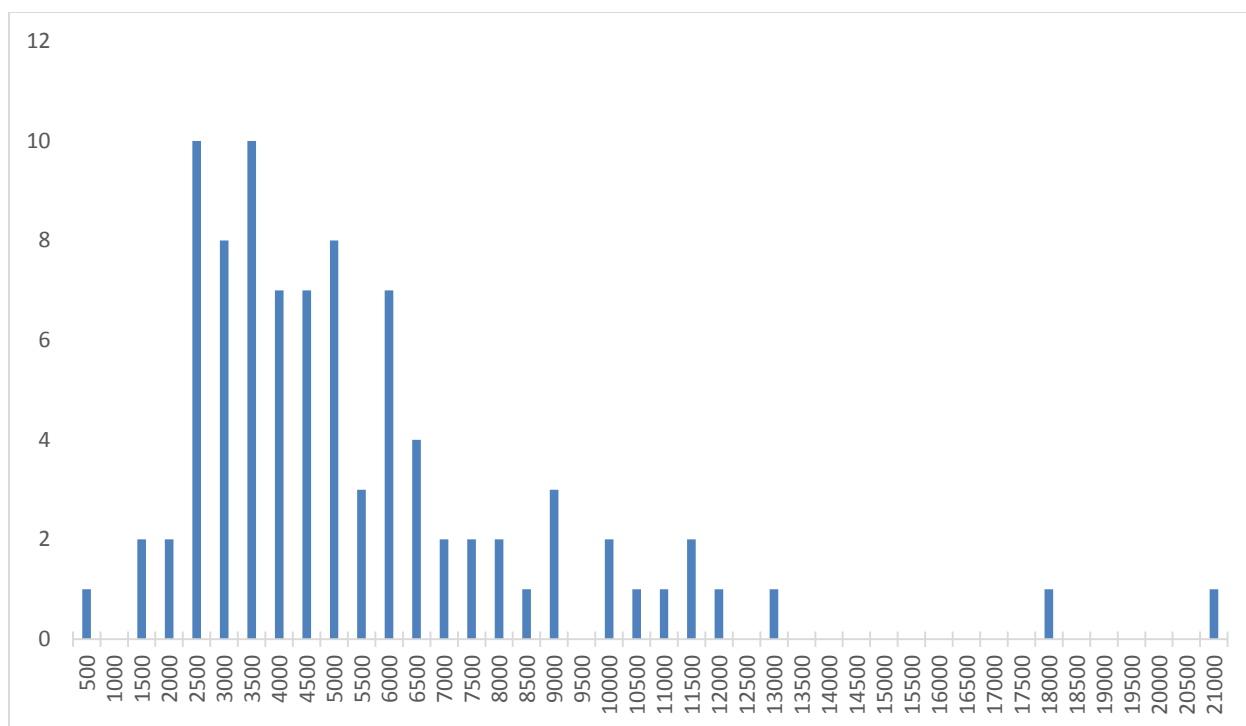


Figure 4b. Unsafe acts present in percentage of human error involved accidents.

## Pilot experience

The number of rotary wing flying hours was extracted for all pilots involved in accidents with human error cause factors. This information was available for 89 of the 101 cases. The resulting histogram is presented in Figure 5. Further analysis determined that 70% of accident pilots had between 2000 and 6000 hours of experience flying helicopters. It is interesting to note that only one accident helicopter had two pilots – the rest were flown by a single pilot, regardless of whether the helicopter had a second pilot seat. Due to a lack of denominator information, it is not clear if single pilot HEMS operations are more susceptible to accidents involving human error or if the imbalance merely reflects the ratio of single pilot to dual pilot HEMS operations overall.



*Figure 5.* A histogram of the rotary wing hours of pilots in accidents involving human error.

## Light conditions

The prevailing natural light conditions at the time of each human error accident was collected from the NTSB database. This data was available for 97 of the 101 cases and is shown in Table 5. Overall, 60% of the accidents occurred at night. Further analysis revealed that night time lighting conditions were cited in the probable cause for approximately half of the accidents that took place at night.

Table 5

*Natural light conditions of HEMS accidents involving human error*

| Light               | Count |
|---------------------|-------|
| Dawn                | 1     |
| Daylight            | 36    |
| Dusk                | 1     |
| Night (Bright)      | 3     |
| Night (Dark)        | 34    |
| Night (Unspecified) | 22    |

### **Engines**

The number of engines possessed by all accident helicopters was counted for the 146 of 147 cases where this information was available. This query revealed a roughly even split, with single engine helicopters slightly outnumbering dual. The data was further broken down in to levels of injury suffered by crew and passengers for each engine category (see Table 6). In general, the injury counts for single and dual engine helicopters are approximately proportional to the population size (i.e. 55% of the injuries were on single engine helicopters which in turn make up 53% of the accident helicopter population). However, twice as many serious and fatal accidents occurred on single engine helicopters.

Table 6

*Comparison of injuries in single and dual engine EMS helicopters*

| Level of Injury | Engines | Injuries |
|-----------------|---------|----------|
| None            | 1       | 121      |
|                 | 2       | 130      |
| Minor           | 1       | 26       |
|                 | 2       | 37       |
| Serious         | 1       | 51       |
|                 | 2       | 27       |
| Fatal           | 1       | 93       |
|                 | 2       | 56       |
| Total           | 1       | 291      |
|                 | 2       | 238      |



## Geographical correlations

Preliminary investigation in a potential relationship between geography was conducted by plotting of all the coordinates of each accident on to a map of the United States. Accident latitude and longitude was available for 121 of 147 cases. This map was then compared to a population density map to see if there were any clusters of accidents that could not be explained by populousness alone. The two maps side by side are shown Figure 6. The comparison did not reveal any anomalous concentrations of accidents.

Given that a number of articles in the relevant literature discuss the proliferation of HEMS operations as a factor in accident rates, it was deemed prudent to investigate if there is a relationship between HEMS operation density and accidents. Using the data from Flanigan & Blatt (2011) the number of EMS helicopters per state was normalized for population (per 100,000 people) and area (per 1,000 square miles). The accidents from the NTSB database were similarly broken down by state and normalized. The top ten states for each metric is presented in Table 7.

Overall, no trends were discovered. No significant correlations between HEMS operation and accident density were discovered ( $p > 0.05$ ). Outliers on the four metrics were readily explainable. For example, Alaska had the highest HEMS to population ratio by an order of magnitude, but this is hardly surprising given the vast area of the state and its reliance on air transportation. The District of Columbia has very high numbers, but this is skewed by its small area. In short, this research found no evidence to support the hypothesis that density of HEMS operation has an impact on accident rates.

Table 7

*Top ten states for HEMS operational and accident density*

|    | Helicopters per<br>100k people |    | Helicopters per<br>1000 sq. mi |    | Accidents per<br>100k people |    | Accidents per<br>1000 sq. mi |
|----|--------------------------------|----|--------------------------------|----|------------------------------|----|------------------------------|
| AK | 4.79                           | DC | 58.82                          | WY | 0.35                         | DC | 14.71                        |
| AZ | 0.92                           | DE | 2.41                           | AZ | 0.23                         | MD | 0.24                         |
| DE | 0.67                           | MD | 1.45                           | NM | 0.19                         | FL | 0.18                         |
| DC | 0.66                           | NJ | 1.15                           | DC | 0.17                         | SC | 0.16                         |
| KY | 0.65                           | PA | 1.04                           | AK | 0.14                         | AZ | 0.13                         |
| ID | 0.64                           | OH | 0.89                           | UT | 0.14                         | IA | 0.11                         |
| ND | 0.59                           | KY | 0.69                           | AR | 0.14                         | PA | 0.09                         |
| WV | 0.59                           | FL | 0.67                           | ID | 0.13                         | MA | 0.09                         |
| NM | 0.53                           | TN | 0.66                           | SD | 0.12                         | HI | 0.09                         |
| MO | 0.52                           | CA | 0.62                           | NV | 0.11                         | TX | 0.08                         |
| US | 0.30                           |    | 0.25                           |    | 0.05                         |    | 0.16                         |

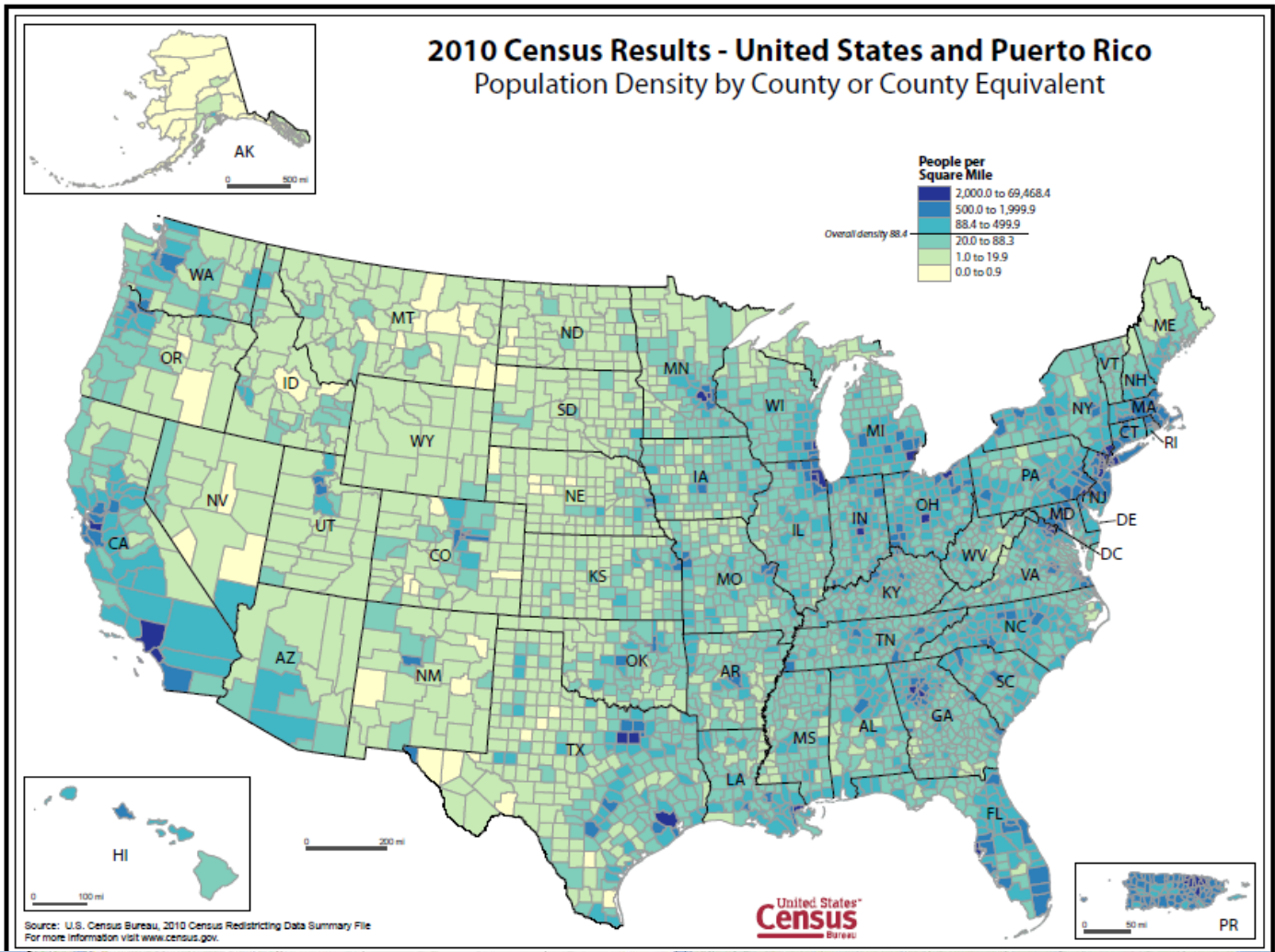


Figure 6. Side by side comparison of population density by county and location of HEMS accidents. Density map reprinted from U.S. Census Bureau, 2010 Census Redistricting Data Summary File. Accident map constructed with data from Google, INEGI and NTSB aviation accident database using multiplottr.com.

## Discussion

The types of human error found in the three phases of flight where HEMS accidents are most prevalent vary in proportion considerably. Accidents that occur when landing at the pickup site frequently are a result of a skill-based or perceptual error in reacting to a physical environment problem. Cruise flight to both the patient pickup site and home base had accidents that primarily involved physical environment and adverse physiological state preconditions, but the former had more skill based errors and the latter had more perceptual errors. Of particular interest is that none of these three human error profiles matched the overall profile or the fatal accident profile. This would suggest that phase of flight is associated with the type of HEMS accident that is most likely to occur.

This link was explored further by examining the seminal event of the accidents in these flight phases. This exploration was expanded to include cruise flight to hospital, given the high number of fatal accidents in this phase of flight. These seminal events were determined by reviewing the accident cases (particularly the probable cause) and characterizing each accident with themes normally found in aviation accidents. The results are shown in Table 8.

Table 8

*Accident seminal events for select phases of flight*

| Phase of flight                | Seminal event                              | Count |
|--------------------------------|--|-------|
| Transit to patient pickup site | Flight into marginal VMC/IMC               | 7     |
|                                | Error during pre-flight inspection         | 4     |
|                                | Violation not related to weather           | 2     |
|                                | Error during emergency situation           | 2     |
|                                | Skill-based error, other                   | 2     |
|                                | Medical incapacitation                     | 1     |
|                                | Perception illusion not related to weather | 1     |
| Landing at patient pickup site | Obstacle collision                         | 12    |
|                                | Brown out                                  | 6     |
|                                | Other                                      | 2     |
| Transit to hospital            | Flight into marginal VMC/IMC               | 4     |
|                                | Violation not related to weather           | 3     |
|                                | Perception illusion not related to weather | 3     |
|                                | Skill-based error, other                   | 1     |
|                                | Obstacle collision                         | 1     |
| Transit to home base           | Flight into marginal VMC/IMC               | 6     |
|                                | Perception illusion not related to weather | 5     |
|                                | Error during emergency situation           | 2     |
|                                | Violation not related to weather           | 2     |
|                                | Obstacle collision                         | 1     |

Overall, a big risk to HEMS operations is encountering bad weather during cruise flight. Regardless of the accident helicopter's destination, this was the top cause of human-error related HEMS accidents that occurred in transit.

Looking at each of the four phases of flight individually yields some interesting observations. Accidents at patient pickup site overwhelmingly (90%) are attributable to the terrain itself. Obstacle clearance and landing visibility hazards at unsuitable or difficult landing sites are the fundamental cause. While these accidents are not normally fatal, they often result in damage to the helicopter that is beyond economical repair.

For accidents occurring during transit to patient pickup, approximately half of the accidents involved an imprudent weather decision or a missed item during pre-flight procedures. This gives support to the idea that HEMS pilots frequently experience acute time pressure when a flight request is received, occasionally resulting in poor judgement or inattention to standard procedures. Accidents occurring during transit to home base (i.e. after the mission had been completed or cancelled) showed a similar trend, with 45% of the accidents involving imprudent

weather decisions and/or self-induced pressure to return to base. This is a more curious finding as any pressure related to saving the patient would have been gone at this point in the mission. It is a possibility that they had received another patient transfer request, but there was no mention of it in the NTSB narratives.

During transit to drop off a patient, the dominating seminal incidents (75%) were poor weather and/or nighttime conditions. There was no trend in the nature of human error resulting from these environmental factors.

## **Interventions**

In order to address the root cause of the greatest number of accidents, the data indicates that interventions should be focused on the areas of improvised landing sites, adverse weather management, nighttime flying, and operational pressure. There is a significant amount of overlap in these areas; for example, dark light conditions were a contributing factor in 30% of all of the accidents surveyed. That said, this section will examine interventions specific to each area.

Of the identified areas for improvement, the challenges of improvised landing sites is the least addressed in the literature. When it is mentioned in an article, it is usually in the context of exemplifying the risks inherent in HEMS operations, rather than as a safety issue requiring action. However, the data found in this analysis clearly identifies it as a significant safety hazard.

There are a number of potential interventions both in the air and on the ground that could reduce the risks of obstacle collisions and degraded visual environments. First and foremost is improving off-site landing areas. Very rarely is a HEMS the first vehicle to arrive at an accident. Requests for helicopter transportation are normally made by on-scene first response agencies (police, ambulances, fire department). These first responders are normally responsible for identifying and marking a landing area for the HEMS. Unfortunately, based on many of the accident narratives, it is apparent that site recce and selection is not properly carried out. This could be improved through better training of ground support agencies or national level guidance/regulation. Alternatively, the use of predetermined off-site landing areas is a best practice that could be more widely adopted. In order to be properly implemented this intervention must be more than a onetime event. For example, a 2006 accident in Ponce De Leon, Florida was caused by an unobserved change to a previously scouted landing area.

On the air side, interventions are primarily focused on training. Confined areas and off-site landing reconnaissance are specific skillsets that could receive increased emphasis in a HEMS operation's training syllabus. Another avenue would be to harness the experience and lessons learned from recent military helicopter pilots who have conducted numerous brown-out landings during desert operations. This training need not be limited to pilots; medical flight crew are used in many HEMS operations as an extra set of eyes during critical phases of flight and this practice could be more formalized.

In addition to training, researchers are currently examining the feasibility of using LIDAR to assist pilots in detecting obstacles in degraded visual environments (Cao, Roy, Roy and Trickey, 2012). While this technology has shown promise, it is still in a nascent state.

Unlike improvised landing sites, adverse weather management is a frequent topic of discussion in the literature. Many of the recommendations in NTSB (2006) and NTSB (2009) are aimed at addressing this issue. Their approach is intervening in three distinct areas: weather reporting, risk assessment processes, and inadvertent entry into IMC training. While there are many weather-related HEMS accidents that may have been prevented by these interventions, it is important to note that 40% of accidents involving human error in adverse weather during transit were caused by the pilot's wilful violation of existing regulations. It would be worthwhile to investigate why such a high percentage of HEMS pilots feel they can (or need to) disregard existing regulations.

Night lighting conditions have similarly been cited by many articles as a serious hazard to HEMS operations. Normally, the proposed mitigation is the use of technology, specifically night vision goggles (NVGs) and terrain avoidance warning systems (TAWS). Given their widespread adoption in other aviation fields (public use and military for NVGs, scheduled and non-scheduled commercial aviation for TAWS), it is likely their use would reduce HEMS accidents associated with night lighting conditions. However, these technologies, NVGs in particular, are not a panacea. In looking at night time human error related accidents, there were 2 instances where NVGs were in use, 3 instances where misuse of the NVGs contributed to the accident, and 1 accident where a limitation of the NVGs (glare from a bright light source) was a causal factor. While this only represents 10% of night time HEMS accidents, the point is that NVGs cannot remove all the risks associated with flying in darkness.

The German approach to night time HEMS operations is quite different (J. Hinkelbein, personal communication, January 7, 2014). Their regulations require two pilots for night operations. Furthermore, HEMS may only land at certified sites (i.e. airports and hospital helipads) at night. Owing to the regulations, only about 10% of German HEMS operators conduct flying at night and those flights are inter-hospital transfers only. While these regulatory decisions can partly be explained by a difference in flying environments (Germany's population density is six times that of the US, resulting in much more built-up areas unsuitable for off-site landings), it is interesting to note that a country that has been conducting HEMS operations for as long as the US has taken a far more conservative approach to flying at night.

While this study has found that operational pressure is a cause of many human error-involved accidents, there is little evidence to support any particular root cause. When a pilot elects to accept a mission despite marginal weather conditions, there is train of thought that led to that decision. Unfortunately, sequence is not usually provided in the accident report, even when the pilot is able to give a post-accident interview. As such, there is no way of knowing if that risky decision was made from concern of the patient's condition, hubris, lack of information, managerial pressure, or inexperience. Therefore, the only interventions that can be recommended are ones that would address all of these root causes. Two such interventions can be found in NTSB (2006):

Require all emergency medical services (EMS) operators to develop and implement flight risk evaluation programs that include training all employees involved in the operation, procedures that support the systematic evaluation of flight risks, and consultation with others trained in EMS flight operations if the risks reach a predefined level. (A-06-13)

Require emergency medical services operators to use formalized dispatch and flight-following procedures that include up-to-date weather information and assistance in flight risk assessment decisions. (A-06-14) (p. 15)

By instilling a culture of formal risk evaluation and management and fostering an organization that makes decisions based on clearly enumerated criteria and the best available information, a HEMS operation can mitigate or prevent the influence of operational pressures on pilot decisions. While the pilot will ultimately remain responsible and accountable for his decision, a robust operational support organization will do much to ensure the right decisions are made.



It should be noted that these interventions are not exhaustive. There are numerous opinions on how to address these root causes and while the solutions presented are supported by literature, it cannot be definitively said that they are the “best.” Fortunately, this fact is not relevant to the discussion. What is relevant is that for maximum effectiveness, any selected intervention must address one or more of these root causes.

### **FAR Part 91 vs 135**

As mentioned previously, the HEMS accident rate conducted under part 91 flight rules is much higher than the one for HEMS flights under part 135. This has led several organizations to conclude that in the interests of safety, all phases of HEMS flight (i.e. not just when a patient is onboard) should be conducted under part 135. NTSB (2006) listed it as one of four recommendations that would lower the accident rate. CAMTS (2012), includes it a requirement for HEMS programs seeking accreditation. In 2010, the FAA issued a notice of proposed rulemaking (NPRM) that would make part 135 flight rules mandatory when either a patient or medical personnel are onboard. That said, the original question remains: is it the part 91 rules that cause the elevated risk of accident or is it simply a reflection of the risks inherent in the phases of flight where part 91 rules are permitted?

This question is beyond the scope of this study, so a simpler statement of the question will be used: of the examined HEMS accidents that occurred under part 91 flight rules, how many may have been avoided if the pilot was flying under part 135 rules? This is still a complex and arguably unanswerable question, but a rough estimate may be achieved by counting all of the part 91 accidents that involved either pilot fatigue or poor weather conditions, less any accidents where the pilot violated existing regulations.

Of the 147 accidents analyzed, 100 occurred under part 91 flight rules. This is not a surprising result as part 135 is mandatory for only one-third of a HEMS mission. Removing 5 accidents that have not been assigned a probable cause brings the total to 95. Within that subset, there were 16 cases involving poor weather or fatigue. However in 5 of those cases part 91 VFR weather minima were intentionally violated by the pilot. This gives a total of 11 cases out of 95 (12%) where adherence to part 135 rules instead of part 91 may have prevented the accident.

From one perspective, any intervention that could decimate the accident rate is highly desirable. On the other hand, this rough examination proposes that 88% of accidents flown under

part 91 rules would have still occurred under part 135 rules. This conflicts with the position in NTSB (2011) that HEMS flights under part 91 are much more dangerous.

One explanation can be found by examining the underlying numbers in NTSB (2011). The denominator information is derived from the FAA general aviation and part 135 activity survey. On average, part 91 flight represented 12% of the total annual HEMS flying hours between 2004 and 2009 (the time period examined by NTSB, 2011). This is an odd outcome, given that HEMS operators can theoretically fly two-thirds of each mission under part 91.

The reason that part 91 flight hours are so low is probably due to current industry practices. According to CAMTS executive director (E. Frazer, personal communication, January 7, 2014), 50% of HEMS programs are CAMTS accredited and these programs employ 70% of the helicopters used for EMS. Since flying under part 135 during all phases of a HEMS flight is required to achieve and maintain CAMTS accreditation, it is unsurprising that part 91 flight hours are underrepresented.

This of course raises the possibility that part 91 flight is just as dangerous as NTSB (2011) claims, but the original analysis does not bear this out. Indeed, almost a quarter of the part 91 accidents involved maintenance failures or other causes not attributable to the pilot. One possibility is that the decision to engage part 91 flying and elevated accident rates are symptoms of a common root cause such as a breakdown in the safety culture of those HEMS operations.

In short, requiring all HEMS flight to be flown under part 135 is a supportable intervention, but the assertion in NTSB (2011) that part 91 HEMS flying has an accident twenty times higher than part 135 greatly overstates the actual risk.

## **Limitations**

The major limitation of this study was the exclusive use of probable cause in determining the modes of human error present in each accident. While the accident narrative was used to better understand the errors described in the probable cause of each NTSB report, it was not used as a primary source. There were numerous times when the coding panel unanimously agreed that a particular cause factor was present but ultimately could not include it because it was not mentioned in the probable cause section. While this approach was necessary to prevent the panel from overreaching or biasing their decisions, it did result in a number of cause factors being omitted.

Another limitation was the depth of investigation conducted by the NTSB in each accident. While their inquiries into the airworthiness of each accident aircraft were unquestionably exhaustive, the human error side of the investigation was not as detailed. Investigations focused almost entirely on the accident pilot and flight crew. Some investigations looked into supervisory and organizational factors, but they were few and far between.

### **Future directions**

Given that decision errors in the context of marginal weather conditions was a frequent accident scenario, further investigation is indicated. Investigation into pilot motivation when intentionally violating weather minima versus times when they are not may prove an interesting contrast.

Further investigation into the efficacy of various strategies to improving landing at semi-prepared or improvised sites is also indicated. Since there is such a large proportion of accidents related obstacle collisions and degraded visibility when landing on-scene, investigating how best to reduce this type of accident would be wise investment of resources.

### **Conclusion**

While the HEMS accident rate has been in decline since 2006, there is still much room for improvement. The risks of transportation by helicopter remain greater than many medical interventions, both for the patient and the health care provider. The injuries sustained in a helicopter accident can easily be greater than the original trauma that necessitated the airborne transportation. In addition to the human costs of each accident, helicopter accidents represent a significant drain on financial resources. A helicopter equipped for EMS operations can cost anywhere from \$800,000 to \$12 million (Sumwalt, 2011). There is also the matter of lawsuits arising from the accident. While the cost of these legal actions are not always available, it should be noted that a fatal HEMS accident in 2008 was settled for the sum of \$14 million (Ortiz, 2009).

Thirty years of research into HEMS accidents have shown that the underlying causes are numerous and complex. Adding further difficulty is that the root causes have changed as the HEMS industry has grown and matured. While this problem is not intractable, it does require specific and focused research to determine what factors are causing the most accidents so that resources can be applied to interventions that target them.

Like virtually all modern fields of aviation, the majority of HEMS accidents were caused by human error. To this end, an analysis of the last twelve years of accident data was conducted using HFACS. The results, interpreted in concert with the objective facts of the accidents, identified specific areas for intervention.

Terrain hazards at patient pick-up sites were the cause of a fifth of all human error related HEMS accidents. There are many opportunities for improvement in this area and further research should be conducted to determine the best set of interventions for this issue.

Sub-optimal decisions in adverse weather conditions was another major cause of HEMS accidents. The literature provides many theories on the motivation behind these decisions however they all appear to lack objective evidence. Fortunately better decisions, regardless of motivation, can be achieved with a robust operational support organization that provides up-to-date weather information, proper dispatch and flight following procedures, and a risk management framework that gives pilots the tools to make an adequately informed decision and mitigates the various pressures to fly in marginal conditions.

The fact that 60% of human error related HEMS accidents occurred at night is not particularly telling, especially given that there is no data on the proportion of day and night flights. What is salient is the fact that 30% of accidents cited nighttime lighting as a primary or contributing cause. While there are technologies that mitigate the effects of darkness, they are not a panacea. Indeed, they have even contributed to a handful of accidents. Consideration should be given to imposing further restrictions on night flying or at least give more weight to the risks of low level flying in the dark when making go/no-go decisions.

The ability to transport critical patients by helicopter is an important capability for the medical field. For patients with time-sensitive injuries in remote areas or impassible terrain, it can mean the difference between life and death. But like any medical procedure, it must have a net benefit. The cure cannot be more harmful than the disease. While HEMS flight will always carry inherent risks, it is incumbent upon everyone in the air medical field to constantly identify and address factors that affect safety of flight. Otherwise, the loss of human lives and resources will continue to mount, undermining patient confidence in this vital service.

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