

Improving the Safety Risk Matrix by Considering Cross-Cultural Risk Perception using HFACS Methodology

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Abstract: This paper addresses the evaluation of safety risks on the basis of probability of occurrence and the severity of potential consequences. Using the Human Factors Analysis and Classification System (HFACS) as a framework, cross-cultural variations in the frequency of occurrences and severity of human factors conditions (as presented in significant ‘routes to failure’) were applied to the Safety Risk Assessment Matrix. Analysis of N = 121 responses highlighted significant cultural differences in safety risk assessments, providing justification for the targeted prioritisation of control actions using safety risk indexes derived from HFACS outputs. The present findings support the more directed administration of risk management resources within flight operations, specifically amongst pilots from civilian, airline-sponsored, and ex-military backgrounds. Safety and risk managers can apply the methodology to improve the selection and prioritisation of safety initiatives, offering potential improvements to the relevance and cost-effectiveness of safety risk management endeavours.

Keywords: Human Factors Analysis and Classification System (HFACS), Safety Risk Matrix, Safety Management Systems

1 Introduction

1.1 Safety Risk Assessment and Tolerability

In Safety Risk Management, individual safety risks are assessed by their probability of occurrence and the severity of potential consequences. A safety risk index can be obtained for each risk factor by multiplying the probability and severity scores, ranging from risk factors with high probability and catastrophic severity to factors of extremely improbable likelihood and negligible severity. The indexes obtained for each factor are typically evaluated against a Safety Risk Matrix in which safety risks are conceptually assessed as acceptable, tolerable, or intolerable (Figure 1). The matrix therefore assists organizations in prioritizing risks to determine which factors require immediate action, which factors can be tolerated but may require management decisions to accept the risk, and which factors are acceptable as is. Control actions to limit potential threats are typically achieved either by reducing the probability component, the severity component,

or both, so that the safety risk index for the particular risk can be managed to an acceptable level [1].

<u>Probability</u>	<u>Severity</u>				
	Catastrophic (5)	Hazardous (4)	Major (3)	Minor (2)	Negligible (1)
Frequent (5)	Intolerable				
Occasional (4)					
Remote (3)			Tolerable		
Improbable (2)					
Extremely Improbable (1)			Acceptable		

Fig. 1. The Safety Risk Matrix (adapted from [1]).

Presently, the assessment of safety risks and their probability and severity remain conceptual and is dependent on the subjective judgment of investigators. Perceptive and predictive biases arising from factors such as national culture, professional experience, training background, and familiarity with elements of the system under analysis can introduce biases in how the probability and severity of risk factors are assessed [2], [3]. This presents a need for further research to evaluate how biases in the investigation stage can influence the consequent safety risk indicators in relation to relevance and objectiveness.

1.2 The Human Factors Analysis and Classification System (HFACS)

The Human Factors Analysis and Classification System (HFACS) has been widely utilized as a taxonomic framework for the categorization of system-wide latent and active human factors conditions implicated in the causal sequence of events [4]. Within the HFACS, human factors deficiencies can be attributed to 18 categories spanning four levels representing different levels of the organization hierarchy (Table 1).

Table 1. Levels and categories of the Human Factors Analysis and Classification System (HFACS).

Level		Categories
L4	Organisational Influences	1. Resource Management
		2. Organizational Climate
		3. Organizational Process
		4. Inadequate Supervision
L3	Unsafe Supervision	5. Planned Inappropriate Operations
		6. Failed to Correct a Known Problem
		7. Supervisory Violations
		8. Environmental Factors
L2	Preconditions for Unsafe Acts	<ul style="list-style-type: none"> • Physical Environment • Technological Environment
		9. Condition of Operators
		<ul style="list-style-type: none"> • Adverse States • Adverse Physiological States • Physical/ Mental Limitations
		10. Personnel Factors
		<ul style="list-style-type: none"> • Crew Resource Management • Personal Readiness
		11. Decision Errors
L1	Unsafe Acts of Operators	12. Skill Based Errors
		13. Perceptual Errors
		14. Violations

The lowest two levels encompassing frontline-level active failures (level 1) and their preconditions (level 2) have been argued as being the most relevant to operations personnel in the aviation environment [5], as frontline personnel in the aviation industry were considered to have a greater degree of social and physical separation with the supervisory and organisational conditions within HFACS levels 3 and 4. Recent research has further suggested the integration of failure modes within level 2 into three underlying categories of ‘Environmental Factors’, ‘Condition of Operators’, and ‘Personnel Factors’ [6]. This consolidates the HFACS into a reduced-size seven-category taxonomy for the categorisation of factors most relevant to frontline-level occurrences (Figure 2).

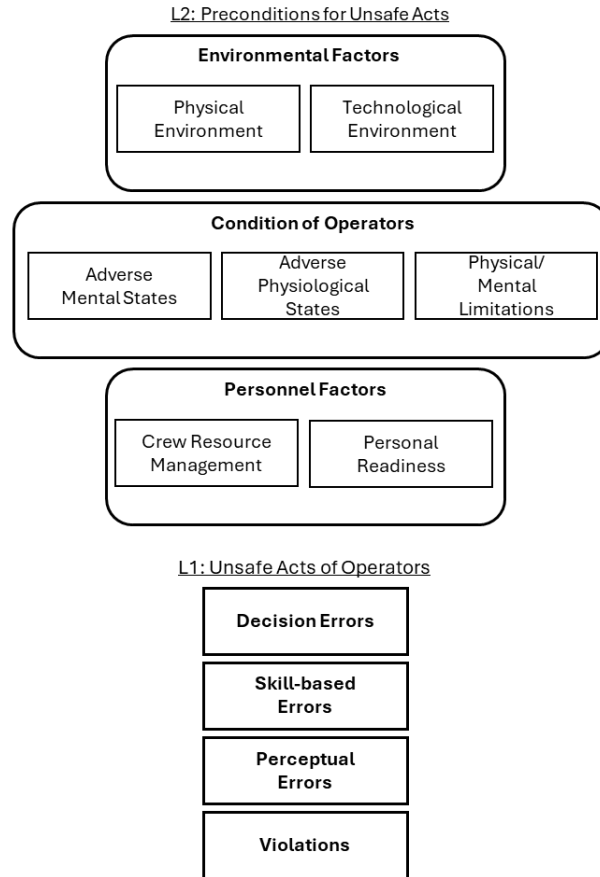


Fig. 2. Reduced-size seven-category taxonomy focusing on frontline-level occurrence factors.

1.3 HFACS Categories as Measure of Probability and Severity

As the seven categories represent frontline-level occurrences, the utilization of these categories within HFACS categorization exercises (for an identical set of causal factors) represents the frequency of occurrence. When applied at the system level this corresponds to the likelihood that a safety consequence or outcome will occur and is therefore reflective of the probability factor within safety risk assessments. This means that HFACS categorization results can be used as an approximation of probability in the Safety Risk Matrix.

In addition, as the HFACS was developed on the basis of Reason's Swiss Cheese model of accident causation [7], the categories can be associated with each other. Interactive linkages amongst categories across the various levels represent 'routes to failure' linking the holes of the Swiss Cheese [4]. Moreover, each factor can be associated with more than one other factor in a 'many-to-one' concept, suggesting that there may be multiple pathways leading to the same outcome. It was therefore argued that

deficiencies (i.e. holes in the Swiss Cheese) which are associated with a greater number of other deficiencies should be the focus for remedial safety actions [8], because rectifying the one problem will create second-order benefits in categories associated with it. This implies that the number of consequential associative factors originating from each HFACS category can function as an approximation of safety risk severity in the Safety Risk Matrix.

1.4 Cross-Cultural Differences in Risk Perception

Although HFACS has been widely used in previous research to capture perceptions of systemic safety deficiencies, it is known that patterns in the utilization of HFACS categories (for an identical set of causal factors) can be affected by cultural differences. The use of HFACS categories was known to be influenced by interpretations of cultural stigma [9]; categorization patterns can be affected by investigators' experience levels within a cultural environment [3]; and viewpoints in relation to both the causes and consequences of human factors were known to differ between civilian and military-trained air pilots [8]. The attribution of factors into HFACS categories and the significant associations amongst them were also found to be different amongst pilots who were trained in civilian, airline-sponsored, or military environments [2].

1.5 Research Gap

There is a research gap in addressing how cultural differences can influence HFACS categorization patterns and the associated routes to failure, and how these can consequently affect their application for the assessment of safety risk components of probability and severity. The goal of the present research was therefore to utilize HFACS categorization patterns to calculate safety risk indexes for each of the seven HFACS categories representing frontline-level occurrences, and to evaluate whether these indexes differed amongst air pilots exposed to different organizational culture environments of civilian, airline-sponsored, and ex-military training backgrounds.

2 Method

2.1 Participants

Responses from $N = 121$ airline pilots were included in this analysis. To capture cultural differences, the participants included $n = 66$ who were trained in a self-funded civilian environment; $n = 30$ who were initially trained in airline-sponsored programs; and $n = 25$ ex-military pilots. Participation was voluntary, anonymous, and participants had the right to terminate their participation at any time. The research design was approved by the Cranfield University Research Ethics System (12950/2021).

2.2 Research Design and Statistical Analysis

The dataset for the present study was drawn from part of a larger research project on mid-air collisions which tasked the participants with categorizing $n = 17$ accident causal factors. An online survey was used for data collection. After demographic questions which enabled the classification of responses into civilian, airline-sponsored, and ex-military groups, the causal factors ($n = 17$) were presented as survey items, and participants were asked to select in a dropdown menu the HFACS category which they considered to be the most relevant, or to select none. The frequency of use of each of the seven categories within the first two HFACS layers (and are considered to reflect front-line-level occurrences: Figure 2) were derived from the resulting dataset. To identify the ‘routes to failure’ linking the various categories, Fisher’s exact tests of association were conducted using IBM SPSS (version 29), with the presence (1) or absence (0) of each HFACS category entered as the binary variables for cross-tabulation.

Safety risk indexes were calculated by multiplying the frequency of use of each of the seven categories, expressed as a percentage of total, with the number of ‘routes to failure’ originating or terminating at the category in question. This was independently performed for data collected from the civilian, airline-sponsored, and ex-military groups.

3 Results and Discussion

3.1 Probability and Severity

The frequency of use of each of the seven consolidated HFACS categories, amongst civilian, airline-sponsored, and ex-military groups, are presented in Table 2. Notably, ‘Environmental Factors’ (level 2) was most frequently utilized in HFACS categorization across all three groups. This reflects a high level of safety risk probability related to ‘Environmental Factors’, and corresponds with previous research which found ‘Environmental Factors’ to have the greatest overall causal impact when multi-order influences are considered at the system level [5]. In contrast, ‘Violations’ (level 1) was least frequently utilized by the airline-sponsored and civilian groups and was the second-least frequently utilized by the ex-military group. This reflects that the ‘Violations’ category had a lower likelihood of occurrence.

Table 2. Frequency of use of the seven consolidated HFACS categories, expressed as percentage of total.

	Civilian	Airline-Sponsored	Ex-Military
Decision Errors (L1)	6.41%	8.09%	4.95%
Skill-Based Errors (L1)	12.62%	18.72%	16.48%
Perceptual Errors (L1)	9.90%	8.94%	12.64%
Violations (L1)	4.85%	4.26%	7.69%
Environmental Factors (L2)	32.43%	27.23%	27.47%
Personnel Factors (L2)	10.87%	12.77%	13.19%
Condition of Operators (L2)	22.91%	20.00%	17.58%
Total	100.00%	100.00%	100.00%

The number of consequential associative factors originating from each HFACS category were considered to reflect the severity or the influence that the category in question has over wider system characteristics. In the civilian group, ‘Environmental Factors’ (level 2) had the most associations with other categories with four significant ‘routes to failure’; whereas in the airline-sponsored group the most influential category was ‘Decision Errors’ (level 1: with two ‘routes to failure’); and in the ex-military group the ‘Condition of Operators’ (level 2) had the greatest number of significant associations (two ‘routes to failure’) (Table 3).

Table 3. Number of significant ‘routes to failure’ associated with each category.

	Civilian	Airline-Sponsored	Ex-Military
Decision Errors (L1)	1	2	0
Skill-Based Errors (L1)	0	0	1
Perceptual Errors (L1)	1	1	0
Violations (L1)	1	0	0
Environmental Factors (L2)	4	1	2
Personnel Factors (L2)	2	0	0
Condition of Operators (L2)	4	0	3

3.2 Safety Risk Assessment

By multiplying the probability of occurrence (represented by the frequency of use of each HFACS category) with the number of consequential associative factors originating from each HFACS category (which provides an approximation of safety risk severity), the safety risk index for each category was calculated and presented in Table 4.

Table 4. Safety Risk Indexes for each category.

	Civilian	Airline-Sponsored	Ex-Military
Decision Errors (L1)	0.06	0.16	0.00
Skill-Based Errors (L1)	0.00	0.00	0.16
Perceptual Errors (L1)	0.10	0.09	0.00
Violations (L1)	0.05	0.00	0.00
Environmental Factors (L2)	1.30	0.27	0.55
Personnel Factors (L2)	0.22	0.00	0.00
Condition of Operators (L2)	0.92	0.00	0.53

Whilst the safety risk index of each category can be observed as fluctuating amongst the three groups, comparing the indexes across the seven HFACS categories presents an interesting picture (Figure 3). Firstly, ‘Environmental Factors’ (at HFACS level 2) had the highest safety risk index across all three groups. Given that the category was considered to have a comparatively high probability (as represented by higher frequency of attributions), it is reasonable to conceive that the high safety risk index is primarily driven by a higher likelihood of occurrence. However, as discussed above, previous research has identified the ‘Environmental Factors’ category to have the highest causal impact (i.e. highest net influence given to other HFACS conditions) in the seven categories of HFACS representing frontline occurrences [5]. In conjunction with the finding that ‘Environmental Factors’ had the largest number of associated ‘routes to failure’ within the civilian group, it is conceivable that the safety risk severity of this factor is also comparatively higher.

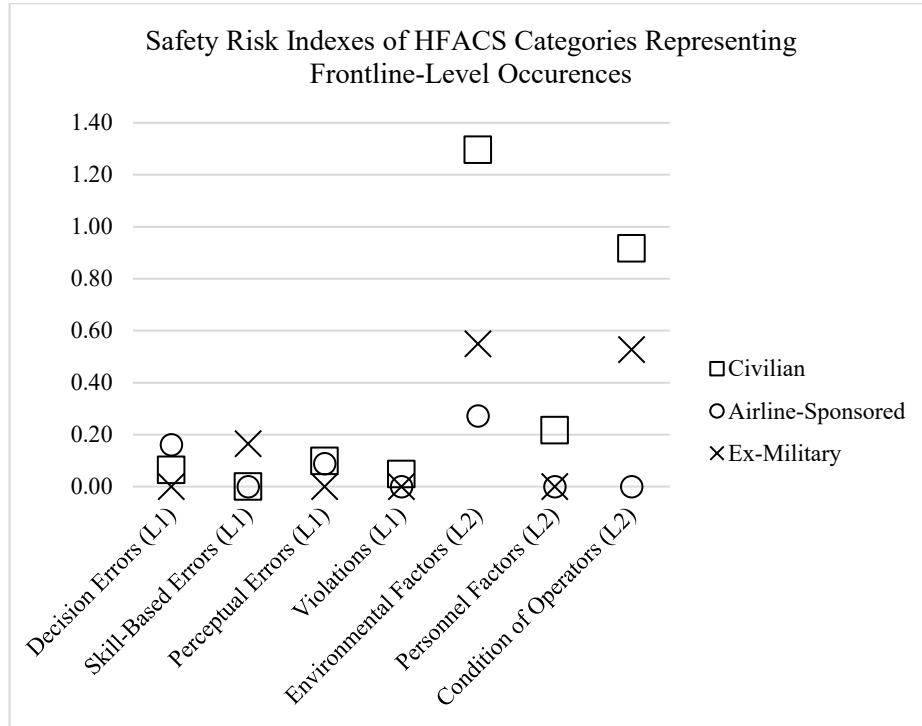


Fig. 3. Safety risk indexes of HFACS categories representing frontline-level occurrences.

Secondly, the ‘Condition of Operators’ category (HFACS level 2) provides support for cross-cultural differences in risk perception. In the present results, the category had the second-highest safety risk index for the civilian and ex-military groups, yet it was oppositely tied lowest for the airline-sponsored participants (Table 4; Figure 3). The comparatively lower risk index found in the airline-sponsored group can possibly be reflective of consequences of familiarity and loyalty to organisational characteristics. Pilots who qualified through airline-sponsored programmes were found in previous research to have a higher level of familiarity with the organisational philosophy [10], a stronger ‘in-group’ identity [11], and less separation between organisation-level and operator-level factors [12]. In the context of HFACS attributions, these features were considered to manifest in more direct attribution to either organisation-level root causes or operator conditions [2]. Therefore, the present finding of a comparatively low safety risk index for ‘Conditions of Operators’ in the airline-sponsored cohort suggests that operator conditions were perceived as more tolerable possibly because the participants contrarily considered the risks to be generated at the higher organisational levels.

3.3 Prioritisation of Mitigation Actions

In accordance with the principles of the Safety Risk Matrix, the rectification of risk factors can be prioritized on the basis of their safety risk index scores [1]. A practical

benefit of the present research is that findings enable the prioritization of the various failure categories and corresponding control actions by ranking the safety risk indexes.

Current industry recommendations, such as those as promulgated by the International Civil Aviation Organization's Standards and Recommended Practices, advocates for remedial safety actions to be directed to specific addressees [13]. Whilst in present industry convention this means that safety actions are directed to specific levels or occupations within the organizational hierarchy (e.g. flight operations or cabin services directives), the separation of participants into civilian, airline-sponsored, and ex-military groups in the present research enables an even finer-grained direction of safety interventions. To illustrate, within the flight operations pilot group, whilst mitigation actions addressing 'Personnel Factors' is recommended for civilian trained pilots (3rd highest ranking of safety risk out of 7 factors), if the target trainees come from airline-sponsored or ex-military backgrounds then risks associated with 'Personnel Factors' are acceptable as is. Armed with this data, safety and risk managers can ensure that resources are more appropriately directed, possibly enhancing the cost-effectiveness of future safety risk management strategies.

4 Conclusion

Current safety risk management practices typically assess risks on the basis of probability and severity, but the evaluation of probability and severity remain dependent on subjective judgement. The present research utilized the Human Factors Analysis and Classification System (HFACS) as a framework to capture the likelihood of frontline occurrences happening within a system. Also, by statistically testing for co-existence of human factors deficiencies, associations amongst HFACS categories were identified and studied as a representation of the safety risk severity. Analysis of responses from N = 121 airline pilots from a range of civilian, airline-sponsored, and ex-military training backgrounds identified cultural differences in safety risk indexes. 'Environmental Factors' was discovered to have high likelihood and high consequential severity across all groups, favoring the prioritization of remedial safety actions to address environmental concerns. The finding of cross-cultural differences in risk perception also provided support for more specific administration of risk management resources depending on target trainee demographics, offering potential improvements in future safety risk management.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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2026-07-26

Springer

https://doi.org/10.1007/978-3-032-29456-2_10

Chan WT-K, Li W-C. (2026) Improving the safety risk matrix by considering cross-cultural risk perception using HFACS methodology. In: Proceedings of the 23rd International Conference, EPCE 2026, Held as Part of the 28th HCI International Conference, HCII 2026, Montreal, Canada, 26-31 July 2026, Volume 16707, Lecture Notes in Computer Science, pp. 139-148