The Application of Human Factors Analysis and Classification System (HFACS) to Investigate Human Errors in Helicopter Accidents

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Abstract. current study investigates 83 civil aviation and military services helicopter accidents in Taiwan between 1970 and 2010. The probable and latent causes of those accidents are clearly defined, and statistically analyzed by error related paths and Human Factors Analysis and Classification System (HFACS). Results indicate that categories of the higher level have better predicted power (between 4.25% and 24.9%) than categories of the lower levels (with odd ratios between 0.19 and 8.67). Fallible decisions in upper command levels directly affect supervisory practices which create pre-conditions for unsafe acts, impair performance of pilots, and lead to unexpected accidents. By identifying the higher level human errors leading to low level helicopter mishaps, HFACS is useful a tool for accident investigations and accident prevention strategies. Current study provides a practical suggestion to top managers for a better helicopter operational safety environment.

Keywords: Human Factors Analysis and Classification System (HFACS), Human Errors, Helicopter Flight Operations.

1 Introduction

Taiwan is a mountainous island surrounded by Pacific Ocean and Taiwan Strait. Natural disasters such as typhoons and earthquakes have constantly led to catastrophic damage in human livies and property. Helicopter, due to its maneuverability and operational flexibility, is very adapted for emergent rescue missions such as ambulance, observation on disastrous landscape, material transportation, and reconnaissance patrol over disastrous regions in Taiwan remote villages. The average flight hours are, therefore, increased from 1,000 hours to more than 10,000 hours per year since 1999 to 2008. (Aviation Safety Council, ASC, 2010). As a result, the average helicopter accident rate in the past ten years had dramatically increased to 10.24 accidents per 100,000 flight hours, which is 38.06 higher than the accident rate in the United States of American (USA). This astonishing accident record has casted

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the public the image that the helicopter is one of the most unsafe transporter in Taiwan. The motivation of current study is to investigate the root causes of those accidents through the application of Human Factors Analysis and Classification System (HAFCS) and propose suggestions for top managers to improve organization aviation safety by reducing those potential hazards. Among those categories of root causes, human errors take part in 70% to 80% of civil and military aviation accidents. (O'Hare, Wiggins, Batt, & Morrison, 1994; Wiegmann and Shappell, 1999). The root causes of helicopter accidents in Taiwan are similar to scenarios worldwide that 57.14% were due to human factors, 28.50% were environmental factors, and 14.28% were contributed as maintenance factors. Human-error related accidents are still relatively high and stable over the last several years worldwide. (Shappell & Wiegmann, 1996). Therefore, Shappell and Wiegmann constructed HFACS as an analytical technique to look into the human error related incidents accidents qualitatively. The HAFCS is based on Reason's model of latent and active failures of an accident. In addition, FAA and NASA, USA have also applied HFACS, as a complement tool to pre-existing system with civil aviation in an attempt to capitalize on gains realized by the military (Ford, Jack, Crisp, & Sandusky, 1999). The HFACS framework bridges the gap between theory and practice by providing safety professionals with a theoretical-based tool for identifying and classifying the causes of human error aviation accidents. Because the framework focuses on both latent and active failures and their interrelationships, it facilitates the identification of the underlying causes of human error. HFACS has been proven to be an useful tool within the context of military aviation. This research examines the applicability of HFACS framework for the analysis of helicopter accidents investigation.

2 Literature Review

Many human factors accident analysis frameworks, taxonomies and analysis strategies have been devised over the years (e.g. Diehl, 1989; Feggetter, 1991). In recent years, accident investigation the scientific focus has shifted away from psychomotor skill deficiencies and emphasis is now more placed upon inadequacies in decision-making, attitude, supervisory factors and organizational culture as being the primary causal factors (Diehl, 1991; Jensen, 1997, and Klein, 2000). Dekker (2001) has proposed that human errors are systematically connected to features of operators' tools and tasks, and error has its roots in the surrounding system: the question of human or system failure alone demonstrates an oversimplified belief in the roots of failure. By examining and correlating information across a number of accidents, predictors may be identified which may then be applied to individual crews or situations in order to develop effective prevention strategies. Wiegmann & Shappell (2001) claim that the HFACS framework bridges the gap between theory and practice by providing safety professionals with a theoretically based tool for identifying and classifying the human errors in aviation mishaps. Since its It is based on a sequential or chain-of-events theory of accident causation and was derived from Reason's (1990), the classification system was originally developed for use within the

US military both to guide investigations and to analyse accident data (Shappell & Wiegmann, 2000b). Development has been used in a variety of transport and occupational settings including aviation, road and rail transport (Shappell & Wiegmann, 2000a; Federal Railroad Administration, 2005; Gaur, 2005; Li & Harris, 2005). It has also been used by the medical, oil and mining industries (Reinach and Viale, 2006). HFACS has also been used to analyse major flying operations (ex, commercial) and specific accident types, such as controlled flight into terrain (CFIT). Within the US aviation studies, the results have been consistent over time, with only small changes in the percentage of accidents associated with unsafe acts observed between earlier and later studies (Wiegmann & Shappell,2001;2005).The application of HFACS has also been effective for conducting comparisons between countries. Studies comparing US aviation accidents and those of other countries including China, Greece and India have been consistent. Their results indicated that while there were differences in the contributory factors between the countries, skill-based errors were associated with the greatest number of accidents in each of the countries followed by decision errors, violations and perceptual errors respectively (Gaur, 2005; Li & Harris, 2005).The system focuses on both latent and active failures and their inter-relationships, it facilitates the identification of the underlying causes of human error. However, as aviation accidents are the result of a number of causes, the challenge for accident investigators is how best to identify and mitigate the causal sequence of events leading up to an accident. whether this framework is suitable to meet needs of aviation accident's classification and investigation.

3 Method

Data: A total of 83 helicopter accidents and reported incidents, from 1970 to 2010 in Taiwan, is investigated. The aviation accident reports were obtained from Aviation Safety Council(ASC), Civil Aeronautical Administration(CAA), and Ministry of Defense(MOD) of Taiwan, R.O.C. There were same types of helicopter involved in the accidents, including commercial and Military aviation. All accidents and serious incidents conformed to the definition within the 9th edition of the Convention on International Civil Aviation, Annex 13 (International Civil Aviation Organisation, 2006).

Classification Framework: HFACS framework proposed by Wiegmann and Shappell (2003). HFACS Level-1: 'unsafe acts of operators' is the probable cause that directly lead to an accident. This Level-1 comprises four categories which are 'decision errors'; 'skill-based errors'; 'perceptual errors' and 'violations'. HFACS Level-2 is concerned with 'preconditions for unsafe acts'. This Level-2 has seven categories including : 'adverse mental states'; 'adverse physiological states'; 'physical /mental limitations';' crew resource management'; 'personal readiness';' physical environment' and 'technological environment'. HFACS Level-3 is concerned with 'unsafe supervision' which includes the four categories 'inadequate supervision'; 'planned inappropriate operation'; 'failure to correct known problem' and 'supervisory violation'. Level-4,the highest level in the framework is labelled 'organizational influences' and comprises of three sub-categories: 'resource management'; 'organizational climate' and 'organizational process'.

Coding Process: Each accident report was scrutinized and coded by two senior aviation investigators whose expertises are instructor pilot and aviation psychologist, respectively. Qualified investigators should possess at least 12-hour HFACS training. The presence (code 1) or the absence (code 0) of each HFACS category was carefully assessed in each accident report, narrative. To avoid over-representation from any single accident, each HFACS category was counted a maximum of only once per accident. The count acted simply as an indicator of presence or absence of each of the 18 categories in a given accident..

4 Analysis

In total instances of 626 category assignments were made to described the causal factors underlying the 83 accidents. The inter-rater reliabilities calculated on a category-by-category basis were assessed using Cohen's Kappa. The values obtained ranged between 0.62 and 1.0 (see table 1). Fourteen HFACS categories exceeded a Kappa of 0.60 indicating substantial agreement (Landis & Koch, 1977). As Cohen's Kappa can produce misleadingly low figures for inter-rater reliability where the sample size is small or where there is very high agreement between raters associated with a large proportion of cases falling into one category (Huddlestone, 2003), inter-rater reliabilities were also calculated as a simple percentage rate of agreement. These showed reliability figures between 89.2% to 100%, further indicating acceptable reliability between the raters. See Li & Harris (Li & Harris, 2006) for further details. Relatively few categories had exceptionally low counts. Only the categories of 'Failed to correct known problem';'Personal readiness' and 'adverse physiological state' failed to achieve double figures. The results reported only to the instances where the PRE was in excess of 5%. The data were cross tabulated to describe the association between the categories at adjacent levels in the HFACS analytical framework. Goodman and Kruskall's lambda (λ) was used to calculate the proportional reduction in error (PRE) (Goodman, 1954). The Lambda statistic is analogous to the R squared statistic for continuous data. For categorical data (such as that found in contingency tables), its value reflects the PRE when predicting the outcome category from simply the baseline prevalence as compared to using information from the predictive category. For the purposes of this study 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 theoretical assumptions underlying HFACS: from this standpoint, lower levels in the HFACS cannot affect higher levels. Finally, odds ratios were also calculated which provide an estimate of the likelihood of the presence of a contributory factor in one HFACS category being associated concomitantly with the presence of a factor in another category. However, it must be noted that odds ratios is an asymmetric measure and so are only theoretically meaningful when associated with a non-zero value for lambda.

Table 1. The frequency and percentage of 83 accidents by HFACS categories

HFACS category		Frequency	Ordinal	Percentage	Inter-rater reliability	Cohen's Kappa
Level 1	Decision errors	68	2	81.9%	92.8%	0.788
	Skill-based Errors	57	4	68.7%	90.4%	0.792
	Perceptual Errors	24	11	28.9%	98.8%	0.970
	Violations	17	14	20.5%	98.8%	0.962
Level 2	Adverse mental State	55	5	66.3%	100.0%	1.000
	Adverse physical state	8	16	9.6%	98.8%	0.927
	Physical/Mental limitation	47	7	56.6%	98.8%	0.976
	Crew resource management	73	1	88.0%	89.2%	0.624
	Personal readiness	2	18	2.4%	100.0%	1.000
	Physical environment	67	3	80.7%	100.0%	1.000
	Technical environment	20	13	24.1%	100.0%	1.000
Level 3	Inadequate supervision	49	6	59.0%	91.6%	0.830
	Planned inappropriate Operation	25	10	30.1%	96.4%	0.911
	Failed to correct known problem	5	17	6.0%	100.0%	1.000
	Supervisory violation	10	15	12.0%	100.0%	1.000
Level 4	Resource management	32	9	38.6%	96.4%	0.922
	Organizational climate	24	11	28.9%	95.2%	0.877
	Organizational processes	43	8	51.8%	94.0%	0.880

5 Result

All these relationships were also associated with high odds ratios, suggesting that inadequate performance in the higher level HFACS categories was associated with much increased levels of poor performance at the lower levels. The strength analysis on HAFCS level-4 'organizational influences' associated with adjacent HFACS level-3 'unsafe supervision' indicates that, among possible 12 pairs of relationships, 3 associations are significant ($p<0.05$), From statistical analysis, 'Inadequate supervision' is 5.28 times more likely to occur when organizational level associates with poor 'Resource management'; 'Supervisory violation' is 0.83 times more likely to occur when organizational level associates with poor organizational climate; Similarly, 'inadequate supervision' is 2.55 times more likely to occur in the presence of poor organizational processes. The strength analysis on HAFCS level-3 'unsafe supervision' associated with adjacent HFACS level-2 'pre-conditions for unsafe acts' indicates that, among possible 28 relationships, 6 associations are significant. ($p<0.05$).'CRM' is 0.91 times more likely to occur when supervision level associates with poor 'inadequate supervision' and 'Adverse mental state' is 0.07 times more likely to occur when supervision level associates with poor 'supervisory violation'; An issue also is associated with 'Adverse physical state' is 4.58 times more likely to occur when supervision level associates with poor 'planned inappropriate operations' and is 8 times more likely to occur when supervision level associates with poor 'failed to correct a known problem'; 'Personal readiness' is 1.25 times more likely to occur when supervision level associates with poor 'Supervisory violation', and 'CRM' is 0.71 times more

Table 2. Significant association between upper level and adjacent downward level categories in the HFACS framework

	χ^2 test		τ (PRE)		Odds rati
	Value	p-level	Value	p-level	
Organizational process vs Inadequate supervision	4.25	.004	.005	.040	5.27
Organizational climate vs supervisory violation	4.63	.005	.056	.033	0.83
Resource management vs Inadequate supervision	10.62	.001	.128	.001	2.55
Inadequate supervision vs Crew resource management	9.33	.002	.112	.002	0.19
Inadequate supervision vs Adverse mental state	16.38	.000	.197	.000	0.70
Planned inappropriate operations Vs adverse Physical state	4.41	.050	.053	.037	4.58
failed to correct a known problem vs adverse Physical state	5.63	.071	.068	.018	8.00
Supervisory violation vs Crew resource management	15.45	.002	.186	.000	0.07
Supervisory violation vs Personal readiness	14.96	.013	.180	.000	1.25
Adverse mental state vs Perceptual errors	9.74	.002	.117	.002	8.66
Physical/mental limitation vs Decision errors	6.35	.001	.077	.050	0.27
Crew resource m nagement vs Violations	24.92	.300	.039	.000	4.56
Crew resource management vs Decision errors	10.90	.004	.131	.001	0.11
Personal readiness vs Decision errors	4.49	.096	.054	.035	0.29
Physical environment vs Decision errors	5.79	.017	.070	.017	0.11
Technological environment vs Perceptual errors	5.57	.025	.067	.019	5.53
Technological environment vs Decision errors	4.58	.046	.055	.033	0.20

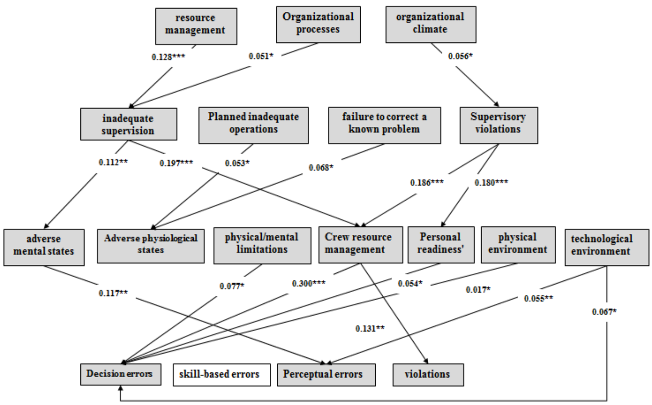

Fig. 1. The significant association of Chi-square (χ2) and Tau (τ)

likely to occur when supervision level associates with poor 'Supervisory violation'. The strength analysis on HAFCS level-2 'pre-conditions for unsafe acts' associated with adjacent HFACS level-1 'unsafe acts of operators' indicates that a possible 28 relationships, 8 pairs of associations are significant (p<0.05)

'Decision errors' is 0.27 times more likely to occur when pre-condition level associates with poor 'Physical/mental limitation'; Similarly, 'Decision errors' is 0.12

times more likely to occur in the presence of poor ‘CRM’; ‘Decision errors’ is 0.29 times associated with poor ‘Personal readiness’ ; ‘Decision errors’ is 0.11 times associated with poor Physical environment, and ‘Decision errors’ is 0.21 times associated with poor technological environment. Perceptual errors are over 8.67 times more likely to occur when there are pre-conditions level issues associated with poor ‘adverse mental state’ and over 5.54 times associated with poor ‘Technological environment’. Similarly, Violations is 4.56 times more likely to occur in the presence of poor ‘CRM’.

6 Discussion

In application of HFACS framework, inadequacies in the following categories of Level-4: ‘Organizational processes’ particularly result from excessive time pressures, poor mission scheduling, poor risk management programs, inadequate management checks for safety, failing to establish safety programs and ‘Resource management’ which involves the staff selection, training of human resources at an organizational level, excessive cost cutting, unsuitable equipment, and failure to remedy-design flaws also shows strong correlation with the level-3 categories of ‘inadequate supervision’. Untrained supervisors and general loss of situation awareness at the supervisory level(Li et al,2006a,b;2008). ‘Organizational climate’ including inadequacies in chain of command, poor delegation of authority, inappropriate organizational customs and beliefs. however, it is strongly correlated with the 'Supervisory violations'. hypothesize that inappropriate decision-making by upper-level management can adversely influence the personnel and practices at the supervisory level (Reason, 1990; Wiegmann & Shappell, 2003). It is strongly correlation with two categories of ‘CRM’, such as Poor ‘CRM’ including ‘Lack of teamwork’ and ‘Adverse mental states' such as ‘Failure to provide proper training’ or ’Adequate rest periods’(Li and Harris, 2006a,b). In addition, Adverse mental state includes ‘Lack of mental fatigue’ and ‘stress’. Inadequacies in ‘adverse mental practices’ are particularly influenced by the level-3 category of ‘inadequate supervision’. This category encompasses issues such as ‘failure to provide adequate rest periods’ and performance of personnel’ (Reason, 1990). These erroneous actions need not be confined to either 'Inadequate supervision’ or ‘Adverse mental’. Poor 'Supervisory violations' includes ‘authorizing an unqualified crew for flight’ and ‘Supervisors violating procedures’, it also shows strong relationships with the level-2 two categories of ‘CRM’ and ‘Personal readiness’. The Poor CRM includes lack of teamwork and ‘failures of leadership’. This category encompasses issues such as ‘failure to provide authorizing an unqualified crew for flight’. Moreover, poor ‘Personal readiness’ includes lack of selfmedication’and overexertion while off duty. Inadequacies in ‘Personal readiness’ practices are particularly influenced by the category of ‘Supervisory violations'. This category encompasses issues such as failure to provide ‘supervisors violating’ inadequate documentation and willful disregard of authority by the supervisor (Li and Harris’, 2008). The ‘preconditions for unsafe acts’ category poor ‘Adverse physiological states’ encompasses issues associated with inadequate training, self-medication and overexertion while off duty. Inadequacies in 'Adverse physiological states' practices are particularly influenced by the level-3 category of' 'Planned inadequate operations' and 'Failures to correct inappropriate behavior'. The Poor 'Planned inadequate operations' includes poor crew pairings and excessive task/workload, 'Failures to correct inappropriate behavior', failing to remove a known safety hazard, failing to report unsafe tendencies. This category in HFACS framework encompasses issues such as failure to provide poor crew pairings, failure to establish if risk outweighed benefit. Current study clearly provides evidence that inadequacies at HFACS level-2 'preconditions for unsafe acts' has associations with further inadequacies at HFACS level-1 'unsafe acts of operators'(Table2). The most frequently occurring category is 'Decision errors' which is also a particularly important factor at this 'unsafe acts of operators'. 'Decision errors' encompasses issues associated with failure of selecting inappropriate strategies during mission. The next most frequent category are lack of teamwork, poor communication, failure of leadership and inadequate briefing. The 'Technological environment' category covers issues such as equipment design, cockpit display interfaces, automation and checklist layout (Li el al, 2006a；2008).The level-1'unsafe acts of operators' category of 'Perceptual errors'. Poor 'Perceptual errors' included encompassed issues associated with experiencing spatial disorientation and descent rate during IMC. 'Perceptual errors' practices were particularly influenced by the level-2 category of' 'adverse mental states' and 'Technological environment'. This category in the HFACS encompasses issues such as a failure to provide, 'adverse mental states' included issues such as over-confidence, stress, distraction, and task saturation (Li and Harris 2008). Another 'Technological environment' by the effects of the lower.This accident involves 'unsafe acts of operators' category of 'CRM' which includes Poor 'CRM' such as lack of teamwork, poor communication and inadequate briefing. 'CRM' practices are particularly influenced by the level-2 category of' 'violations'. 'Violations' in HFACS framework encompasses issues such as pilots fail to provide or follow standard operation procedures (SOPs) (Li et al, 2008).

7 Conclusion

The Human Factors Analysis and Classification System (HFACS) was developed as an analytical framework for the investigation of the role of human factors in aviation accidents, becoming one of the most commonly used and is the one used herein as a basis for the current work. Strategies in application of HFACS on accident investigations have been successfully verified by many aviation psychological scholars. (Diehl, 1989; Wiegmann & Shappell, 2003). The benefit of HFACS is that the contributing human errors in any single accident can be properly categorized regardless the aircraft type of helicopter accident, and provide a preventive strategy for safety assurance. In most cases, space Disorientation and CFIT are two major probably causes for helicopter accidents. Consequently, strategy for helicopter safety promotion suggested from current study to the top management of helicopter organization is as follows. First, supervision on flight plan and pre-condition briefing requires reinforced compliment, particular on violators. Second, safety equipment promotion such as all weather radar and terrain detection radar increases the quality on decision-making of crewmembers.

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