Proceedings of the 37th Annual International Seminar: Incidents to Accidents— Breaking the Chain,
Cancun, Mexico, 11–14 September 2006, Pages 70-76

Breaking the Chain: An Empirical Analysis of Accident Causal Factors by Human Factors Analysis and Classification System (HFACS)

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ABSTRACT

This research analyzed 523 accidents in the R.O.C. Air Force between 1978 and 2002 using the Human Factors Analysis and Classification System (HFACS) framework described by Wiegmann & Shappell (2003). This study provides an understanding, based upon empirical evidence, of how actions and decisions at higher levels in the organization to result in operational errors and accidents. Suggestions are made about intervention strategies focusing on the categories at higher levels of HFACS. Specific targets for remedial safety actions should be aimed in the areas that share the strongest and greatest number of significant associations with 'Organizational Influences' (for example, 'organizational process', 'inadequate supervision' and 'Crew Resource Management'). The greatest gains in safety benefit could be achieved by targeting these areas. Furthermore, this study also demonstrates that the HFACS framework is a useful tool for guiding accident investigations and for targeting potentially cost-effective remedial safety actions for breaking the chain of accidents.

Keywords: *Accident Investigation; Human Error; Human Factors Analysis and Classification System (HFACS)*

INTRODUCTION

In accident investigation, it is easier to identify the cause with factual proof for hardware failures than for human failure. The role of human error in aircraft accidents is a topic of much scientific debate. There are a number of perspectives for describing and analyzing human errors, each based on different assumptions about their nature and the underlying causal factors of the human contribution in the sequence of events leading up to an accident. Accidents, especially those involving human errors, normally are associated with a chain of events --- a series of problems which degrade the performance of the equipment, the crewman, or both until the accidents are inevitable (Diehl, 1989). Feggetter (1991) suggested that the role of psychologists who investigate accidents is to collect and make a detailed examination of the large amounts of information associated with human errors and to gain a complete understanding of the surrounding circumstances. 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 developing the effective prevention strategies for breaking the chain leading to accidents.

Helmreich (1994) suggested that despite impressive technological advances, aircraft accidents continue to happen, and it is now suggested that humans, primarily the aircraft pilot and crew, are the weak link in the aviation safety chain. In general aviation, pilots are assessed as being the cause of accidents in over 80% of cases and that more than half of these accidents are the result of poor pilot judgment (Trollip & Jensen, 1991). As aircraft have become increasingly more reliable, human performance has played a proportionately increasing role in the causation of accidents. As a result, many human factors accident analysis frameworks, taxonomies and analysis strategies have been devised over the years (e.g. Diehl, 1989; Harle; 1995; Hollnagel, 1998; Hunter & Baker, 2000). The Human Factors Analysis and Classification System (HFACS) developed by Wiegmann & Shappell (2003) is the most commonly used and is the one used herein as a basis for the current work.

HFACS is a generic human error framework originally developed for US military aviation as a tool for the analysis of the human factors aspects of accidents. It is based on Reason's (1990) system-wide model of human error in which active failures are associated with the performance of front-line operators in complex systems and latent failures are characterized as inadequacies or mis-specifications which might lie dormant within a system for a long time and are only triggered when combined with other factors to breach the system's defenses. These latent failures are spawned in the upper management levels of the organization. As Reason (1997) noted, complex systems are designed, operated, maintained and managed by human beings, so it is not surprising that human decisions and actions are implicated in all organizational accidents. Reason's model revolutionized the manner in which the role of human error in aviation accidents was viewed but it did not provide a detailed method for the analysis of aviation accidents and mishaps. However, Wiegmann and Shappell developed the HFACS to fulfill such a need. The development of HFACS is described in a series of books and papers (e.g. Shappell & Wiegmann 2001; 2003 & 2004; and Wiegmann & Shappell 1997; 2001a; 2001b; 2001c & 2003). Wiegmann & Shappell (2001b) suggest that the HFACS framework bridges the gap between theory and practice by providing safety professionals with a theoretically based tool for identifying and classifying human errors. The tool focuses on both latent and active failures and their inter-relationships, and it facilitates the identification of the underlying causes of human error. However, as aviation accidents are often 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.

HFACS examines human error at four levels. Each higher level is assumed to affect the next downward level in the HFACS framework (see figure 1).

- Level-1 'Unsafe acts of operators': This level is where the majority of causes of accidents are focused. Such causes can be classified into the two basic categories of errors and violations.
- Level-2 'Preconditions for unsafe acts': This level addresses the latent failures within the causal sequence of events as well as more obvious active failures. It also describes the context of substandard conditions of operators and the substandard practices they adopt.
- Level-3 'Unsafe supervision': This level traces the causal chain of events producing unsafe acts up to the front-line supervisors.
- Level-4 'Organizational influences': This level encompasses the most elusive of these latent failures, fallible decisions of upper levels of management which directly affect supervisory practices, as well as the conditions and actions of front-line operators.

Wiegmann and Shappell (2001a) reported that the framework as a whole had an inter-rater reliability figure (using Cohen's Kappa) of 0.71, indicating substantial agreement, however no figures were reported for the individual HFACS categories. Li and Harris (2005) conducted further research and found the inter-rater reliabilities for the individual categories in the HFACS framework (assessed using Cohen's Kappa) ranged between 0.440 and 0.826, a range of values spanning between moderate agreement and substantial agreement. Fourteen HFACS categories exceeded a Kappa of 0.60, which indicates substantial agreement. Four categories had Kappa values between 0.40 and 0.59 indicating only moderate levels of agreement (Landis & Koch, 1977).

Maurino, Reason, Johnston and Lee (1995) suggested that it is important to understand how decisions made by people at the sharp-end (in this case, pilots) are influenced by the actions of the people at the blunt-end of their operating worlds, the higher levels in their organizations. However, there is little empirical work formally describing the hypothesized relationship between organizational structures, psychological pre-cursors of accidents and the actual errors committed by pilots. This research investigated 523 accidents in the ROC Air Force occurring between 1978 and 2002 through the application of the HFACS. The objective was to provide probabilities for the co-occurrence of categories across adjacent levels of the HFACS to establish how factors in the upper (organizational) levels in the framework affect categories in lower (operational) levels. Once the significant paths in the framework have been identified, the development of accident intervention strategies should proceed more rapidly and effectively for breaking the chain leading to accidents.

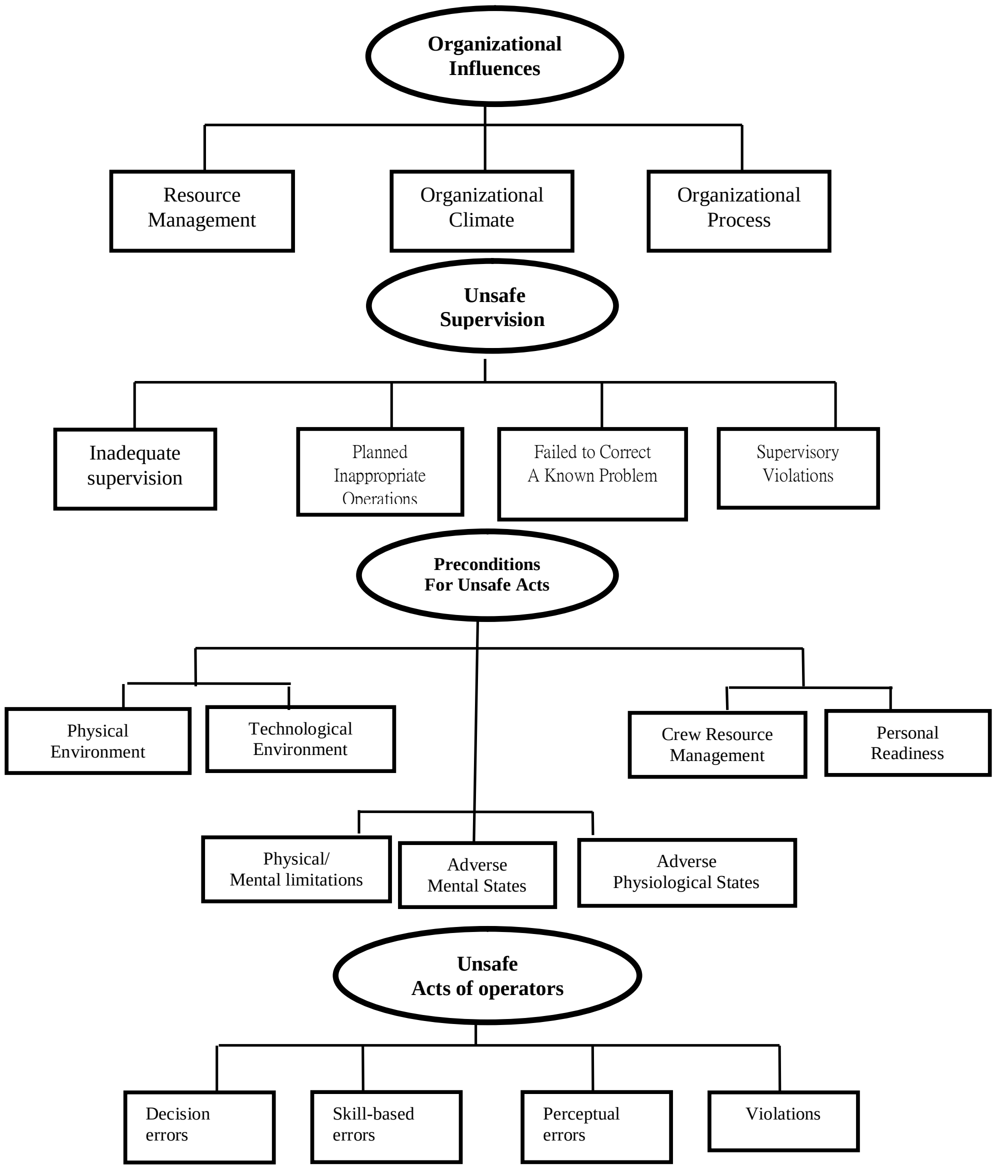

Figure 1 **The HFACS framework, each upper level would affect downward level, proposed by Wiegmann & Shappell (2003)**

METHOD

Data

The data were derived from the narrative descriptions of accidents occurring in the R.O.C. Air Force between 1978 and 2002. The data set comprised of 523 accidents occurring during this 25-year period of time. For each accident, the 24-hour on call Investigator-In-Charge follows a standard procedure for conducting the investigation. The initial stage collects relevant information for further analysis including the accident classification; identification details; pilots' information; personnel involved; aircraft information; mission and flight details; history of flight; impact and post-impact information; meteorological information; radar information and transmissions to and from Tactical Air Traffic Control. The wreckage of the aircraft is then recovered for investigation by the engineering teams. The final report details the causal factors of the accident and contains recommendations for accident prevention.

Classification framework

This study used the version of the HFACS framework described in Wiegmann & Shappell (2003). The first (operational) level of HFACS categorizes events under the general heading of 'unsafe acts of operators' that can lead to an accident. This comprises of four sub-categories of 'decision errors'; 'skill-based errors'; 'perceptual errors' and 'violations'. The second level of HFACS concerns 'preconditions for unsafe acts' which has seven further sub-categories: 'adverse mental states'; 'adverse physiological states'; 'physical/mental limitations'; 'crew resource management'; 'personal readiness'; 'physical environment', and 'technological environment'. The third level of HFACS is 'unsafe supervision' which includes 'inadequate supervision'; 'planned inappropriate operation'; 'failure to correct known problem', and 'supervisory violation'. The fourth and highest level of HFACS is 'organizational influences' and comprises of the sub-categories of 'resource management'; 'organizational climate' and 'organizational process'. HFACS is described diagrammatically in figure 1.

Coding process

Each accident report was coded independently by two investigators, an instructor pilot and an aviation psychologist. These investigators were trained on the use of the HFACS framework together for 10 hours to ensure that they achieved a detailed and accurate understanding of its categories. The presence or absence of each HFACS category was assessed in each report narrative. To avoid over-representation from any single accident, each HFACS category was counted a maximum of only once per accident.

Statistical analysis

Chi-square (χ^2) analyses of the cross-tabulations to measure the statistical strength of association between the categories in the higher and lower levels of the HFACS were used. As the χ^2 test is a simple test of association these analyses were supplemented with further analyses using Goodman and Kruskall's lambda (λ) which was used to calculate the proportional reduction in error (PRE). Goodman and Kruskall's lambda has the advantage of being a directional statistic. 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. The value for lambda indicates the strength of the relationship, with the higher levels in the HFACS being deemed to influence (cause) changes at the lower organizational levels, thus going beyond what may be deemed a simple test of co-occurrence between categories. Finally, odds ratios were also calculated which provided 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 as odds ratios are an asymmetric measure they are only really theoretically meaningful when associated with a non-zero value for lambda. From a theoretical standpoint, lower levels in the HFACS cannot adversely affect higher levels.

RESULTS

The frequency of occurrence the individual causal factors coded in the analysis of the 523 accidents is given in table 1. In these accidents, 1,762 instances of human error were recorded within the HFACS framework. Initial results found that acts at the level of 'unsafe acts of operators' were involved in 725 (41.1%) of instances; the 'preconditions for unsafe acts' level was as a causal factor in 552 (31.3%) of instances; the 'unsafe supervision' level was involved in 221 (12.5%) of instances, and the 'organizational influences' level in the HFACS model was involved as a factor in 264 (15 %) of instances. Relatively few categories had exceptionally low counts. Only the categories of 'organizational climate' (level-4); 'supervisory violation' (level-3) and 'adverse physiological state' (level-2) failed to achieve double figures.

Table I Frequency and percentage counts for each HFACS category for all 523 accidents.

HFACS Category		Frequency	Percentage
Level-4 Organizational Influences	Organizational process	76	14.5
	Organizational climate	4	0.8
	Resource management	184	35.2
Level-3 Unsafe Supervision	Supervisory violation	8	1.5
	Failed to correct a known problem	12	2.3
	Planned inadequate operations	24	4.6
	Inadequate supervision	177	33.8
Level-2 Preconditions for Unsafe Acts	Technology environment	44	8.4
	Physical environment	74	14.1
	Personal readiness	29	5.5
	Crew resource management	146	27.9
	Physical/mental limitation	73	14.0
	Adverse physiological states	2	0.4
	Adverse mental states	184	35.2
Level-1 Unsafe Acts of Operators	Violations	160	30.6
	Perceptual errors	116	22.2
	Skilled-based errors	226	43.2
	Decision errors	223	42.6

Analysis of the strength of association between categories at HFACS level-4 ‘organizational influences’ and HFACS level-3 ‘unsafe supervision’ found that out of a possible 12 relationships there were eight pairs of significant associations between categories at adjacent levels. ‘Organizational process’ was significantly associated with all four supervisory factors at level-3: ‘inadequate supervision’; ‘planned inappropriate operations’; ‘failed to correct a known problem’; and ‘supervisory violations’. ‘Organizational climate’ was significantly associated with ‘inadequate supervision’; ‘failed to correct a known problem’; and ‘supervisory violations’. ‘Resource management’ was significantly associated with only one category at level-3, ‘inadequate supervision’. Further examination of the directional PRE showed two significant associations between categories at level-4 and level-3; ‘organizational climate’ with ‘inadequate supervision’ and ‘organizational process’ with ‘inadequate supervision’. It should be noted, though, that only four instances were observed in which ‘organizational climate’ was implicated as a contributory factor. As a result, any associations involving this category should be treated with extreme caution. The association between ‘organizational process’ with ‘inadequate supervision’ also had a high odds ratio, suggesting that poor supervisory practices were over 13 times more likely to occur when associated with poor higher level managerial processes in the air force. These statistically significant relationships are summarized in table 2 and are described diagrammatically in figure 2.

Table II Chi-square test of association, Goodman and Kruskall's Lambda and Odds ratios summarizing significant associations between categories at the level of 'organizational influences' and 'unsafe supervision'

Organizational Influence *With* Unsafe Supervision	Pearson Chi-square			Lambda		Odds Ratio
	Value	df	p	Value	P	
Resource Management * Inadequate Supervision	13.525	1	<.001	.000	ns	0.473
Organizational climate * Inadequate Supervision	7.562	1	<.006	.023	<.045	nc
Organizational climate * Failed to correct known problem	39.753	1	<.001	.000	ns	49.500
Organizational climate * Supervisory violation	61.121	1	<.001	.000	ns	83.167
Organizational process * Inadequate Supervision	91.208	1	<.001	.282	<.001	13.561
Organizational process * Planned inappropriate operations	14.174	1	<.001	.000	ns	4.535
Organizational process *Failed to correct a known problem	11.899	1	<.001	.000	ns	6.100
Organizational process * Supervisory violation	46.307	1	<.001	.000	ns	nc

ns: *not significant*
nc: *not computed due to a zero frequency in one cell of the contingency table*

Analysis of the strength of association between categories at HFACS level-3 'unsafe supervision' and HFACS level-2 'preconditions for unsafe acts' showed that out of a total number of 28 possible comparisons, a further eight pairs of significant associations between categories at adjacent levels were found. 'Inadequate supervision' showed significant statistical associations with five categories; 'adverse mental states'; 'physical/mental limitations'; 'crew resource management'; 'personal readiness'; and 'physical environment'. 'Planned inappropriate operations' had significant relationships with two level-2 categories; 'adverse mental states'; and 'crew resource management'. 'Failed to correct a known problem' was significantly associated with the lower level category of 'adverse mental states'. These significant associations are summarized in table 3 and in figure 2. Further examination of the directional PRE found that there was a significant association between the level-3 and level-2 categories of 'inadequate supervision' and 'crew resource management'. This relationship also had a high odds ratio, suggesting that poor supervisory practices were almost 13 times more likely to subsequently result in poor CRM.

Table III Chi-square test of association, Goodman and Kruskall's Lambda and Odds ratios summarizing significant associations between categories at the level of 'unsafe supervision' and 'precondition for unsafe acts'

Unsafe Supervision *With* Preconditions for Unsafe Acts	Pearson Chi-square			Lambda		Odds ratio
	Value	df	P	Value	p	
Inadequate Supervision * Adverse mental states	29.545	1	<.001	.038	ns	2.824
Inadequate Supervision *Physical/mental limitation	7.945	1	<.005	.000	ns	2.036
Inadequate Supervision * CRM	143.573	1	<.001	.281	<.002	12.780
Inadequate Supervision * Personal readiness	10.101	1	<.001	.000	ns	3.304
Inadequate Supervision * Physical environment	6.604	1	<.010	.000	ns	0.469
Planned inappropriate operations *Adverse mental states	5.730	1	<.020	.022	ns	2.594
Planned inappropriate operations *CRM	10.824	1	<.001	.027	ns	3.744
Failed to correct a known problem * Adverse mental states	6.958	1	<.008	.000	ns	nc

ns: *not significant*
nc: *not computed due to a zero frequency in one cell of the contingency table*

Analysis of the strength of association between categories at HFACS level-2 'preconditions for unsafe acts' and HFACS level-1 'unsafe acts of operators' showed a further 16 pairs of significant associations out of a possible 28. The level-2 category of 'adverse mental states' exhibited significant statistical associations with four level-1 categories; 'decision errors'; 'skill-based errors'; 'perceptual errors'; and 'violations'. 'Crew resource management' was also associated with four lower-level categories in the HFACS framework; 'decision errors'; 'skill-based errors'; 'perceptual errors'; and 'violations'. 'Physical/mental limitations' was associated with three categories; 'decision errors'; 'skill-based errors'; and 'perceptual errors'. The 'technology environment' was also statistically associated with a further three level-1 categories; 'decision errors'; 'skill-based errors'; and 'perceptual errors'. Finally, 'personal readiness' was associated with 'decision errors' and 'skill-based errors'. Further examination of the directional PRE found that there were eight significant associations between level-2 and level-1 categories. These were 'adverse mental states' with 'decision errors' and 'skill-based errors'; 'physical/mental limitations' with 'decision errors' and 'skill-based errors'; 'crew resource management' with 'decision errors' and 'skill-based errors'; and 'personal readiness' with the categories of 'decision errors' and 'skill-based errors'. These significant statistical relationships are summarized in table 4 and are described diagrammatically in figure 2. All these significant associations were associated with high odds ratios, suggesting that inadequate performance in the higher level HFACS categories was associated with much increased likelihood of poor performance at the lower levels.

Table IV Chi-square test of association, Goodman and Kruskall's Lambda and Odds ratios summarizing significant associations between categories at the level of 'precondition for unsafe acts' and 'unsafe acts of operators'

Precondition for Unsafe Acts With *Unsafe Acts of Operators*	Pearson Chi-square			Lambda		Odds ratio
	Value	df	p	Value	P	
Adverse mental state * Decision errors	59.226	1	<.001	.269	<.001	4.364
Adverse mental states * Skill-based errors	61.701	1	<.001	.283	<.001	4.518
Adverse mental states * Perceptual errors	43.730	1	<.001	.000	ns	4.106
Adverse mental states * Violations	13.025	1	<.001	.000	ns	2.019
Physical/mental limitation * Decision errors	50.996	1	<.001	.211	<.001	7.730
Physical/mental limitation * Skill-based errors	33.051	1	<.001	.164	<.001	4.735
Physical/mental limitation * Perceptual errors	27.401	1	<.001	.000	ns	3.764
CRM * Decision errors	42.578	1	<.001	.215	<.001	3.724
CRM * Skill-based errors	35.423	1	<.001	.195	<.001	3.299
CRM * Perceptual errors	62.086	1	<.001	.000	ns	5.435
CRM * Violations	19.850	1	<.001	.000	ns	2.462
Personal readiness * Decision errors	10.220	1	<.001	.058	<.015	3.613
Personal readiness * Skill-based errors	15.181	1	<.001	.075	<.001	5.231
Technology environment * Decision errors	3.982	1	<.046	.000	ns	0.509
Technology environment * Skill-based errors	5.724	1	<.017	.000	ns	0.440
Technology environment * Perceptual errors	6.982	1	<.008	.000	ns	0.228

ns: *not significant*
nc: *not computed due to a zero frequency in one cell of the contingency table*

DISCUSSION

It can be seen from the data presented in table 1 that the vast majority of HFACS categories had large numbers of instances of occurrence in the data set, which allows reasonable confidence in the results of the statistical analyses and the pattern of results obtained. Reason (1990 & 1997) has suggested that there is a 'many to one' mapping of the psychological precursors of unsafe acts and the actual errors themselves, making it difficult to predict which actual errors will occur as a result of which preconditions. This research, using the HFACS framework developed by Wiegmann & Shappell (2003) goes some way to supporting this assertion. There are statistically significant associations between causal factors at higher organizational levels, the psychological contributory factors and the errors committed by pilots (see tables 2-4 and figure 2). However, some care needs to be taken when interpreting the statistical relationships presented within HFACS. In a few categories (noted earlier) the frequency counts are small. Furthermore, the frequency counts within categories were all derived from accidents. It is unknown (and unknowable) how often instances within the various HFACS categories have occurred in day-to-day operations that have not resulted in an accident. Thus, the relationships between HFACS levels and categories should not be interpreted outside the accident causal sequence. It should also be noted that only in those cases where a significant χ^2 test of association is accompanied by a significant value for lambda can it be assumed that the categories in the lower levels of the HFACS framework were dependent upon the higher-level categories, as is congruent with the underpinning theory.

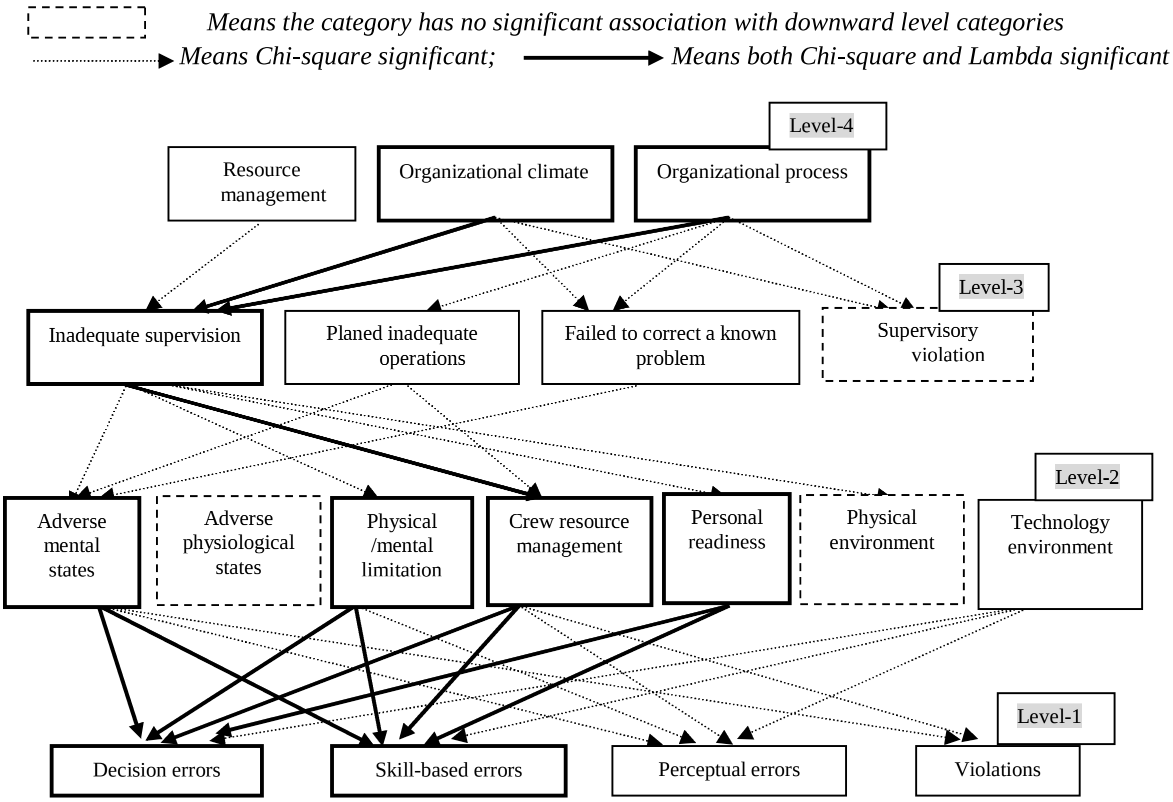

Figure II. Paths between categories at the four levels in the HFACS framework showing the significant associations using Chi-square ($\chi 2$) and Lambda (λ)

Orasanu and Connolly (1993) have suggested that decision-making occurs in an organizational context, and that the organization influences decisions directly by stipulating standard operating procedures, and indirectly through the organization's norms and culture. Reason (1990) proposed that latent conditions are present in all systems and they are an inevitable part of organizational life. For example, resources are normally distributed unequally in organizations. The original decision on how to allocate resources may have been based on sound commercial arguments but such inequities may create reliability or safety problems for someone somewhere in the system at some later point. This analysis showed that at HFACS level-4, 'organizational influences', all the categories had some association with causal factors at level-3 ('unsafe supervision'). However, the category of 'organizational process' is the key factor at this highest organizational level. Poor 'organizational processes' were associated with inadequacies in all categories at the level of 'unsafe supervision' and hence indirectly were ultimately at the root of many operational errors resulting in accidents. Well-developed 'organizational processes' that are consistently adhered to are key to all safety management systems. The commitment to safety must come from the very highest levels of the organization if it is to be successful in this respect (Reason, 1997). Both Reason (1990) and Wiegmann & Shappell (2003) hypothesized that 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 hence the subsequent actions of the front-line operators. This study provides statistical support for this hypothesized relationship. Furthermore, the odds ratios associated with 'supervisory failures' were over 13 times more likely to occur in the presence of a concomitant failure in the category of 'organizational process' (see table 2).

Wojcik (1989) proposed that some conditions are studied by psychologists and are reasonably well understood, such as work schedules that allow adequate sleep. However, other conditions related to management and organizational factors are more difficult to observe and quantify. At present the accident causal factors cited by investigation authorities usually, though not always, emphasize technology, the physical environment and the more immediate human factors, an emphasis partly due to the 'stop rules' of investigators when searching for accident causes (Rasmussen, 1988). The category of 'inadequate supervision' was the key factor at HFACS level-3. It had many, significant statistical associations with categories in level-2, however, there was only one significant 'causal' relationship observed, which was with the level-2 category of 'Crew Resource Management'. The failure of senior officers in a supervisory position to provide guidance and operational doctrine to pilots was associated with many forms of psychological precursor that subsequently resulted in active, operational failures. Again, the values for the odds ratios associated with 'supervisory failures' and several level-2 categories strongly suggest that this is a key area for breaking the chain leading to accidents. This suggests that accident investigations should be pursued further back into the organization than is often the case at present.

Reason (1990) suggested that human behavior is governed by the interplay between psychological and situational factors. The pre-conditions for unsafe acts (level-2) show a number of strong statistical relationships with the active failures of the operators at level-1. In many cases the relationships uncovered in the data suggest a strong 'causal' influence of the higher-level HFACS categories on the level-1 errors. These level-2 factors show Reason's classic 'many to one' mapping of psychological precursors to active failures in all of the level-1 categories with the exception of 'violations' which is only closely related to two higher level categories suggesting that a completely different mechanism is at play here to cause such failures (see figure 2).

Some aspects, however, are almost out of the control of even the higher levels of the organization. It is interesting to note that the level-2 category of the 'technological environment' (which is essentially concerned with such factors as the quality of cockpit interfaces) is not at all influenced by the higher managerial levels. However, it has a significant association with several HFACS level-1 categories. This is probably a result of the higher levels in the ROC Air Force chain of command having little or no influence on the cockpit design of their aircraft. Indeed, it is often the case in the military that those responsible for the design and/or procurement of large pieces of equipment are in entirely different organizations to the operators of these systems. Those responsible for the technology environment are not actually in the same management hierarchy as the people using it.

It will be noted from the results presented in tables 2 to 4 (and in figure 2) that even though there were a considerable number of statistically significant associations between HFACS categories at adjacent organizational levels, there were relatively few 'causal' relationships, where the lower level categories were statistically dependent upon higher-level categories. This may lead to the suggestion that unlike the proposition expounded in the HFACS model (and in its associated underlying theory) organizational influences are not always unidirectional. People at lower levels in the organization may, in some circumstances, adversely influence behavior at higher managerial levels. It is conceivable that pilots exhibiting 'poor personal readiness', an 'adverse mental state' or who had 'physical or mental limitations' could cause problems which resulted in 'inadequate supervision'. On the other hand, though, it is difficult to see how 'decision errors' could cause an 'adverse mental state'. The results obtained suggest that the HFACS framework needs to be modified slightly to encompass a more dynamic view of organizations.

The results suggest that interventions at HFACS levels 1 and 2 would only have limited effect in improving overall safety. As an example, improving CRM practices alone is unlikely to have a major impact on safety unless the supervisory processes (level-3) and organizational processes (level-4) are in place to provide facilities; oversee CRM training; monitor its effectiveness and respond to any further changes required in the training program. All of these activities require organizational commitment and capacity, which can only be provided from the highest levels of management. Furthermore, on a 'dollar-for-dollar' basis, interventions at higher levels are also likely to be more cost effective in terms of the net safety benefits they realize. Specific targets for remedial safety action should be aimed in the areas that share the strongest and greatest number of significant associations with lower levels in the organization (for example, 'organizational process', 'inadequate supervision' and 'Crew Resource Management'. All of these categories are also at the root of paths of association with other HFACS categories that have very high values for the odds ratios associated with them which further suggests that the greatest gains in safety benefit could be achieved by targeting these areas.

CONCLUSIONS

There is a growing awareness of the role of management and organizational factors in aviation accidents (Orasanu & Connolly, 1993). There is an explicit relationship between organizational conditions and the individual psychological factors affecting safety performance. It is important to understand how the errors committed by pilots are influenced by the actions of management at the higher levels in their organizations (Maurino et al., 1995). If the aviation industry wants to achieve the goal of significantly reducing the aviation accident rate these organizational and human factors must be addressed. Before research efforts can be systematically refocused, a comprehensive analysis of existing databases needs to be conducted to determine the most prevalent underlying organizational factors, as well as the more immediate human factors responsible for aviation accidents and incidents. Furthermore, if these efforts are to be sustained, appropriate human factors investigation methods and techniques will need to be developed so that data gathered during human factors accident investigations can be improved, and analysis of the underlying causes of human error facilitated (Wiegmann & Shappell, 2001c). This study provides an understanding, based upon empirical evidence, of how actions and decisions at higher levels in the organization promulgate throughout the R.O.C. Air Force to result in operational errors and accidents. There are clearly defined, statistically-described paths that relate errors at level-1 (the operational level) with inadequacies at both the immediately adjacent and higher levels in the organization. The accidents and incidents analyzed all occurred in the ROC Air Force thus the patterns of inter-relationships reported may be culturally specific. However there is no reason why this analytical methodology cannot be employed on other data sets to establish if the patterns observed hold good in other cultures, thereby providing further empirical evidence to support the HFACS methodology. This research draws a clear picture that supports Reason's (1990) model of active failures resulting from latent conditions in the organization. Furthermore, the HFACS framework has been proven to be a useful tool for guiding accident investigations and for targeting potentially cost-effective remedial safety actions for breaking accidents chain.

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