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Trends of Non-Fatal HEMS Accident-Related Injuries

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We conducted an investigation into non-fatal helicopter emergency medical service accidents from January 26, 1991 to April 26, 2018 via the National Transportation Safety Board aviation accident database. Over this 28-year timeframe 247 accidents results in 251 fatalities and 179 non-fatal injuries. Exploratory analysis of the data indicate that more non-fatal injuries occurred in September compared to any other month during the study timeframe. Exploratory correlational analysis via elastic net logistic regression concluded that no linear relationship of NTSB accident database data provide insights into what factors are correlated with an increased likelihood of non-fatal injuries. Further, no linear relationships of available variables provide insights into the increased number of non-fatal injuries in September during this investigation's timeframe. Future research should identify if these null results are due to a true lack or no relationship between available data and non-fatal injuries or if these results are due to inaccessibility to relevant data.

INTRODUCTION

Helicopter emergency medical services (HEMS) are medical transportation services that expedite the transport of a patient from one location to another, typically from the scene-of-injury to a care facility or a care facility to another care facility. The HEMS program was initially implemented during the Vietnam war where injured combatants who were in dangerous or difficult to reach areas via ground units were evacuated by helicopter to care locations (Reddick, 1979). Shortly thereafter, the first United States of America based implementation was used by the Maryland state police in 1970 with helicopter 108 in response to a car crash on falls road and interstate 695 (Parsons, 2020). Since then, The National Transportation Safety Board (NTSB) and Federal Aviation Administration (FAA) have reported a significant increase of HEMS utilization from 25,000 flight hours in 1980 to nearly 600,000 flight hours in 2017 (Bluemen, 2009; FAA, 2017). The increase in HEMS usage may be tied to the multitude of benefits that have been associated with the transit method.

Proposed Benefits of HEMS

First, helicopters can significantly decrease the transportation time of a patient compared to ground emergency medical services (GEMS). However, Diaz et al. (2005) indicate that this benefit only exists when the distance between that care facility and the location of the patient is greater than 50 miles. When under 50 miles, they find that ground-based EMS can be dispatched and completed in less time than a HEMS flight.

Second, and tied to the quicker transportation time, certain patients (depending on injury and demographic factors) have been shown to have an increased chance of survival when medical care is administered within a certain period of time. Dubbed the golden-hour, patients are proposed to have significantly higher chances of survival when care is administered within one hour of the initial injury. Specifically, evidence submitted by Pham et al. (2017) suggests that a direct linear relationship exists between length of on-scene time and risk of mortality.

Finally, HEMS have been shown to provide a significant benefit to patients in rural areas by transporting those who are severely injured to care facilities better equipped to handle their level of injury. Kornhall et al. (2018) indicated that, due to the availability of care and location, rural facilities may not have the tools and equipment necessary to provide specialized treatment for severely injured patients. They suggest HEMS flights were able to provide rapid transit from un-equipped rural facilities to better resourced facilities, thereby reducing patient mortality.

Suggested Challenges of HEMS

While the use of HEMS has been suggested to increase patient survivability in a multitude of ways, the service also comes with its challenges.

Primarily, this method of transportation is typically utilized when a patient with a high injury severity score (ISS), which is associated with a significant injury, is identified. Udekwu et al. (2019) found in their review that patients who were transported by helicopter had a significantly higher median ISS (14.0) as compared to GEMS patients (8.3). Additionally, it is more widely perceived and accepted that a patient who enters the emergency room via helicopter is more injured than those who are not. While this perception may seem beneficial by increasing responder response time and medical staff preparedness, the reality is risk-decision making can be influenced by a multitude of factors in high-pressure and high-injury severity situations. Mainly, some evidence suggests that pilot decision-making may result in riskier flying when patient status is known (Rodi, 2014). Thus, there may be a relationship between HEMS flight risk taking and high injury severity of HEMS transported patients. It should be noted, however, that the injury severity of patients transported via HEMS is contested and may not be as high as previously believed (Bledsoe et al, 2006).

Other significant risks of HEMS flights have also been identified. First, the vast majority, if not all, of HEMS flights within the United Stated of America are single pilot flights. Single pilot setups have been associated with higher risk factors that contribute to accidents as the pilot must perform the heavy workload of flying the aircraft while managing the

navigation and planning duties associated with EMS transport tasking (European Aviation Safety Agency, 2017). Second, HEMS utilize on-board medical teams that are expected to provide expedited care to severely injured patients. While no explicit evidence has been suggested directly associating on-board medical teams and increases in risk, it has been suggested that HEMS medical teams expect to be airborne "within a matter of minutes" of receiving a dispatch, which may in-turn pressure the crew to make riskier flight decisions. (Winn et al, 2012, p. 78). Finally, and equally as concerning, HEMS pilots have reported to be pressured by their managing teams to make riskier flight decision due to possible fiscal motivations (Parsons, 2019). These fiscally motivated decisions may be associated to the higher ratio of privatized HEMS organizations in the United States of America, which has been associated with the increased the phenomenon of helicopter shopping, wherein a care facility will contact multiple HEMS organizations until one accepts the risks of the flight.

Purpose of the Study

The challenges presented via HEMS flights have led it to become the riskiest form of transportation as compared to any other aviation domain. Consistently, each year HEMS flights report the highest fatality rates with nearly twice the fatal accident rate as compared to any other form of aviation (Blumen, 2009). In response to this concerning statistic, the NTSB along with various other researchers have dedicated research to identifying the factors that are associated with high levels of HEMS fatal accidents as well as attempting to implement policies that may reduce these statistics (Blumen, 2009). However, the vast majority of investigations regarding this domain have been focused on investigating fatalities as a result of a HEMS accident. Conversely, non-fatal injuries have been nearly un-studied. While fatalities are a significant focus within the medical domain, helicopter accident-related non-fatal injuries can have significant life-altering and debilitating outcomes that should not be ignored. Thus, this investigation provides an exploratory analysis of HEMS accident-related non-fatal injuries in an attempt to understand the factors that may contribute to higher injury rates.

METHODS

A retrospective investigation of non-fatal HEMS accident-related injuries from January 26, 1991 to April 26, 2018 was conducted. We utilized the National Transportation Safety Board aviation accident database to source our data. The inclusion criteria for a HEMS accident necessitated that a helicopter with a medical flight designation was involved in an unintentional impact to any area of the aircraft or any event that necessitated an NTSB investigation into the incident. Through this timeline, a total of 247 accidents were extracted from the database. Injury categorization is provided by the NTSB Code of Federal Regulations (CFR) Part 830.2 (NTSB, 2011) where a fatal injury is classified as any fatality that occurs as a result of the accident up to 30 days of the accident. A serious injury is any injury that requires hospitalization for

more than 48 hours within seven days of the accident, any bone fracture with the exception of simple fractures (e.g., fingers, toes, or nose), results in severe hemorrhaging or nerve, muscle, or tendon damage, involves injury to any internal organ, or results in second- or third-degree burns of more than five percent of the body. Minor injuries are not classified by this code but are assumed to be any injury that is not considered to be a fatal or serious injury, and no injuries will indicate that the patient did not receive any injury that required medica attention.

All numerically displayed data points (e.g., tables or figures) presented in the included NTSB accident reports were coded into a code sheet. Narratively presented information within the NTSB accident reports were avoided as it was outside the scope of this investigation and suffered from inconsistent reporting between accident dockets. Where applicable, categorical and ordinal values were assigned a code (e.g., 0 or 1 for binary and 1+ for ordinal) in preparation for statistical analysis.

Statistical Analysis

We utilized R version 4.0.4 (R Core Team, 2014) and its associated glmnet package (Friedman et al., 2010; Simon et al., 2011) to conduct descriptive data exploration, data visualization, and elastic net logistic regression to explore possible relationships within the data.

Elastic net regression is a model selection technique that attempts to discover the most optimal model via regularization and parameter shrinkage (Hastie et al., 2019). This technique utilizes a linear combination of the sum of squares of the residual error (SSQ_{resid}) and the Ridge regression penalization (λ_1) in combination with the Lasso regression penalization (λ_2) to reduce non-influential variables within a model (Eq 1.; Engebretsen & Bohlin, 2019).

$$Elastic_{net} = SSQ_{resid} + \lambda(\frac{1}{2}(1-\alpha)\beta^2 + \alpha|\beta| \qquad \text{(Eq 1.)}$$

λ_1 and λ_2 add up to a total of one. When λ_1 is zero and λ_2 is one, then the elastic net regression takes on the properties of Lasso regression. Vice-versa, when λ_1 is one and λ_2 is zero, the elastic net takes on the properties of Ridge regression. The parameter α is a numerical representation of which λ receives the most weight. An α of zero means that λ_1 is zero (i.e., Ridge regression), an α of one indicates that λ_2 is one (i.e., Lasso regression), and an α of .5 indicates that both λ_1 and λ_2 receive equal weight. The essential difference between the two techniques is that Lasso attempts to fully remove variables by reducing their weights to zero while Ridge attempts to keep all variables in while reducing their weights as much as possible. The benefit of elastic net regression over either of these techniques is that it allows for a more dynamic range of variable combinations and reductions in order to increase the model fit, in this investigations case deviance. Further, the benefit of elastic net regression over other exploratory modeling techniques is that it is reduces the bias it places on the model by disregarding significance of a variable via either the p-value or the resulting F-test of the model in place for the beta-weight of the variable. Additionally, elastic-net

regression utilizes cross-validation via training models to assist in confirming and verifying its suggested results. The outcome of the model is a linear combination of variables that are able to optimize model fit but, however, are not guaranteed to be associated with a high R^2 value (in the case of linear regression) or be significant within the model. Further, elastic net regression is unable to handle categorical variables. As such, any categorical variable was dummy coded and the first dummy variable removed to account for artificial multicollinearity.

Variables

The variables included in our investigation from the NTSB accident report database included accident location (i.e., latitude and longitude), visibility at the time of the accident, the pilots age and their total flight time as well as their flight time with the accident airframe, the month of the accident, if the weather was designated as instrument meteorological conditions (IMC) or visual meteorological conditions (VMC), if there was an associated post-crash fire, what the pilots medical class was and if they had a medical waiver, if the accident occurred in the day time or night time, what the aircrafts phase of flight was and finally what the accident airframe was.

Extra considerations were given to the phase of the flight and the accident airframe as it required our specific subjective decision on how to report the data. First, the NTSB aviation accident database altered how it classified the phase of flight in 2008. Prior to 2008 the NTSB reported one phase of flight. However, after 2008, multiple phases of flight were reported with one being designated as the defining moment. In order to maintain consistency in out phase of flight variable, we chose to only use the defining moment as our data point for the phase of flight for any accidents that occurred after 2008. Additionally, the phase of flight was also reported with more specificity after 2008 (i.e., pre-2008: take-off; post-2008: initial takeoff, initial climb, climb, etc.) In these cases, we chose to report exactly what the NTSB report states in order to remove any bias or erroneous error in our data. Next, the accident airframes are reported with a wide range of variability. Some reports provide the base model of the airframe while others provide the base-model along with specific modifiers (e.g., Bell-206 vs. Bell-206L4). In these cases, we chose to only report the base model as no evidence could be sourced that significant differences are present in accident data between these models. Table 1 provides a full list of phase of flights and airframes collected from the database that were included in our analyses.

Table 1.

Phase of Flights and Airframes

Phase of Flight	Airframe
Approach	Agusta 109
Autorotation	Agusta 119
Climb	Astar 316
Cruise	Astar 350
Descent	Astar 355
Enroute	Astar 365
Go-Around	Bell 205
Hover	Bell 206
Initial Climb	Bell 222
Landing	Bell 230
Maneuvering	Bell 407
Standing	Bell 412
Takeoff	Eurocopter 130
Taxi	Eurocopter 135
	Eurocopter 145
	MBB/Kawasaki 417
	McDonnell Douglas 900
	McDonnell Douglas 902
	Messerschmitt-Bölkow-Blohm 105
	Sikorsky 76

RESULTS

During this investigation time frame, 94 accidents resulted in 251 fatalities, 48 accidents resulted in 87 serious injuries, 40 accidents resulted in 92 minor injuries, and 106 accidents results in 327 non-injured individuals.

A timeseries trend of accidents revealed that 2013 resulted in the highest number of non-fatal injuries (serious n = 7; minor n = 12). Upon further examination of the aggregate non-fatal injuries by months from January 26, 1991 to April 26, 2018 we found that September had significantly more non-fatal injuries compared to any other month (serious n = 15; minor n = 12) and April as well as August had the least amount of non-fatal injuries by month (serious n = 3, 1; minor n = 7, 1) respectively. The data for the accidents by month are presented in Table 2.

Table 2

Non-Fatal Injuries by Month

Month	Serious Injuries	Minor Injuries	Total
January	8	7	15
February	8	4	12
March	11	1	12
April	3	4	7
May	12	8	20
June	7	11	18
July	6	12	18
August	1	7	8
September	15	12	27
October	3	8	11
November	3	12	15
December	10	6	16

Serious Injuries

Our exploratory elastic net logistic regression for serious injuries indicated that no optimal training α (minimum deviance = 2.03, maximum deviance = 2.03) value could be identified, thus, a default α of one (i.e., Lasso regression) was

utilized. The results of the Lasso regression indicated that all of our included variables were forced to zero and therefor removed from the training model. This indicated that the model fit was maximized when all of the variables were removed from the model and that there was no linear combination of variables that will maximize the model fit. Thus, we did not implement a model into the test data.

Minor Injuries

Our exploratory elastic net regression for minor injuries indicated that no optimal training α (minimum deviance = 7.24, maximum deviance = 7.24) value could be identified, thus a default α of one was utilized (i.e., Lasso regression). The results of the Lasso regression indicated that all of our included variables were forced to zero and subsequently removed from the training model. This indicated that the model fit was maximized when all of the variables were removed from the model and that there was no linear relationship of variables that would improve model fit. Thus, we did not implement the model into the test data.

Non-Fatal Injuries in September

Our exploratory elastic net logistic regression for non-fatal injuries that occurred during September during every year of our investigation timeframe indicated that no optimal training α (minimum deviance = .363, maximum deviance = .363) value could be identified, thus, a default α of one (i.e., Lasso regression) was utilized. This model indicated that all of our included variables were forced to zero and subsequently removed from the training model. This indicated that the model fit was maximized when all of the variables were removed from the model and that there was no linear combination of variables that would improve model fir. This, we did not implement the model into the test data.

DISCUSSION

The rapid transit from either a scene to hospital or inter-hospital transport that HEMS provides has been shown to be a highly effective method of transit for severely injured patients. However, evidence also indicates that due to the high-risk factor associated with HEMS due to its single-pilot setups, on-board medical crews, and organizational pressures for risky performance decisions that the transit method may be riskier than it is worth. Prior evidence further suggests that the HEMS are currently being over-utilized as the average injury severity score is lower than what may necessitate a helicopter ambulance (Blumen, 2006). This over-utilization may increase the likelihood that a patient or crew member are placed in an unnecessarily risky situation.

As a result of these risks and factors, prior research into HEMS accidents provided evidence of what factors are associated with HEMS accident and accident-related fatalities. Specifically, Baker et al (2006) found that flying at night, flying in instrument meteorological conditions, and the result of a post-crash fire were statistically significantly associated with increased likelihoods of accident-related fatalities.

Unfortunately, little focus has been dedicated to understanding what factors are associated with increased non-fatal injuries. As described by 49 CFR part 830.2 (NTSB, 2011), non-fatal serious injuries can include life-altering and debilitating injuries such as significant 3rd degree burns, internal organ damage, musculoskeletal damage, and nerve damage. Individuals with these types of outcomes may never return to a normal lifestyle after such an injury.

To bridge the gap of our understanding of these injury-related factors, we investigated non-fatal HEMS accident-related injuries. Our results indicated that currently available data by way of the National Transportation Safety Board aviation accident database may not provide relevant information regarding what factors may influence non-fatal accident-related HEMS injuries. Specifically, none of our included variables provide any statistically or practically significant information regarding the increased likelihood of a non-fatal injury via a logistic regression. In an attempt to verify our elastic net regression model performance, we replicated a logistic regression from Simonson et al. (In-Press) and Baker et al. (2006) who identified that post-crash fires, flying in IMC conditions, and flying at night predicted the likelihood of a fata accident. When implemented into an elastic net logistic regression, along with our other included variables, the model finds that a multitude of potential variables may be influential in increasing model fit including the occurrence of a post-crash fire, flying in IMC conditions, and flying at night. Thus, we posit that our model selection process does suggest that currently available data may be inappropriate in predicting the likelihood of non-fatal HEMS injuries.

However, two patterns emerged from exploratory analyses that should be investigated by future research. First, similar to fatalities, we found a significant increase in non-fatal injuries that occurred in 2008. This increase in non-fatal injuries is most likely due to the significant increase in HEMS accidents during that year. Second, all injuries from January 26, 1991 to April 26, 2018 aggregated by month indicate that September holds the most amount of serious and minor non-fatal injuries. After further exploration, none of our included variables were able to provide insights into any possible relationships that may describe the higher rate of non-fatal injuries in September.

The null results found in this investigation suggest two possibilities that may be present. First, we posit that helicopter accidents are inherently dangerous; thus, no clearly defined relationship may be identifiable or present between the available data and our non-fatal outcome data. Second, there is a possibility that no relationship was found due to a possible survivorship bias in determining which data is pertinent in including various accident-related data into aviation accident data reports. Due to the predominant focus on fatal injuries from prior research and accident investigations, it is possible that certain factors that were deemed to be insignificant in their relationship to fatalities and were subsequently disregarded over the evolution of an accident investigation, However, there may have been an unidentified association with non-fatal injuries.

CONCLUSION

Our investigation served to provide insights into the factors that may be associated with non-fatal HEMS accident-related injuries. The results of our investigation suggest that a relationship between the month of the year and the number of non-fatal injuries is present, where September resulted in the highest number of accident-related non-fatal injures while April and August resulted in the least. Further investigation into the data and these relationships indicated that, with currently available data, no variable was influential or significantly correlated with predicting non-fatal HEMS accident-related injuries or the increase in non-fatal injuries in September during our investigations 28-year time frame.

LIMITATIONS

There are a few limitations that should be considered when interpreting the results of this study. First, our sample and available variables are limited to those that were chosen to be included in the NTSB's aviation accident databased within our investigation's timeline. As such, we may not have included data that other HEMS accident databases may have considered pertinent to HEMS crashes. Second, without prior evidence to provide guidance on what may contribute to non-fatal injuries, we chose to explore our data utilizing an advanced model selection technique (e.g., elastic net regression). As a result, we may not have included certain model parameter or model specific results that may have indicated a statistically or practically significant relationship between a variable and its outcome. Further, the large number of variables and elastic net regressions limitation on only including linear relationships may have limited our ability to uncover important interactions or non-linear relationships between variables. Finally, our effort to identify relationships in the data via binary and zero-inflated methods resulted in a large number of models re-using data. While we did use cross-validation techniques with training and testing data to further reduce the possibility of type one and type two errors, the number of models may have influenced our interpretation via spurious relationships.

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