Reliability Engineering and System Safety 183 (2019) 39–46

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

journal homepage: www.elsevier.com/locate/ress

An analysis of helicopter accident reports in Brazil from a human factors perspective

Anastácio Pinto Gonçalves Filho[a,*], Carlos Augusto Souza[b], Eduardo Luiz Bonecker Siqueira[c], Mozart Anderson Souza[c], Tales Pinheiro Vasconcelos[c]

[a] Ministry of Labour, Federal University of Bahia, Salvador, Brazil
[b] Mechanical Engineering Department, Federal University of Bahia, Salvador, Brazil
[c] Industrial Engineering Program, Federal University of Bahia, Salvador, Brazil

ARTICLE INFO

Keywords:
Helicopter
Accident
Human factors

1. Introduction

According to the Centre for the Investigation and Prevention of Aviation Accidents (CIPAA [1]), 211 accidents occurred from 2006 to 2015 in Brazil, when the average number of accidents was 21 per year. As a result, 133 people died, an average of 133 deaths per year and 63 deaths per hundred accidents. This outcome is a clear indication of the high severity of helicopter accident outcomes. Fig. 1 shows the number of helicopter accidents and deaths over the investigated period, as well as that the deaths per hundred accidents, which have shown steep increase between 2013 and 2015. Brazil has over 1700 registered helicopters, which is the fourth largest helicopter fleet in the world, and at least 4900 helicopter landings and takeoffs occur every day in the country [1].

It is currently largely accepted that the accidents which happen in complex sociotechnical systems, including the aviation system, are caused by a variety of interaction human and systemic factors. There has been previous research in this area showing that human and organisational factors play a significant role in the risk of system failures and accidents. For example, Gordon [2] published a paper on the human factors contribution to accidents in the offshore oil industry; Sotiralis et al. [3] on the incorporation of human factors into ship collision risk models; Ribeiro et al. [4] evaluated the human factors in Tokai-Mura accident; Theophilus et al. [5] on the development of an accident method to identify human factors in oil and gas companies; Skalle, Aamodt and Laumann [6] integrated human related errors with technical errors to determine causes behind offshore accidents; finally, Zhang et al. [7] evaluated collisions and grounding accidents with human factors and statistical methods.

In addition, reliability and safety are system properties which emerge from the interactions of all the diverse system constituents, hardware, software, human and organisational factors [8]. Therefore, human factor as a part of the sociotechnical system should not be ignored. From this perspective, in recent years more focus has been aimed at studying the isolation and evaluation in human and organisational factors and their influence on reliability and safety of complex technological systems. For instance, Rahimi and Rausand [9] researched the human and organisational factors influencing common-failure of safety-instrumented system; Farcasiu and Prisacaru [10] studied human factors in nuclear installations failure and Chidambaram [11] on why addressing human factors in today's shifting operating environment is important to reduce incidents; Banick and Wei [12] evaluated human factors in engineering design; Sujan Embrey and Huang [13] applied Human Reliability Analysis in healthcare; finally, Norazahar et al. [14] developed a methodology for identifying critical human and organisational factors in the escape, evacuation and rescue (EER) systems of offshore installations in a harsh environment. More examples can be seen in the following papers [15–20].

In this context, understanding the human and organisational factors underlying helicopter accidents is of key importance for applying this knowledge in design, training, policies, procedures and development of system of error identification to reduce the number of accidents, which

* Corresponding author. Ministério do Trabalho, Rua Ewerton Visco, 190, Caminho das Árvores, Salvador – Bahia, CEP 41.820.022, Brazil.
E-mail addresses: anastaciofilho@ufba.br (A.P.G. Filho), gutosouza25@hotmail.com (C.A. Souza), eng.eduardosiqueira@gmail.com (E.L.B. Siqueira), mozartengmec@hotmail.com (M.A. Souza), tales.pv@hotmail.com (T.P. Vasconcelos).

https://doi.org/10.1016/j.ress.2018.11.003
Received 7 April 2018; Received in revised form 28 October 2018; Accepted 6 November 2018
Available online 07 November 2018
0951-8320/

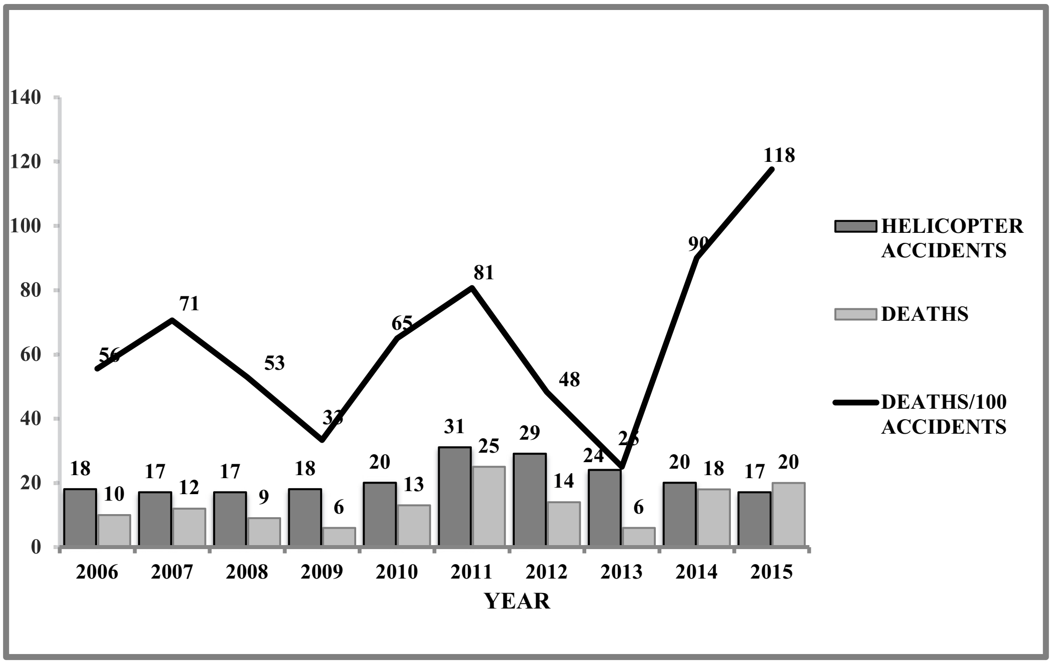

Fig. 1. Number of helicopter accident and deaths in Brazil between 2006 and 2015 (source: CIPAA [1]).

is the primary objective of system safety. However, there is a lack of studies that relate the human and organisational factors, which could affect the success or failure of helicopter operations.

The variety of forms and types in which human errors occur is one of the main difficulties in identifying them in accident analysis. A set of classifications or taxonomies have been developed into which specific errors can be placed, as described in the next Section 1.1. These taxonomies enable the forms of the error to define and to provide useful information thereby promoting understanding. Besides, this opens the way to identification of the systemic causes of the error and ultimately the remedial measures to reduce its probability [21–23].

This study conducted an analysis of Brazilian helicopter accident investigation reports to identify human errors. A human error method or error taxonomy was used to accomplish this. No research to date has examined the contribution of human error in helicopter accident reports in Brazil. This paper represents our first attempt to apply an error taxonomy to Brazilian helicopter accident data.

1.1. Human error framework

Human error has been acknowledged in many accident causation models (e.g. [24–27]). Reason [24] lists the most influential of these, in which active and latent error were defined. Active errors, whose effects are felt almost immediately, are associated with the front-line operators of the system, while latent errors, whose adverse consequences may lie dormant within the system for a long time, only become evident when they combine with other factors to breach the system's defences [24]. Three system levels were incorporated by Reason [27] in a later version of his model, the so-called "Swiss Cheese Model": unsafe acts, local workplace factors and organisational factors.

Reason's [27] model has supported the development of several accident investigation and analysis methods. Examples of these models include the Integrated Safety Investigation Methodology (ISIM), TRIPOD, Norske Statesbaner (NSB), Health and Safety Executive (HSG245), Work Accidents Investigation Technique (WAIT), and the Human Factors Analysis and Classification System (HFACS) [28–30].

HFACS is a taxonomic accident coding system developed for the US Marine Corps aviation sector for application by practitioners to aid in investigating and analysing the role of human factors in accidents and incidents [29]. Its development came from the absence of taxonomies of latent failures and unsafe acts within Reason's Swiss cheese model, an omission which limited its application as an accident analysis framework [31]. HFACS provides taxonomies of human errors across the following four levels: unsafe acts; pre-conditions for unsafe acts; unsafe supervision; and organisational influences [30]. However, the HFACS was not developed to categorise some failure modes and mechanisms (e.g. airworthiness, technical e mechanical failure). A brief description of each HFCAS category is provided in Table 1 to familiarise the reader.

In recent years, the HFACS framework has been used to analyse accident data in different domains, such as mining [32,33], railways [34,35], civil aviation [36–39], healthcare [40] and helicopter maintenance [41], in which the causal factors reported are classified into HFACS categories, and then they are analysed. Following these examples of HFACS' applicability, and due to the fact that the taxonomy is based on a widely accepted error model that considers all levels of the organisation as a system, HFACS was selected here as an appropriate framework to highlight the role of human factors in Brazilian helicopter accident reports. In this study, HFACS was not adopted as a means of identifying causal factors from the helicopter accidents themselves, rather it was adopted as a means of extracting human error from helicopter accident reports filed at the time by aviation experts using the Convention on International Civil Aviation, Annex 13, protocol.

1.2. Aims of this study

The primary aim of this study is to elicit human error from Brazilian accident investigation reports using a human errors taxonomy. This study, as previously stated, is the first to apply a human error analysis approach to helicopter accident reports in Brazil. A secondary aim was also to ascertain the effectiveness of HFACS to classify the data from existing investigation reports on helicopter accidents and determine its usefulness in capturing relevant human factors from these reports.

2. Method

2.1. Data source

The predominant means of investigating the causal role of human

Table 1
Brief description of HFACS category (adapted from Shapell et al. [30]).

L4 - Organisational influences	
Organisational climate	Prevailing atmosphere/vision within the organisation, including such things as policies, command structure, and culture.
Operational process	Formal process by which the vision of an organisation is carried out including operations, procedures, and oversight, among others.
Resource management	How human, monetary, and equipment resources necessary to carry out the vision are managed.
L3 - Unsafe supervision	
Inadequate supervision	Oversight and management of personnel and resources, including training, professional guidance, and operational leadership, among other aspects
Planned inappropriate operations	Management and assignment of work, including aspects of risk management, crew pairing, operational tempo, etc.
Failed to correct known problems	Those instances in which deficiencies among individuals, equipment, training, or other related safety areas are “known” to the supervisor yet are allowed to continue uncorrected.
Supervisory violations	The willful disregard for existing rules, regulations, instructions, or standard operating procedures by managers during the course of their duties
L2 - Preconditions for unsafe acts	
Environmental factors	
Technological environment	This category encompasses a variety of issues, including the design of equipment and controls, display/interface characteristics, checklist layouts, task factors, and automation.
Physical environment	Included are both the operational setting (e.g. weather, altitude, terrain) and the ambient environment (e.g. heat, vibration, lighting, toxins).
Condition of the operator	
Adverse mental states	Acute psychological and/or mental conditions that negatively affect performance, such as mental fatigue, pernicious attitudes, and misplaced motivation.
Adverse physiological states	Acute medical and/or physiological conditions that preclude safe operations, such as illness, intoxication, and the myriad pharmacological and medical abnormalities known to affect performance.
Physical/mental limitations	Permanent physical/mental disabilities that may adversely impact performance, such as poor vision, lack of physical strength, mental aptitude, general knowledge, and a variety of other chronic mental illnesses.
Personnel factors	
Crew resource management	Includes a variety of communication, coordination, and teamwork issues that impact performance.
Personal readiness	Off-duty activities required to perform optimally on the job, such as adhering to crew rest requirements, alcohol restrictions, and other off-duty mandates
L1 - Unsafe acts	
Errors	
Decision errors	These “thinking” errors represent conscious, goal-intended behavior that proceeds as designed, yet the plan proves inadequate or inappropriate for the situation. These errors typically manifest as poorly executed procedures, improper choices, or simply the misinterpretation and/or misuse of relevant information.
Skill-based errors	Highly practiced behavior that occurs with little or no conscious thought. These “doing” errors frequently appear as breakdown in visual scan patterns, inadvertent activation/deactivation of switches, forgotten intentions, and omitted items in checklists. Even the manner or technique with which one performs a task is included.
Perceptual errors	These errors arise when sensory input is degraded, as is often the case when flying at night, in poor weather, or in otherwise visually impoverished environments. Faced with acting on imperfect or incomplete information, aircrew run the risk of misjudging distances, altitude, and descent rates, as well as of responding incorrectly to a variety of visual/vestibular illusions.
Violations	
Routine violations	Often referred to as “bending the rules,” this type of violation tends to be habitual by nature and is often enabled by a system of supervision and management that tolerates such departures from the rules.
Exceptional violations	Isolated departures from authority, neither typical of the individual nor condoned by management.

error in accidents is the analysis of post-accident data [21,42]. The post-accident data used in this analysis were obtained from reports drawn up by the CIPAA, which conducts helicopter accident investigations and is under the authority of the Aeronautical Ministry of Brazil. The investigation report form is completed by the military investigation team despite the fact that most helicopter accidents occur in civil aviation. These reports are based on the Convention on International Civil Aviation, Annex 13, and have been used in Brazil since 1946. However, it is difficult to get information about the methods used and the training of the professionals who write them, but the finished anonymous reports are available on the CIPAA site. Human error taxonomy is not used and there is little information on the role of human factors in these reports. A total of 165 reports of helicopter accidents, which occurred between January 2006 and December 2015, were obtained. Although 211 helicopter accidents occurred in this interested period, these 165 constituted the entire population of cases for which investigation final reports were available on the CIPAA site. Some of those reports, 32 in total, have identified causal factors, yet they were not described in detail, and consequently, were not conducive to analysis. Only final reports in which causal factors were identified and described in detail were included in this study. Therefore, a total of 133 final helicopter accident reports were submitted for further analysis.

2.2. Coding process

Four postgraduate engineering students at the Federal University of Bahia were previously trained together on the use of the HFACS framework by a human factor expert with extensive experience of accident investigation of all types. This face-to-face training comprised seven half-day modules and included an introduction to the HFACS framework, examples of factors and errors, explanation of the definitions of the four different levels of HFACS, and a further detailed description of the content of the eighteen individual HFACS categories.

Subsequent to the training the four students were asked to independently analyse all the 133 final helicopter accident reports and classify each causal factor described in the 'Conclusions' section of each report into a unique HFACS category. Following this, the four students and the human factor expert discussed possible discrepancies in the classification, which were evaluated from the narrative, sequence of events, findings, and conclusion of each helicopter accident report. Although there was often more than one causal factor classified within the same HFACS category in a particular report, each category was counted only once per report; therefore, this count acted simply as an indicator of the existence or absence of each of the 18 HFACS categories within a given report.

2.3. Causal factors classification reliability

As one of the aims of this study was to examine the reliability of HFACS to categorise helicopter accident errors from existing investigation reports, the assessment of the reliability of the causal factor classification into HFACS category produced was important. In this study, a sensitivity index score was used for this assessment, because it provides a simple means of assessing the reliability and sensitivity of error and accident analysis methods, such as HFACS, and has been used to evaluate the reliability in different studies [31,43,44].

Each classification produced by four students who analyzed the helicopter accident reports and classified the contributing factor into HFACS categories were compared with the classification of the human factors expert and a general agreement between them and sensitivity index score were calculated. The sensitivity index score was calculated using the formula: SI = ((Hit/Hit + Miss) + 1 − (False Alarm/False Alarm + Correct Rejection))/2, which was adapted from Salmon et al. [31]. Hits represent the number of HFACS categories that were selected by both the expert and the students. Misses represent the categories that were selected by the expert but not by the students. False alarms represent the categories that were selected by the students but not by the expert. Correct rejections represent the categories from the classification scheme which were not selected by either students or expert (read Stanton and Stevenage [44] for more details). The criterion of 70% of agreement between expert and student was adopted to evaluate whether the reliability of the classification was acceptable [44].

2.4. Statistical analysis

Preliminary assessments of the HFACS categories were performed using frequency counts. The nature of the relationships, if any, between each HFACS level with the level immediately above was conducted using a Chi-square test (χ^2). The lower level categories in the HFACS were designated as being dependent upon the categories at the immediately higher level in the framework, which is congruent with the framework's underlying theoretical assumptions. From a theoretical standpoint, lower levels in the HFACS cannot adversely affect higher levels. Higher levels in the HFACS are deemed to influence (cause) changes at the lower organisational levels, thus going beyond what may be deemed a simple test of co-occurrence between categories.

Finally, odds ratio is calculated for lower-level factors. The odds ratio can be calculated under two conditions: one for when a higher-level factor is present, and another for when a higher-level factor is absent. For example, to calculate the odds ratio presence of the violation category (lower-level) when adverse mental states category (higher-level) also present: first, calculate the odds of violation present given that adverse mental states are also present (odds1). Second, calculate the odds of violation present given that adverse mental states are absent (odds2). Third, calculate the ratio of these two odds (odds ratio = odds1/odds2). If the odds ratio value is greater than 1 then it indicates that as adverse mental states increase, the odds of violation present increases. Conversely, an odds ratio value less than 1 indicates that as adverse mental states increase, the odds of violation also present decrease. An odds ratio of 1 implies no association (read Field [45] for more details). In the example described above, if the calculated odds ratio value was 4.5, this would mean that when adverse mental states were present the odds of violation present would increase by 4.5 times. The statistical analyses were conducted using the software Statistical Package for the Social Sciences (SPSS).

3. Findings

3.1. Overall results

As can be seen in Table 2, the second column shows the percentage of the examined helicopter accident reports in which a HFACS category was present. As the reports are generally associated with more than one HFACS category, the percentages do not add up to 100%. For example, when decision errors and skill-based errors were present in the same report, this report was computed twice, once for decision errors and another one for skill-based errors. Likewise, when three HFACS categories were present, this report was computed three times and so on.

The majority of the causal factors reported involved errors and the environment. Causal factors classified into *unsafe acts* category were identified in more than three-quarters (81.2%) of the sample. Preconditions for unsafe acts were identified in 37.6% of the cases, whereas unsafe supervision was identified in 48.9% of the reports. Organisational influences were identified in relatively few reports (18%).

The most frequent unsafe acts reported were decision errors (67.7%), skill-based errors (59.4%) and violations (33.1%). Decision errors commonly involved were "*wrong decisions made*" by the pilot (e.g. to abort a landing or take off). The most common type of causal factors classified into Skill-based errors was "*inadequate application of controls*", whereas violations were typically related to failure to follow organisational procedures (e.g. intentionally ignoring standard operating

Table 2
Frequency and percentage of HFACS categories.

HFACS category	Frequency	Percentage
Level-1 Unsafe acts	**108**	**81.2**
Decision errors	90	67.7
Skill-based errors	79	59.4
Perceptual errors	9	6.8
Routine violations	44	33.1
Exceptional violations	0	0.00
Level-2 Preconditions for unsafe acts	**50**	**37.6**
Physical environment	20	15.0
Technological environment	19	14.3
Adverse mental states	9	6.8
Adverse physiological states	0	0.0
Physical/mental states	0	0.0
Crew resource management	12	9.0
Personal readiness	0	0.0
Level-3 Unsafe supervision	**65**	**48.9**
Inadequate supervision	61	45.9
Planned inappropriate operations	15	11.3
Failed to correct problem known	0	0.0
Supervisory violations	2	1.5
Level-4 Organisational influences	**24**	**18.0**
Resource management	0	0.0
Organisational process	20	15.0
Organisational climate	8	6.0

Note: Because helicopter accident reports are generally associated with more than one HFACS category, the percentages in the table do not add up to 100%.

procedures, neglecting standard operating procedures, applying improper standard operating procedures and diverting from standard operating procedures).

The preconditions for unsafe acts reported most commonly involved were the physical environment (15%), which typically involved "*adverse weather conditions*" (e.g. poor visibility caused by fog and rain), and the technological environment (14.3%) commonly involved "*poor infrastructure*" (e.g. precarious helipad). Causal factors classified into crew resource management was found in 9.0% of the sample, which involved mostly "*poor crew coordination*", whereas adverse mental states (e.g. anxiety and impulsiveness of pilot) were identified in 6.8% of the accident reports. Causal factors were not classified into other *preconditions for unsafe acts*, such as *adverse physical states* and *physical or mental limitations*.

The unsafe supervision failures reported included inadequate supervision (45.9%), which commonly involved "*oversight of personnel and resources*" (e.g. oversight of maintenance services, lack of training to crew), planned inappropriate operations (11.3%) (e.g. assignment of inexperienced crew), and supervision violation (1.5%) (e.g. flight hours were not recorded on the supervisor`s recommendation). No causal factors were classified into failure to correct a known problem. Finally, the organisational influences reported included organisational process (15%), which mostly involved "*lack of procedure to guide the pilot under critical flight condition*", and organisational climate (6.0%), in which "*work group culture*" (e.g. culture based on informal procedure) was the most frequent. Causal factors which could be categorised into resource management were not found in the reports examined.

3.2. Relationships between categories at adjacent HFACS levels

Table 3 presents all higher-level factors that have a statistically significant association (p-value < 0.05) with lower-level factors. There are five pairs of significant associations between the categories at HFACS level-2 'pre-conditions for unsafe acts' and level- 1 'unsafe acts'. The level-2 category of the 'physical environment' was significantly associated with two categories of unsafe acts: 'violations' and 'perceptual errors'. 'Technological environment' was also significantly associated with the unsafe act category 'skill-based errors'. Finally, the HFACS level-2 category of 'adverse mental states' and 'crew resource management' are significantly associated with level-1 categories of 'violation' and 'perceptual errors', respectively. Decision errors were not significantly associated with any level-2 categories.

Two pairs of significant associations exist between the categories at HFACS level-3 'unsafe supervision' and level-2 'pre-conditions for unsafe acts': the level-3 categories of 'inadequate supervision' and 'planned inappropriate operations' are significantly associated with the level-2 category of 'crew resource management'. The last two levels, level-4 'organisational influences' and level-3 'unsafe supervision', have two pairs with significant associations: 'organisational process' at level-4 is significantly associated with level-3 categories of 'inadequate supervision' and 'planned inappropriate operations'.

The statistically significant odds ratio (OR) and 95 percent confidence intervals (CI) for lower level factors is present when higher level is also presented in Table 3. The 95% confidence interval gives an estimate of the plausible range of values within which the true odds ratio lies. The observed associations indicate that when poor physical environment (e.g. poor visibility caused by fog and rain) was present in the examined helicopter accident reports the odds that violation and perceptual errors present increased by 2.9 and 5.4 times, respectively. In turn when adverse mental states of the pilot (e.g. anxiety and impulsiveness) was present the odds violation present increased by over four times. Similarly, perceptual errors were nearly six times more likely to be present in the presence of poor crew resource management (e.g. poor cabin coordination), whereas skill-based error was almost four times more likely to be present when a poor technological environment (e.g. a precarious helipad) was present.

In the presence of inadequate supervision (e.g. lack of training of crew), the odds of poor crew resource management present in the examined sample increased 6.8 times. When planned inappropriate operations (e.g. assignment of inexperienced crew) were present the odds of poor crew resource management present rose 12.4 times. Finally, with poor organisational process present the odds of inadequate supervision and planned inappropriate operations present rose by six and three times, respectively.

4. Discussion

4.1. Using HFACS to examine helicopter accident reports

The level of agreement was over 80% for all four comparisons between the students and the expert and the sensitivity index score values range from 0.70 to 0.79, which means good level of reliability for the HFACS classification carried out by the four students.

The HFACS framework was found to accommodate all the causal factors reported in the 133 helicopter accidents reports. Nonetheless, no causal factors were classified into some of the HFACS categories. For example, adverse physiological states, physical/mental states, personal readiness, failure to correct a known problem and resource management were not causal factors classified into them. Some reasons can explain the absence of these categories. First, the accident investigators might have focused on causal factors that were classified into the unsafe acts category, which are present in over 80% of reports analysed, while organisational influences are present in 18% of them (see Table 2). Second, those factors may contribute to accidents, yet they are rarely identified using existing accident investigation processes. Third, it may be difficult or impractical, to examine such high-level organisational issues and assign them a causal role in a helicopter accident investigation. Finally, the causal factors which could be classified into these categories simply do not play as large a role in the aetiology of helicopter accidents. As a result, the HFACS framework would need to be reduced or simplified for use with helicopter accidents.

Table 3
Significant Chi-square test of association (χ^2) and odds ratios for associations between categories from each HFACS level.

HFACS category	Chi-square test (χ^2) Value	*p*-Value	Odds ratio Value	CI(95%)
Level-2 association with level-1 categories				
Physical environment × routine violation	5.108	0.037	2.963	1.123–7.814
Physical environment × perceptual errors	6.534	0.029	5.400	1.311–22.245
Technological environment × skill-based error	7.113	0.011	3.858	1.363–10.917
Adverse mental states × routine violation	4.918	0.036	4.526	1.075–19.057
Crew resource management × perceptual errors	6.950	0.035	6.389	1.366–29.892
Level-3 association with level-2 categories				
Inadequate supervision × crew resource management	7.458	0.012	6.863	1.441–32.674
Planned inappropriate operations × crew resource management	19.765	0.000	12.444	3.325–46.571
Level-4 association with level-3 categories				
Organisational process × inadequate supervision	11.047	0.001	6.044	1.898–19.254
Organisational process × planned inappropriate operations	4.430	0.050	3.433	1.032–11.427

All tests have 1 degree of freedom. Associations at conventional level of significance ($p < 0.05$). All other comparisons were non-significant.

4.2. Human factors extracted from helicopter accidents reports

4.2.1. Unsafe acts

The violations were the third most frequent classified category of unsafe acts and therefore they played important role in the examined helicopter accident reports. Here, the violations were significantly associated with adverse mental states and physical environment, which is suggestive that these categories of preconditions for unsafe acts may be the most important precursors of the violations. As a result, measures must be taken to eliminate or mitigate these preconditions. Violations are the deliberate disregard for the rules and regulations, which take the violator to the edge; consequently, "increasing the chance that subsequent errors will have damaging outcomes" [46]. Furthermore, the constant violations may become accepted components of procedures, and they may be tolerated by supervisors and management as they often get the job done and may even be passed on to new workers through on the job training, which leads to a lack of awareness that they are in fact violations and not the norm [29].

The percentage of accidents reported associated with perceptual errors was relatively low. In fact, only 9 of the 133 accidents (6.3%) involved some form of perceptual error. The reduced perceptual error was not unexpected. It may be explained by good and stable weather (physical environment) throughout the year in large Brazilian cities or near them where most of the accidents occurred. Furthermore, there are fewer helicopter flights at night when the probability of perceptual errors is higher. In addition, a considerable effort has been made by aerospace engineering and human factor communities to improve warning devices (ground collision avoidance systems) and awareness of perceptual errors caused by visual illusions.

The causal factors classified into decision errors (67.7%) and skill-based errors (59.4%) had the highest percentages in the helicopter accidents reports, which is not surprising given that these findings parallel the results of similar HFACS and human error analyses of civil aviation accidents [36,38,47,48]. Nonetheless, this is may be an indicative that accident investigators focus on unsafe acts.

Active failures of the pilot at level-1 (skill-based errors, routine violation and perceptual errors) showed a statistical association with four preconditions for unsafe acts (HFACS level-2— 'physical environment', 'technological environment', 'adverse mental states' and 'crew resource management') (Table 3), which is in line with what was suggested by Reason [24] that human behaviour is governed by the interaction between psychological and situational factors.

There are many precursors of unsafe acts and the actual errors themselves, this makes it difficult to predict which actual errors will occur as a result of which preconditions [24,27]. In this study, some details may explain the unsafe acts reported in the sample. First, the increasing demand for helicopter trips in the examined period might have led the company owners to hire crew who lacked experience, i.e., that might mean pilots with a lack of flight hours or merely inexperienced with the operational setting or aircraft. This is not uncommon, as accidents associated with the pilot's lack of experience have been found in previous studies by Shappel et al. [30] and Lenné et al. [38]. Second, the increasing demand for helicopter trips might also have increased the workload and pressure on the crew, consequently, affecting their mental states, which are preconditions for unsafe acts. Likewise, the aviation literature has many examples in which pressure, either self-induced or from management, have led a pilot to accept risks beyond his or her abilities [36,49]. Finally, there could be poor infrastructure (technological environment) for helicopter flights in the country where accidents occurred. These are supported in this sample by statistically significant associations between the preconditions for unsafe acts (adverse mental states, physical environment, technological environment and crew resource management) and unsafe acts (skill-based errors, perceptual errors and violation) (Table 3).

4.2.2. Precondition for unsafe acts

The preconditions for unsafe acts category were lightly populated (50 of 133 accidents). The helicopter accident reports that identified causal factors that were classified into technological environment (14.3%) and physical environment (15%) accounted for the highest percentages within the preconditions for the unsafe acts category. The former was mostly influenced by poor infrastructure (e.g. precarious helipad), as mentioned previously. While the latter is related to adverse weather, this is a relatively unusual problem in Brazil as a whole, and this may explain the low percentage in this category. Moreover, information related to the weather has been much improved recently.

The odds of a Crew resource management to be present in the examined sample were increased 5.5 times in the presence of the level-3 category of 'inadequate supervision'. This category in turn had the odds of appearing rose by 11 times when a poor organisational process issue (Table 3) was present. Therefore, these associations suggest that inadequacies in crew resource management practices were influenced by the level-3 category of 'inadequate supervision'. This category was in turn greatly inflated by poor organisational processes. The issue of inadequate supervision was a link between organisational process and poor crew resource management. Inadequate supervision in the HFACS framework encompasses issues such as a failure to provide proper training and failure to track qualifications and performance of personnel. This may indicate that the Brazilian helicopter industry has not invested enough in intervention strategies specifically targeted at improving crew resource management.

Adverse mental states are those that affect pilot performance, such as distraction and mental fatigue due to stress. Such mental states predispose accident-involved pilots to the main categories of human error. Adverse mental states are particularly dangerous in helicopters, as there is often just a single pilot. Without a co-pilot in the cockpit, any distraction of the pilot is likely to be catastrophic. In this study, when adverse mental states were identified raised the odds of routine violation occurring by 4.9 times. As mentioned before, adverse mental states may be explained in this sample as workload and lack experience of pilots due to the increasing demand for helicopter trips.

4.2.3. Unsafe supervision and organisational influences

Causal factors attributed to unsafe supervision mostly centred on category inadequate supervision (45.9%) rather than the full range of supervisory factors described within the framework. When supervisors were identified as contributory in the chain of events leading to an accident, issues such as the lack of general supervision or the failure to provide adequate training were usually reported. There were few helicopter accident reports with organisational influences category (18%), which were mainly centred on organisational process (15%). When considering helicopter accidents reports between 2006 and 2015 in Brazil, it is possible that inadequacies at the higher organisational levels are under-reported. This may be explained by the current investigative process not capturing all the organisational influences associated with helicopter accidents.

According to Reason [27] unsafe acts are caused by latent conditions, which are present in all systems. Reducing resources for training and maintenance, decisions made at the highest levels in the organisation, may be based on sound financial arguments, yet other operational parts of the system can be affected by such inequities. The data analysis in this study demonstrates that flaws at HFACS level-4 (organisational influences) had associations with further flaws at HFACS level-3 (unsafe supervision) (Table 3). Poor 'organisational processes' were associated with inadequacies in categories at the level of 'unsafe supervision' (inadequate supervision and planned inappropriate operations), as mentioned before. Consequently, they were indirectly related to many operational errors resulting in accidents. In the HFACS framework, inadequacies in 'organisational processes' encompass issues such as procedures (e.g. inadequate procedures, no procedures available, or poor awareness of procedures), hazard identification and risk assessment (e.g. failure to identify hazards, hazard identification/risk assessment not undertaken, and a lack of an appropriate risk assessment procedure/tool), and inadequate, or lack of, work instructions. Inappropriate decision-making by upper-level management can adversely influence the personnel and practices at the supervisory level, which in turn affects the psychological pre-conditions, and consequently, the subsequent actions of the frontline operators. This study provides statistical support for this suggested relationship.

4.3. Limitations and future work

The major limitation of the current study was investigating the human factors in helicopter accidents by classifying causal factors from preexisting accident reports. There is a difference between talking about how investigators reconstruct causation, and how accidents are caused. "What caused the accident?" is not the same question as "What did the investigators say caused the accident?". Understanding this difference must be the starting point for any retrospective analysis of accidents. In addition, the quality of the data provided in the reports may affect the findings when HFACS framework is used [30,50,51]. For example, if the investigators do not have autonomy. In Brazil all aviation accident investigation is conducted by the military. They might play down some important factors so as not to be too incriminating, or to avoid negative consequences, or the reports could be considered just be an administrative document with no consequences or suffer bias. The training they undergo, and standardisation of their work, their satisfaction with the methods used are all directions for further study.

A future work could be to conduct helicopter accident investigation using HFACS framework or another human error theoretical model to identify human error from primary data rather than on data collected by aviation experts using a Convention on International Civil Aviation, Annex 13 protocol. These models could be used to guide the collection of data during the investigations and consequently support the understanding of the human factors involved and aggregate the findings across large number of accidents. They can also be used to evaluate the measures to correct specific types of human error that result in helicopter accidents.

5. Conclusion

HFACS was useful in classifying causal factors from existing investigation reports and in capturing the full range of relevant helicopter accident human factors reported. All the causal factors reported were classified into HFACS category, no new error-categories were needed to classify them, and this allowed the associations between categories at the different levels to be analysed statistically. Inter-rater evaluation demonstrated acceptable agreement levels between the raters involved and the expert.

The categories of "decision errors", "skill-based errors" and "violations" (unsafe acts) were the most frequent human errors reported, whereas "inadequate supervision" (unsafe supervision) was the most common precondition for unsafe acts category. Therefore, these human errors played an important role in helicopter accidents in Brazil based on the examined reports. Despite the lack of causal factors that do not fall into HFACS categories, no causal factors were classified into "adverse physical states", "physical or mental limitations", "failure to correct a known problem" or "resource management", which may be indicative that Brazilian investigators focus on unsafe acts and technical failure.

The results of this study highlight human factors from helicopter accident reports, which is an area in need of further research. These results can provide valuable insight aimed at the reduction of helicopter accidents through data-driven investment strategies, since different human error forms require different types of interventions, knowing the most common error forms will enable safety professionals to develop targeted interventions and an objective evaluation of system safety programs. Finally, results from this study, such as presented in this paper, allow the comparison with other helicopter accident reports worldwide, where data has been similarly analyzed from the human factor perspective. This comparison may raise cross country information sharing and safety interventions, which have proved to be successful in one country, may be taken up by other countries with the view of mutual transference.

References

[1] CIPAA. Center for the Investigating and Preventing Aviation Accidents. Statistical Summary; 2006-2015.

[2] Gordon RPE. The contribution of human factors to accidents in the offshore oil industry. Reliab Eng Syst Saf 1998;61:95–108.

[3] Sotiralis P, Ventikos NP, Hamann R, Golyshev P, Teixeira AP. Incorporation of human factors into ship collision risk models focusing on human centred design aspects. Reliab Eng Syst Saf 2016;156:210–27.

[4] Ribeiro AC, Sousa AL, Duarte JP, Melo PFF. Human reliability analysis of the Tokai-Mura accident through a THERP–CREAM and expert opinion auditing approach. Saf Sci 2016;87:269–79.

[5] Theophilus SC, Victor N, Esenowo VN, Arewa AO, Ifelebuegu AO, Nnadi EO, Mbanaso FU. Human factors analysis and classification system for the oil and gas industry (HFACS-OGI). Reliab Eng Syst Saf 2017;167:168–76.

[6] Skalle P, Aamodt A, Laumann K. Integrating human related errors with technical errors to determine causes behind offshore accidents. Saf Sci 2014;63:179–90.

[7] Yıldırım U, Başar E, Uğurlu Ö. Assessment of collisions and grounding accidents with human factors analysis and classification system (HFACS) and statistical methods. Saf Sci 2017http://dx.doi.org/10.1016/j.ssci.2017.09.022.

[8] Zio E. Reliability engineering: old problems and new challenges. Reliab Eng Syst Saf 2009;94:125–41.

[9] Rahimi M, Rausand M. Monitoring human and organisational factors influencing common-cause failures of safety-instrumented system during the operational phase. Reliab Eng Syst Saf 2013;120:10–7.

[10] Farcasiu M, Prisecaru I. MMOSA–a new approach of the human and organisational factor analysis in PSA. Reliab Eng Syst Saf 2014;123:91–8.

[11] Chidambaram P. Perspectives on human factors in a shifting operational environment. J Loss Prev Process Ind 2016;44:112–8.

[12] Banik WR, Wei C. Application of human factors evaluation in engineering design and safe operation of dense phase ethylene treaters. J Loss Prev Process Ind 2016;44:671–80.
[13] Sujan MA, Embrey D, Huang H. On the application of human reliability analysis in healthcare: opportunities and challenges. Reliab. Eng Syst Saf 2018https://doi.org/10.1016/j.ress.2018.06.017.
[14] Norazahar N, Khan F, Veitch B, Scott MacKinnon S. Prioritizing safety critical human and organisational factors of EER systems of offshore installations in a harsh environment. Saf Sci 2017;95:171–81.
[15] Burns K, Bonaceto C. An empirically benchmarked human reliability analysis of general aviation. Reliab Eng Syst Saf 2018https://doi.org/10.1016/j.ress.2018.07.028.
[16] Laumann K. Criteria for qualitative methods in human reliability analysis. Reliab Eng Syst Saf 2018https://doi.org/10.1016/j.ress.2018.07.001.
[17] Oguz E, Kubicek M, Clelland D. A large group decision making approach for dependence assessment in human reliability analysis. Reliab Eng Syst Saf 2018;178:247–54.
[18] Bevilacqua M, Ciarapica FE. A large group decision making approach for dependence assessment in human reliability analysis. Reliab Eng Syst Saf 2018;169:149–59.
[19] Liu HC, Li Z, Zhang JQ, You XY. A large group decision making approach for dependence assessment in human reliability analysis. Reliab Eng Syst Saf 2018;176:135–44.
[20] Kyriakidis M, Kant V, Amir S, Dang VN. Understanding human performance in sociotechnical systems–steps towards a generic framework. Saf Sci 2018;107:202–15.
[21] Baysari MT, McIntosh AS, Wilson J. Understanding the human factors contribution to railway accidents and incidents in Australia. Accid Anal Prev 2008;40:1750–7.
[22] Whittingham RB. The Blame Machine: Why Human Error Causes Accidents 2004.
[23] Embrey DE. Incorporating management and organisational factors into probabilistic safety assessment. Reliab Eng Syst Saf 1992;38:199–208.
[24] Reason JT. Human Error. Cambridge: Cambridge University Press; 1990.
[25] Lucas D. Human factors aspects of signals passed at danger. Rail Saf Stand Board Res Catalogue 1989.
[26] O'Hare D. The ‘Wheel of Misfortune’: a taxonomic approach to human factors in accident investigation and analysis in aviation and other complex systems. Ergonomics 2000;43(12):2001–19.
[27] Reason JT. Managing the Risks of Organisational Accidents. Aldershot: Ashgate; 1997.
[28] Katsakiori P, Sakellaropoulos G, Manatakis E. Towards an evaluation of accident investigation methods in terms of their alignment with accident causation models. Saf Sci 2009;47:1007–25.
[29] Wiegmann DA, Shappell SA. A Human Error Approach to Aviation Accident Analysis: the Human Factors Analysis and Classification System. Burlington: Ashgate; 2003.
[30] Shappell S, Detwiler C, Holcomb K, Hackworth C, Boquet A, Wiegmann DA. Human error and commercial aviation accidents: an analysis using the Human Factors Analysis and Classification System. Hum Factors 2007;49(2):227–42.
[31] Salmon MP, Stanton NA, Lenné M, Jenkins DP, Laura R, Walker GH. Human Factors Methods and Accident Analysis: Practical Guidance Case Study Applications 2011 Surrey: Ashgate; 2011.
[32] Lenné MG, Salmon PM, Liu CC, Trotter M. A systems approach to accident causation in mining: an application of the HFACS method. Accid Anal Prev 2012;48:111–7.
[33] Patterson JM, Shappell SA. Operator error and system deficiencies: analysis of 508 mining incidents and accidents from Queensland, Australia using HFACS. Accid Anal Prev 2010;42:1379–85.
[34] Madigan R, Golightly D, Madders R. Application of human factors analysis and classification system (HFACS) to UK rail safety of the line incidents. Accid Anal Prev 2016;97:122–31.
[35] Reinach S, Viale A. Application of a human error framework to conduct train accident/incident investigations. Accid Anal Prev 2006;38:396–406.
[36] Gaur D. Human factors analysis and classification system applied to civil aircraft accidents in India. Aviat Space Environ Med 2005;76(5):501–5.
[37] Li WC, Harris D. HFACS analysis of ROC air force aviation accidents: reliability analysis and cross-cultural comparison. Int J Appl Aviat Stud 2005;5:65–81.
[38] Lenné MG, Ashby K, Fitzharris M. Analysis of general aviation crashes in Australia using the human factors analysis and classification system. Int J Aviat Psychol 2008;18:340–52.
[39] Wiegmann DA, Shappell SA, Boquet A, Detwiler C, Holcomb K, Faaborg T. Human Error and General Aviation Accidents: a Comprehensive, Fine-Grained Analysis Using HFACS. University of Illinois: Aviation Human Factors Division, Institute of Aviation; 2005.
[40] El Bardissi AW, Wiegmann DA, Dearani JA, Daly RC, Sundt TM. Application of the human factors analysis and classification system methodology to the cardio vascular surgery operation room. Ann Thorac Surg 2007;83:1412–8.
[41] Rashid HSJ, Place CS, Braithwaite GR. Helicopter maintenance error analysis: beyond the third order of the HFACS-ME. Int J Ind Ergon 2010;40:636–47.
[42] Shappell SA, Wiegmann DA. A human error approach to accident investigation: the taxonomy of unsafe operations. Int J. Aviat Psychol 1997;7:269–91.
[43] Goode N, Salmon PM, Taylor NZ, Lenné NG, Finch CF. Developing a contributing factor classification scheme for Rasmussen's Accimap: reliability and validity evaluation. Saf Sci 2017;64:14–26.
[44] Stanton NA, Stevenage SV. Learning to predict human error: issues of acceptability, reliability and validity. Ergonomics 1998;41(11):1737–56.
[45] Field A. Discovering Statistics Using SPSS. London: SAGE; 2009.
[46] Reason J. A systems approach to organisational error. Ergonomics 1995;38:1708–21.
[47] Li WC, Harris D, Yu C S. Routes to failure: analysis of 41 civil aviation accidents from the Republic of China using the human factors analysis and classification system. Accid Anal Prev 2008;40:426–34.
[48] Liu S.Y., Chi C.F., Li W.C. The application of Human Factors Analysis and Classification System (HFACS) to investigate human errors in helicopter accidents. Engineering Psychology and Cognitive Ergonomics Applications and Services. 10th International Conference, EPCE 2013: 85–94.
[49] Veillette PR. Human error cited as major cause of U.S. commercial EMS helicopter accidents. Flight Saf Dig 2001;20(4–5):1–38.
[50] Ergai A, Cohen T, Sharp J, Wiegmann D, Gramopadhye A, Shappell S. Assessment of the Human Factors Analysis and Classification System (HFACS): intra-rater and inter-rater reliability. Saf Sci 2016;82:393–8.
[51] Olsen NS, Shorrock ST. Evaluation of the HFACS-ADF safety classification system: inter-coder consensus and intra-coder consistency. Accid Anal Prev 2010;42:437–44.