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Pilots' training backgrounds affecting the attribution of event causal factors and airline safety management

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ABSTRACT

For safety management in diverse aviation operators, it is necessary to investigate how different cultural factors interact in flight operations. Whilst prior studies have evaluated between-group cultural differences, there remains a research gap on whether within-group subcultural differences challenge the assimilation of people into the safety culture of the wider group. Cultural differences in how causal factors are perceived in the context of systemic safety deficiencies can affect the implementation of safety management strategies. In the present study, pilots from airline-sponsored, self-funded, and ex-military initial training backgrounds were invited to categorise an identical set of aircraft accident causal factors using the Human Factors Analysis and Classification System (HFACS). Results from 121 participants found significant differences amongst the three groups in the attribution of human factors conditions to organisational-level and supervisory-level categories. Significant associations amongst HFACS categories also differed amongst the three professional groups, with a considerable number of same-level associations found between 'Preconditions for Unsafe Acts' at the same level. Familiarity with organizational cultures was considered to impact the perception of causal factors. The finding of same-level associations presents a new contribution to the theoretical basis of the HFACS taxonomy, calling for a conceptual change in the directionality of causal sequences. The results suggest that the direction of safety remedies for different parts of the organisation is dependent on perceived relevance, which differs amongst subcultural groups. Findings are relevant to industry, particularly international airlines with diverse employee subcultural groups, for the implementation of safety management systems.

1. Introduction

Safety Management System (SMS) functions within aviation organisations manage systemic threats through the four components of Safety Policy and Objectives, Safety Risk Management, Safety Assurance, and Safety Promotion (ICAO, 2018). Cultural factors can influence all four of these SMS components. Firstly, cultural differences on what is perceived to be important or achievable can influence what policies and objectives are established. Secondly, perceptive biases in the identification of safety hazards and deficiencies may alter the categorisation of human factors deficiencies in the investigation stage, and consequently impact what issues are included in remedial safety risk management. Thirdly, as consequential interventions are more likely to be successful if they are considered to be relevant and acceptable by the target users, an awareness of cultural differences will assist in ensuring that the safety assurance and safety promotion components are designed to be well-received by the target user groups (Simard and Marchand, 1997).

Airline companies are often regarded as a singular organisational unit with a consistent company safety culture and its own SMS (Dahlstrom and Heemstra, 2009; ICAO, 2018). In reality, as organisations becoming larger and more multicultural, a combination of subcultures will interact within each company (Kaminska et al., 2021). Helmreich (1999) proposed that aviation operations are influenced by the three cultures of national, professional, and organisational culture. Whilst the effects of national and professional experiences on safety culture have been widely examined, there is few research on how exposure to previous organisational cultures can affect SMS applications. Workers with different work experiences may bring with them different subcultures. For example, within large airlines it is not uncommon for pilots from different training backgrounds (e.g., airline-sponsored, self-funded, ex-military) to operate together on the flight deck. Little is known as to whether these subcultural groups can fully assimilate into the wider organisational safety culture. If cultural remnants from previous experiences remain, then organisational SMS

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components have to be adjusted to ensure their validity and relevance for different employee groups.

1.1. Cultural effects on airline safety management

To effectively understand and manage cultural differences in the implementation of SMS, it is necessary to consider how different cultural factors interact in relation to the wider safety culture. The composition of safety culture within open systems can be considered as multiple layers surrounding the line workers (Fig. 1). The outer layers represent societal or supervisory influences, whereas the inner layers represent components within the system. Like ripples in a pond, latent conditions across the various layers are considered to transpire interactively through the meta-categories of concerns, influences, and actions, to shape eventual safety outcomes (Morley and Harris, 2006).

Employees from different backgrounds may bring with them different experiences which moderate how the various levels interact and how the interactions are elaborated. These include factors such as professional and national background which may vary the context within which the concerns, influences, and actions are considered (e.g., what is concerning within one culture may not be concerning in another) (Inglis et al., 2010a; Li et al., 2007). Experience within an 'in-group' may act through factors such as perceptive biases (Leveson et al., 2019; Lundberg et al., 2009), and the identification of safety hazards and deficiencies within the safety management process may be influenced by relative familiarity with human factors analysis frameworks (Cohen et al., 2015; Olsen and Shorrock, 2010). Specifically, within heterogenous, 'melting-pot' societies (e.g., large, international airline groups), cultural variations within the system were known to create differences in attitudes towards flight safety (Chan and Harris, 2019). Thus, the present argument is that the subcultural differences amongst line workers with different previous training and experiences will affect how concerns, influences, and actions function as conduits of culture. As the identification of existing safety hazards and deficiencies during the accident investigation phase forms the basis for the establishment of safety policy and objectives in the SMS, cultural differences in the attribution of causal factors can subsequently alter what factors are included in future SMS strategies (Li et al., 2007).

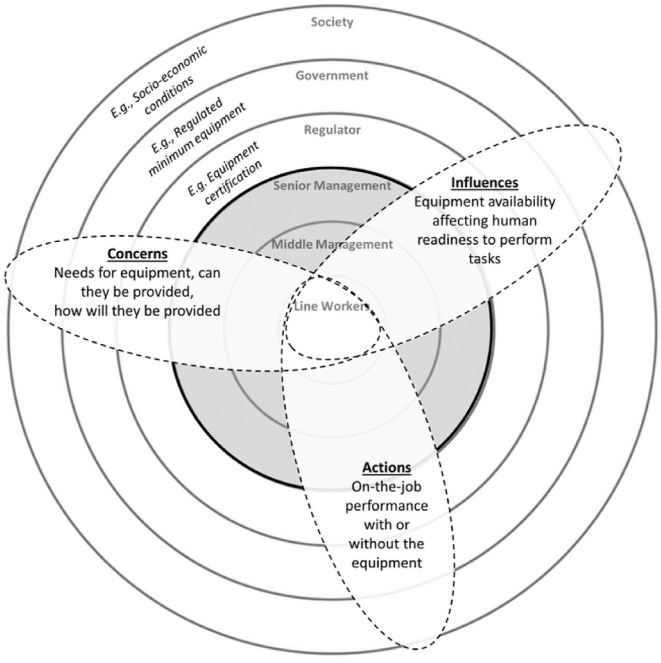


Fig. 1. *The 'Ripple Model' of culture showing layers of cultural influence and the interactive meta-categories transpiring across the layers* (Chan and Li, 2023).

1.2. Airline recruitment sources induced cultural differences

In previous research, demographic and cultural differences were found to influence attitudes towards safety practices and adherence to SOPs, perceptions of and interactions with other employee groups, attitudes towards organisational weaknesses and improvements (Helmreich and Merritt, 1998); commitment to duty (Cooper et al., 2018); and adherence to regulations (Hörmann, 2001). Further, as organisational SMS functions and its processes can be considered as a subset of national or regional cultures (Dahlstrom and Heemstra, 2009; Sevillian and Jarvis, 2014), factors which may influence how causal factors are perceived may include attitudes related to hierarchy, interpersonal relationships, and hidden power structures (Liao, 2015). Differences in how people choose to balance mission success, safety, and profit (Cooper et al., 2018; Leaver and Reader, 2019) may also affect hazard identification and evaluation of SMS interventions. Operationally, these factors may in turn affect crew members' perception towards SMS processes related to Crew Resource Management training (Metscher et al., 2009) and flight deck and system interface designs (Sevillian and Jarvis, 2014).

Some airlines train and hire their own ab-initio cadets through airline-sponsored programmes, some airlines hire pilots with previous civilian experience, and other airlines hire ex-military pilots (Hörmann et al., 1998). Pilots who qualified for airline sponsored programs through extensive testing and selection procedures and were trained from day one within the employing airline's organisational environment are known to be more loyal to the airline and hence are more willing to prioritise and subscribe to organisational safety and just cultures (Dahlstrom and Heemstra, 2009). They are also more likely to have a higher level of alignment between their personal professionalism and the prevailing organisational culture (Hörmann et al., 1998), possibly as a result of shared training experiences which creates an 'in-group' identity (Chan and Harris, 2019). This closer alignment at the interface between individual and organisational contexts can affect individuals' integration into cultural processes (Merritt and Maurino, 2004), potentially influencing the pilots' perceptions of their employer and subsequently impact job performance (Helmreich and Merritt, 1998). Ab-initio pilots, for example, were known to be more dependent on the support of the operator than pilots with previous experience (Kilic and Ucler, 2019).

Prior research has also found that civilian-trained and ex-military pilots differed in factors related to performance, behaviours, and team interactions (Kaminska et al., 2021). Ex-military pilots are exposed to a more enclosed environment where most of the personnel encountered (pilots, air traffic controllers, engineers, etc.) will be within the organisation (Helmreich and Merritt, 1998). Ex-military pilots also have higher levels of uncertainty avoidance as adherence to rules and procedures are to a larger extent related to life and death (Soeters and Boer, 2000), and factors such as strict discipline, determination, and commitment to completing the mission are indoctrinated through military bootcamps (Cooper et al., 2018). Decision making preferences can be influenced by differences in the trade-off between efficiency and thoroughness (Hollnagel, 2017). Consequently, this can affect their attitudes towards the usage of standardised procedures (Merritt and Maurino, 2004), as well as influence viewpoints towards the causes of human factors issues and their subsequent consequences and interventions (Li and Harris, 2006).

In the long run, individuals' experiences during initial training in the early stages of their career may influence cultural values and practices which persist even after the individuals go on to switch organisations and acquire experiences that are comparable with others from differing groups. Routines acquired by individuals early in their careers can become deeply implanted, even if they become inconsistent with the present or future methodology (Peter and Lauf, 2002). Stressful situations may also cause individuals to revert to deeply held schemata (Edwards et al., 2013). In a comparison of ex-military and

civilian-trained pilots working in the same civilian airline, ex-military pilots were more likely to deviate from the rules to complete the mission, whereas their civilian-trained colleagues had no reservations to abort the mission if a rule-based threshold was breached (Kaminska et al., 2021). Between air safety investigators who were initially trained in frontline operational roles and those who were initially trained in more conceptual roles, differences were also detected in causal attribution, as well as the acquisition and projection of information (Chan and Li, 2022a).

1.3. Accident investigation and hazard identification using HFACS

Within the SMS, the components of Safety Policy and Objectives and Safety Risk Management involves the establishment of safety accountability and responsibilities, and hazard identification (ICAO, 2018). To enable these components, risk factors and human factors deficiencies within each system have to the categorised. The Human Factors Analysis and Classification System (HFACS) provides an 18-category taxonomy of latent and active failures across four hierarchical organisational levels (Table 1). Based on Reason's (1990) Swiss Cheese concept that resilient systems require several breaches before resulting in unsafe or unintended outcomes, deficiencies are assumed to progress through the HFACS levels as upper-level management decisions trickle down to frontline-level failures (Wiegmann and Shappell, 2003). By using the HFACS taxonomy, SMS managers can direct safety management functions to relevant parts of the organisation for subsequent interventions (Li et al., 2010).

The HFACS has been widely researched and utilised in both academic and industrial settings, ranging from aviation (Daramola, 2014; Dönmez and Uslu, 2020), maintenance (Illankoon et al., 2019; Krulak, 2004), air traffic control (Chen et al., 2013; Xu et al., 2021), mining (Liu et al., 2018; Patterson and Shappell, 2010), maritime (Kaptan et al., 2021), rail (Reinach and Viale, 2006), medicine (ElBardissi et al., 2007), amongst others. In application, prior researchers have argued that a certain level of expertise is desired as coders without subject matter knowledge may not be able to distinguish between contextual and cognitive concepts when using incident coding systems (Baker and Krokos, 2007; O'Connor and Walker, 2011). Evaluations of HFACS, in particular, have found that whilst raters were able to reliably agree on which of the four levels ('Unsafe Acts' at L1 to 'Organisational Influences' at L4) to utilise, they generally found it difficult to agree on choosing a particular category at each level (Ergai et al., 2016).

Thus, when utilising the HFACS framework it is necessary to consider the demographic and cultural characteristics of the coders and how they may impact the categorisation outcomes. The effects of national and professional cultures on the perception of human factors deficiencies have been previously examined (Li et al., 2007). However, there exists a research gap on how differences in previous organisational experience can impact HFACS categorisation, and if different cultural subgroups can become assimilated into wider organisational safety cultures. As individuals' experiences during initial training in the early stages of their career were known to be deeply implanted, the effects of organisational differences during initial training and how they play a role in subsequent career stages merits further investigation.

Table 1
Participant characteristics by training background.

	Mean Flight Experience (Hours)	Mean Age (Years)
Self-Funded (n = 66)	10409 (s.d. = 6598)	41.8 (s.d. = 8.2)
Airline-Sponsored (n = 30)	6075 (s.d. = 5853)	35.6 (s.d. = 9.1)
Ex-Military (n = 25)	15030 (s.d. = 5678)	50.9 (s.d. = 7.8)
All Groups (N = 121)	10273 (s.d. = 6918)	42.2 (s.d. = 9.8)

1.4. Research questions

It was identified that although cultural influences on the attribution of human factors deficiencies were widely examined, there exists a research gap on how differences amongst subcultural groups with different organisational experiences may affect these attributions. An understanding of these differences will provide safety managers with an idea of how safety hazards are identified for inclusion in the establishment of SMS objectives. If there are differences amongst different subcultural groups, then the findings can provide information as to how SMS processes can be adapted so that pilots from different backgrounds can be assimilated into the wider safety culture. The first objective of the present research was to compare current airline pilots who were initially trained in airline-sponsored ab-initio programs, self-funded civilian training programmes, and those initially trained in the military, to evaluate if the three groups differed in their attribution of human factors deficiencies to active failures and latent conditions across different levels as represented by the HFACS framework.

Where the groups differed in their attribution of human factors deficiencies, a secondary objective was to determine mutually associated categorical factors. By determining whether the utilisation of one category was associated with the utilisation of another category, the results can provide more possibilities for targeted SMS interventions. For example, in previous research on civilian aviation accidents, the presence of 'Adverse Mental States' predicted the existence of at least one unsafe act (Inglis et al., 2010b). Thus, for safety management, rather than solely focusing on rectifying first-order unsafe acts, another possibility is to direct SMS interventions to the second order 'Adverse Mental States' category as the management of mental states such as distraction and mental fatigue are likely to also rectify consequential unsafe acts.

In addition, prior research on the reliability of coding taxonomies have argued that as the number of available coding options increases, system reliability will decrease as coders find it challenging to consider the large numbers of options (Krippendorff, 2019). Therefore, a third objective of the present research was to look for significant associations between HFACS categories at the same level. This will help to identify any duplication of categories at each system layer to inform the reduction of system size. Based on the literature review, there were three research questions as follows:

RQ1. Do airline pilots from different initial training backgrounds (airline-sponsored, self-funded, ex-military) differ in their classification of an identical set of safety factors into HFACS categories?
RQ2. If the utilisation of HFACS categories differed significantly between the airline pilot groups, what human factors conditions were associated with each other?
RQ3. Were there any significant associations between HFACS categories at the same level?

2. Method

2.1. Research design

2.1.1. Coding framework

The Human Factors Analysis and Classification System (HFACS) is an analytical framework providing 18 categories over four organizational levels into which analysts can categorise safety deficiencies (Table 2). The lowest level, *Unsafe Acts of Operators,* covers errors and violations committed by frontline personnel. The second level, *Preconditions for Unsafe Acts*, represent latent conditions arising from substandard conditions and practices. The third level, *Unsafe Supervision*, traces these latent conditions to inadequacies to the supervisory levels in an organisation. The fourth and highest level, *Organisational Influences*, represents conditions at higher management levels, such as corporate resource management and deficiencies in organisational processes and

climate (Wiegmann and Shappell, 2003).

2.1.2. Research process

Members of a trade union representing the cockpit crew members of a large international airline group were invited to participate in the study. The airline group operated and had employees based across Australasian, European, and North American regions. An email which contained an anonymous hyperlink to a survey hosted on the Qualtrics platform (www.qualtrics.com) was sent to prospective participants through internal email. The survey did not contain identifying information and was only available to the research team. Ethics approval was provided by the University Research Ethics Committee (12950/2021).

On opening the hyperlink to the survey, the process continued as follows: (1) A participant information page where the research purpose, ethics approval, data handling procedures, and participant rights were presented; (2) A specific item requesting consent; (3) If the participant provided consent, then the web interface redirected to a set of demographic questions including age (years) and work experience (flight experience in hours, initial training background) items which enabled the categorisation of participants into groups; (4) The HFACS coding exercise. Thus, the present research included a total of 21 survey items. These included one consent to participate item (mandatory response - if they do not check 'Yes' then the survey closes); three demographic items on participants' age (open-ended numerical input of age in years), flight experience (open-ended numerical input of experience in total flight hours), and initial training background (single-choice option of either 'Airline-Sponsored', 'Self-Funded', or 'Ex-Military'); followed by 17 items in the HFACS coding exercise (single-choice dropdown menu containing 18 options).

2.1.3. HFACS coding exercise

The HFACS coding exercise was based on a case study of the mid-air collision between a Boeing 757 and a Tupolev 154 aircraft over Uberlingen, Germany, on July 1, 2002 (BFU, 2004). This accident was selected as the case study subject for several reasons. Firstly, the case provides a high level of commonality as it was widely used in previous studies on HFACS and similar human factors investigation frameworks (Brooker, 2008; Li et al., 2007), as well as in studies of situation awareness and systemic faults (Masys, 2005; Nunes and Laursen, 2004) and technical and regulatory deficiencies (Bennett, 2004). Secondly, as the accident involved a mix of cultures across national (Western and Eastern-bloc aircraft designs), professional (pilots and ATC), state, and organisational boundaries, the cultural factors involved in this incident have already been analysed through different perspectives (Chan and Li, 2023; Harris and Li, 2011). This makes the case ideal for the present research as it enables any findings to be discussed in the context of other confounding cultural issues.

In the exercise, the participants were presented with a synopsis of the event (BFU, 2004). After reading the synopsis they were presented with a list of 17 contributing factors. These factors were identified as proximal major failures in a previous analysis of the accident using a combination HFACS-STAMP method (Harris and Li, 2011). The contributing factors were paraphrased by two subject matter experts in aviation safety and accident investigation and listed as 17 independent survey items. Each item was connected with a dropdown menu listing the 18 HFACS categories (Appendix A). For each item (contributing factor), participants were instructed to select the HFACS category that they considered to be the most relevant, or to select none, if they did not think that any of the 18 categories were appropriate.

2.2. Statistical analysis

Statistical analysis was performed using IBM SPSS (version 29). For the first research question ("Do airline pilots from different initial training backgrounds differ in their classification of an identical set of safety factors into HFACS categories?"), the participants' initial training backgrounds were entered as the independent variable with three levels including: (1) airline-sponsored; (2) self-funded civilian; and (3) ex-military. The dependent variables were the frequency in which participants chose each of the 18 HFACS categories.

As the responses were based on the frequency of utilisation of each HFACS category, and a greater (or lower) frequency was not representative of higher (or lower) risk levels, the data was at the ordinal level. To compare ordinal level data across the three groups, non-parametric, rank-based comparisons were carried out. Kruskal-Wallis H tests were used to test for differences between the medians of the airline-sponsored, self-funded, and ex-military groups on their utilisation of each HFACS category. As the Kruskal-Wallis H test is based on ranks shared across all the groups, the test assesses whether the distributions of values were in the same general location, rather than testing for differences in the means of the different groups. Thus, following cases where H test results showed a significant main effect amongst the three groups, post-hoc Dunn's tests were performed in a pairwise manner between two groups at a time, with Bonferroni adjustments for multiple comparisons applied. Effect sizes (Epsilon square ε^2) were also calculated. To interpret the effect size, the interpretation of correlation coefficients by Rea and Parker (2014) was adapted following Haque et al.'s (2023) methodology by squaring the threshold values of each bin to correspond with the ε^2 as a squared variable. The classifications ranged from negligible ($0.00 < 0.01$), weak (<0.04), moderate (<0.16), relatively strong (<0.36), strong (<0.64), and very strong (<1.00).

Additionally, as the HFACS is based on the Swiss Cheese model of accident causation, tests of association were carried out between HFACS categories to test if each category was significantly associated ($p < 0.05$) with any of the 17 other HFACS categories. Fisher's exact test was the selected analytical method as the expected frequencies were expected to be less than 5. The presence (1) or absence (0) of each HFACS category amongst the participants' selections in the HFACS coding exercise were entered as binary variables for cross-tabulation (e.g., if the participant selected 'Skill-Based Error' in any one of the survey items, then 'Skill-Based Error' as a category was coded as (1)). The null hypotheses were that the presence of one category was independent to the presence of other categories. Significant associations between categories are representative of concomitant categories, which answers the second and third research questions ("What human factors conditions were associated?"; and "Were there cases where the utilisation of one category was associated with the utilisation of another same-level category?").

As the goals of the research were to find differences in the utilisation of HFACS categories and to search for associations amongst HFACS categories, formal reliability checks were not suitable for this study. Firstly, the selection of one HFACS category does not preclude the selection of the same category or of other categories elsewhere in the HFACS coding exercise. This makes measures of inter-rater reliability at the item level inappropriate, even within groups, because the subject of interest is the presence (or absence) of HFACS categories across all 17 items in the entire exercise. Secondly, adjustment of levels of agreement amongst participants for chance events (such as in the Kappa procedure) are not suitable for expert-led taxonomic frameworks. Even where the participants were unable to decide on a specific code, they would choose one based on some degree of logic, rather than by guessing arbitrarily. In fact, situations where different expert participants had conflicting attributions for a given contributing factor (low levels of inter-rater agreement) may actually highlight categories that were closely associated with each other and may therefore help to answer the second and third research questions. Therefore, to ensure the reliability of the survey, the present research utilised purposive expert sampling, ensuring that only qualified professions from an internal mailing list were invited to participate.

3. Results

3.1. Sample characteristics

One-hundred and twenty-one (N = 121) airline pilots participated in the present research, of which n = 30 were initially trained in airline-sponsored ab-initio programs, n = 66 were initially trained in self-funded civilian programs, and n = 25 were trained in the military. The participants' flight experience and age are presented in Table 1.

The frequency of participants choosing a particular HFACS category is presented in Table 2. As there was no limit to how many times the participant can choose a particular HFACS category, the participant may have repeatedly selected the same HFACS category across different items in the survey. Thus, a higher frequency was not representative of higher risk levels associated with the category itself, but merely a greater likelihood for the participant to choose a certain category in the course of conducting a HFACS coding exercise. The focus is on whether the three groups comparatively differed in their likelihood to the utilise specific categories within the HFACS framework.

3.2. Differences between airline sponsored, self-funded, and ex-military trained pilots on the attribution of human factors issues

To answer the first research question ("Do airline pilots from different initial training backgrounds differ in their classification of an identical set of safety factors into HFACS categories?"), Kruskall-Wallis test results showed significant differences in two HFACS categories. Participants from airline-sponsored, self-funded, and ex-military backgrounds differed in their attribution of deficiencies to the 'Planned Inappropriate Operations' category at level 3, and the 'Organisational Climate' category at level 4 (Fig. 2).

For the 'Planned Inappropriate Operations' (level 3) category, moderate but significant differences were found amongst the three groups ($H(2) = 7.38$, $p = 0.025$, $\varepsilon^2 = 0.046$). Ex-military pilots were most likely to attribute faults to this category, followed by self-funded pilots, and lastly their airline-sponsored colleagues (Fig. 2). Dunn's pairwise tests with Bonferroni correction found further differences between the airline-sponsored and the ex-military group ($p = 0.25$), but differences between the other pairs were non-significant.

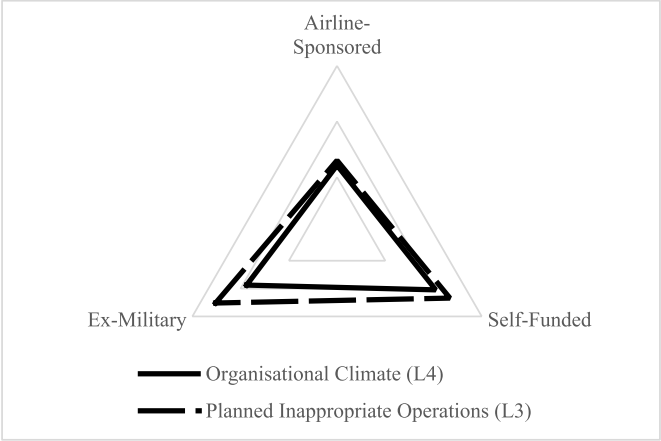


Fig. 2. Comparison of the frequency of utilisation of the 'Organisational Climate' and 'Planned Inappropriate Operations' HFACS categories amongst the airline-sponsored, self-funded, and ex-military groups.

The present results also revealed significant differences amongst the three groups in their utilisation of the 'Organisational Climate' (level 4) category, $H(2) = 6.47$, $p = 0.039$, but the effect size was comparatively smaller ($\varepsilon^2 = 0.038$). Self-funded pilots were most likely to attribute deficiencies to this category, followed by their ex-military and lastly airline-sponsored colleagues (Fig. 2). In this case, Dunn's post-hoc tests showed significant differences between the airline-sponsored and self-funded groups only.

Table 2
Frequency and percentage of participants attributing causal factors in the Uberlingen mid-air collision to HFACS categories amongst the airline-sponsored, self-funded, and ex-military groups.

	HFACS Categories	Self-Funded (n = 66)		Airline-Sponsored (n = 30)		Ex-Military (n = 25)	
	Frequency of classification =	1017	100.00 %	461	100.00 %	405	100.00 %
Level 1	Decision Errors	33	3.24 %	19	4.12 %	9	2.22 %
	Skill Based Errors	65	6.39 %	44	9.54 %	30	7.41 %
	Perceptual Errors	51	5.01 %	21	4.56 %	23	5.68 %
	Violations	25	2.46 %	10	2.17 %	14	3.46 %
	Level 1 Total	174	17.1 %	94	20.4 %	76	18.8 %
Level 2	Adverse Mental States	24	2.36 %	7	1.52 %	4	0.99 %
	Adverse Physiological States	10	0.98 %	0	0.00 %	6	1.48 %
	Physical/Mental Limitations	84	8.26 %	40	8.68 %	22	5.43 %
	Crew Resource Management	35	3.44 %	22	4.77 %	17	4.20 %
	Personal Readiness	21	2.06 %	8	1.74 %	7	1.73 %
	Physical Environment	17	1.67 %	5	1.08 %	4	0.99 %
	Technological Environment	150	14.75 %	59	12.80 %	46	11.36 %
	Level 2 Total	341	33.5 %	141	30.6 %	106	26.2 %
Level 3	Inadequate Supervision	18	1.77 %	12	2.60 %	7	1.73 %
	Planned Inappropriate Operations	119	11.70 %	30	6.51 %	51	12.59 %
	Failed to Correct a Known Problem	42	4.13 %	25	5.42 %	27	6.67 %
	Supervisory Violations	17	1.67 %	6	1.30 %	9	2.22 %
	Level 3 Total	196	19.3 %	73	15.8 %	94	23.2 %
Level 4	Resource Management	59	5.80 %	32	6.94 %	32	7.90 %
	Organizational Climate	104	10.23 %	28	6.07 %	38	9.38 %
	Organizational Process	143	14.06 %	93	20.17 %	59	14.57 %
	Level 4 Total	306	30.1 %	153	33.2 %	129	31.9 %

3.3. Association between categories on both vertical and horizontal HFACS framework

Fisher's exact tests of association were carried out to test the second research question ("What human factors conditions were associated?"). Pairs of categories with statistically significant associations are presented in Fig. 3.

Specifically, having identified that the three pilot groups differed in their frequency of attributing deficiencies to the 'Planned Inappropriate Operations' (L3) and 'Organisational Climate' (L4) categories, by determining which other categories were associated with these categories, influential factors in the causal chain can be identified. For the airline-sponsored group, the 'Planned Inappropriate Operations' (L3) category was significantly associated with 'Technological Environment' at the *Preconditions for Unsafe Acts* level (L2) ($p = 0.009$), and the 'Organisational Climate' category was associated with 'Decision Errors' ($p = 0.042$) and 'Perceptual Errors' ($p = 0.046$), both at level 1. For the self-funded group, 'Organisational Climate' was associated with 'Technological Environment' at level 2 ($p = 0.007$), but no significant associations were found between 'Planned Inappropriate Operations' and the other HFACS categories. For the ex-military group, Fisher's exact tests did not find any significant associations in relation to the 'Planned Inappropriate Operations' and 'Organisational Climate' categories.

Taking a wider perspective and focusing on the significant associations across the four HFACS levels, the results also revealed differences in attributing human factors conditions amongst the three groups (Fig. 5). The airline-sponsored group had a larger proportion of associated categories originating or terminating at levels 1 (38 %) and 4 (25 %) compared to their self-funded (L1: 15 %; L4: 10 %) and ex-military (L1: 13 %; L4: 13 %) colleagues. Conversely, associative linkages involving at least one level 2 category made up a larger proportion amongst the self-funded (50 %) and ex-military (63 %) groups than in the airline-sponsored group (13 %).

In addition, to answer the third research question ("Were there any significant associations between HFACS categories at the same level?"), Fisher's exact tests were also run between HFACS category pairs at the same levels. Significant same-level associations were found within levels 2 and 3 (Fig. 6), and across-the-board there were more same-level associations between level 2 categories (n = 4) than associations between categories at level 2 and categories at any other individual level (Fig. 4a). It was notable that the same-level associations at level 2 were exclusively found in the self-funded (Fig. 4c) and ex-military groups (Fig. 4d).

4. Discussion

4.1. Training backgrounds affected attribution of causal factors in flight operations

The finding of differences amongst the three groups in utilising 'Organisational Climate' (L4) and 'Planned Inappropriate Operations' (L3) categories when classifying an identical set of safety factors positively supports the first research question ("Do airline pilots from different initial training backgrounds differ in their classification of an identical set of safety factors into HFACS categories?": Table 2; Fig. 2).

4.1.1. Organisational Climate

The 'Organisational Climate' category covers issues related to the organisational structure, policies, and cultural norms, customs, values, and beliefs (Wiegmann and Shappell, 2003). In the present results, the self-funded and ex-military groups were comparatively more likely to utilise the 'Organisational Climate' (L4) category (Table 2; Fig. 2). This finding may be because both of these groups will have entered the airline with previous experience, and hence their levels of loyalty to the airline can be expected to be lower (Dahlstrom and Heemstra, 2009). More individualistic conditions (i.e., when there is greater separation between the organisation and the individual) promote greater autonomy between the organisation and the actions of frontline operators (Li et al., 2007). The results on pairwise associations between categories offers support for this proposition. As presented in Fig. 3, both self-funded and ex-military groups did not return significant associations between 'Organisational Climate' and factors associated with human deficiencies. This may explain why they were less inhibited in attributing deficiencies to organisational-level conditions than their airline-sponsored counterparts.

Contrarily, airline-sponsored pilots were least likely to utilise the 'Organisational Climate' (L4) category (Table 2; Fig. 2). Following the same logic as the above discussion, the airline-sponsored group's lower propensity to use this category may simply be due to their greater familiarity with the airline's organisational philosophy (Hörmann et al., 1998). If the expectations and attitudes of the individual pilots and the organisational processes are aligned, then it is logical to conceive that they will attribute fewer human factors conditions to faults at this level. Likewise, the two pairwise associations between 'Organisational Climate' conditions and the frontline faults of decision and perceptual errors in the airline-sponsored group (Fig. 3) supports the proposition of closer dependency between organisational and lower-level operator

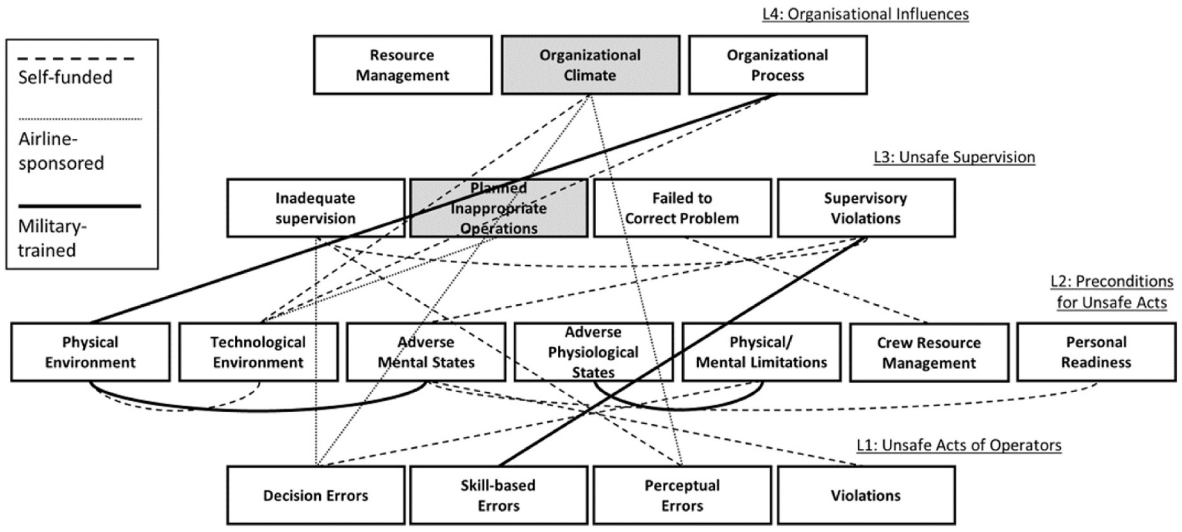


Fig. 3. Significant associations ($p < 0.05$) between HFACS categories, amongst the airline-sponsored, self-funded, and ex-military groups. Categories where frequency of utilisation differed amongst the three groups are shaded in grey.

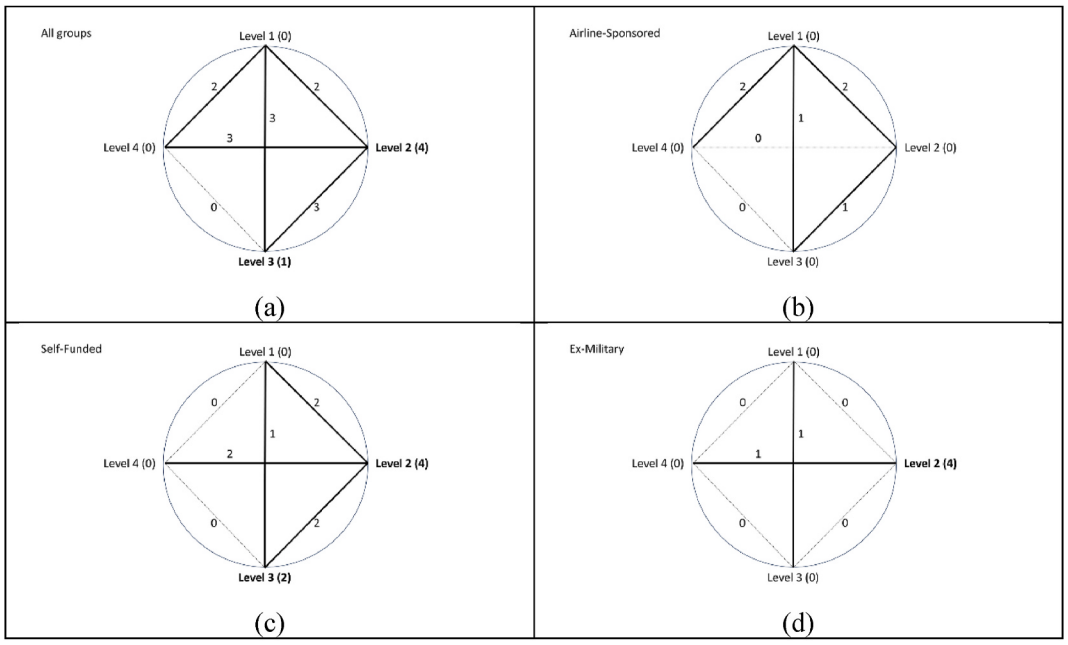


Fig. 4. Associations between categories across the four HFACS levels, across-the-board (a) and amongst the airline-sponsored (b), self-funded (c), and ex-military (d) groups. Significant associations within and between levels highlighted in bold.

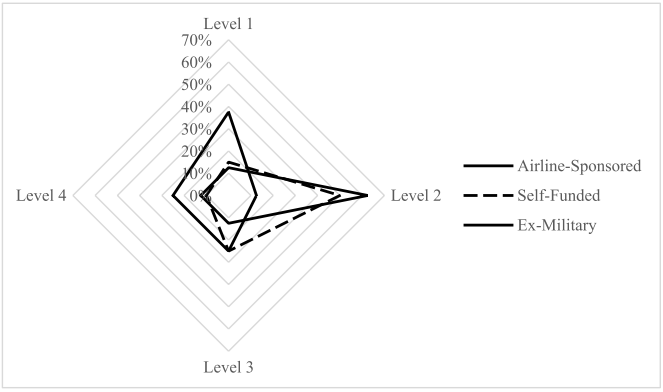


Fig. 5. Proportion of the associative linkages between categories involving each of four HFACS levels, amongst the airline-sponsored, self-funded, and ex-military groups.

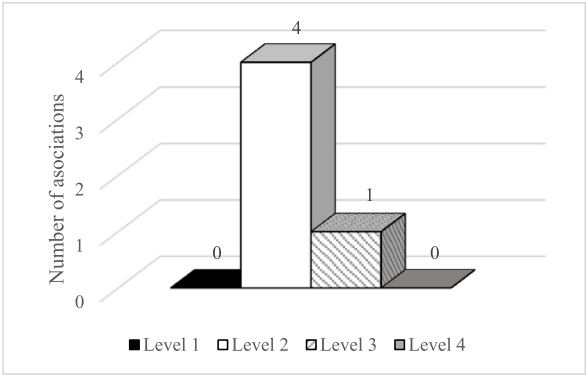


Fig. 6. Number of same-level significant associations between categories at each level, across all groups.

actions.

4.1.2. *Planned Inappropriate Operations*

'Planned Inappropriate Operations' refers to operational decisions such as scheduling and tasking which involves risk management, and certain operations are acceptable during emergencies but are inappropriate during normal operations (Wiegmann and Shappell, 2003). The present research found significant differences between ex-military pilots, who were most likely to attribute factors to this category, and their airline-sponsored counterparts, who in contrast were the least likely to utilise this category (Table 2; Fig. 2).

The contrast between ex-military and airline-sponsored pilots can possibly be explained in the context of the risk-benefit trade-off (Hollnagel, 2017). Uncertainty avoidant ex-military pilots may have been more inclined to view operational decisions and procedures through a life and death perspective (Soeters and Boer, 2000), which explains their higher frequency in attributing deficiencies to the planning of operations. In contrast, airline-sponsored pilots' greater exposure and cultural alignment to the prevailing operational processes may have given them a greater awareness to the variables in the consideration of risks and benefits (Merritt and Maurino, 2004). Rather than simply attributing causal factors to 'Planned Inappropriate Operations', their familiarity with the system enabled airline-sponsored pilots to directly attribute deficiencies to the root causes or final consequences.

This finding was also supported by the pairwise association results (Fig. 3). The ex-military group did not return significant associations between the 'Planned Inappropriate Operations' category with any of the 17 other options, whereas the airline sponsored group associated 'Planned Inappropriate Operations' with 'Technological Environment'. Reason (1997) proposed that whilst latent conditions are inevitably present in all systems, there is a 'many to one' mapping of precursors to these conditions. As each condition can be triggered by more than one precursor, and each precursor can exist in undetectably low frequencies, it has been argued that extended exposure to everyday operations is a prerequisite for the accurate attribution of root cause precursors (Li et al., 2008). This lends support to the argument that the airline-sponsored group, who are more familiar with the operation, will be better in identifying root cause conditions leading to 'Planned Inappropriate Operations' deficiencies.

Safety managers need to understand subcultural differences in order to better integrate and assimilate different employee subgroups into the overarching safety culture at the system or organisation level. Even when pilots are indoctrinated into the same organisation where outer layer factors are often considered to be consistent, individual-level differences at the inner layers of culture can affect how outer layer factors perpetuate through the system. The present finding showcases that when managing safety within large, diverse airlines, rather than simply directing safety remedies towards 'Organisational Climate' or 'Planned Inappropriate Operations', it may be beneficial to work on the enhancement of loyalty, familiarity, and the cultural alignment of safety values amongst different employee subgroups. An understanding of how influential associations flow through the meta-categories of concerns, influences, and actions amongst different cultural subgroups will be beneficial to align the different layers of culture.

4.2. Operational backgrounds affecting meta-categories across cultural layers

Differences amongst the three groups in considering interrelations between different human factors conditions were highlighted by variations in significant associative relationships between levels. Compared to their self-funded and ex-military colleagues, the airline-sponsored group had a greater proportion of associations originating or terminating at levels 1 and 4, and fewer at level 2 (Fig. 5). This finding can be explained in the context of familiarity with the 'in-group'. It was known that higher levels of exposure are associated with better performance in identifying patterns of association (Klein, 2008). Airline-sponsored pilots will have a stronger 'in-group' identity and will understandably be more accustomed to how things are done within the airline (Chan and Harris, 2019). They will therefore have a greater understanding of the contexts influencing the interactions between organisation-level decisions (L4) and operator-level actions (L1) (Merritt and Maurino, 2004). This essentially enables them to bypass the 'preconditions' at level 2 and instead directly attribute deficiencies to root causes or final consequences at either the organisation (L4) or operator (L1) levels.

A closer look into significant associations between HFACS categories provides support for this concept and addresses the second research question ("What human factors conditions were associated?"). The airline-sponsored group was the only group which had significant associations between the 'Organisational Climate' (L4) category and the operator level 'Decision Error' and 'Perceptual Error' categories at level 1 (Fig. 3). These direct connections between organisation-level decisions (L4) and operator-level actions (L1) may similarly be due to airline-sponsored pilots' greater familiarity with the interactive contexts.

Further, familiarity with the operational context can also explain the airline-sponsored group's proportionately fewer associative linkages originating or terminating at HFACS level 2 ('Preconditions for Unsafe Acts'). HFACS level 2 encompasses factors such as environmental, personnel, and operator conditions which are primarily dependent on the route structures, aircraft types, and training conducted within airlines (Hörmann et al., 1998; Wiegmann and Shappell, 2003). As airline-sponsored pilots' exposure to these factors are typically exclusive to their sponsoring airline, any deficiencies at level 2 may have already become normalised and thus not considered as the origin or consequence of associated human factors deficiencies.

The finding of differences between airline-sponsored, self-funded, and ex-military subcultural groups suggests that subcultural differences at the line worker level can affect how the meta-categories of concerns, influences, and actions interact across all system levels. As the participants were working in the same environment, cultural 'layers' from the middle management outwards should be similar, but the present finding of differences in both the attribution of safety factors into HFACS categories and in associations between categories suggests otherwise. For safety managers, consideration of subcultural categories at the line worker level may provide improvements to the development of inclusive safety cultures. To illustrate, safety remedies focusing on level 2 factors (e.g., environmental, personnel, and operator conditions) may be perceived by airline-sponsored pilots as less relevant, as they will consider deficiencies at this level to be more normalised and less changeable. The findings can therefore assist safety management functions in creating culturally suitable interventions to assimilate people recruited from different backgrounds into the wider organisational safety culture.

4.3. Horizontal categories of HFACS convergence

In comparison with the airline-sponsored group, the self-funded and ex-military groups had comparatively more associations originating or terminating at level 2 categories (the 'Preconditions for Unsafe Acts' level; Fig. 5). As prior research has found that a higher number of coding options is associated with lower system reliability (Krippendorff, 2019), a possible explanation is that the self-funded and ex-military pilots may have found it challenging to consistently choose from the seven categories within level 2 (Krippendorff, 2019). In contrast, the airline-sponsored group's greater familiarity with the airline may explain their lower proportion of associated level 2 'preconditions', simply because they were able to pin-point the most relevant options with their greater level of familiarity.

In addressing the third research question ("Were there any significant associations between HFACS categories at the same level?"), the present analysis revealed same-level 'horizontal' associations between categories on the same level, at HFACS levels 2 and 3 (Fig. 6). This contrasts with the original HFACS approach. In its original format, the HFACS was built on the Swiss Cheese model, and factors in the causal sequence were considered to flow 'vertically' from each level to the immediately adjacent level (i.e., level 4 to 3 to 2 to 1; Wiegmann and Shappell, 2003). The present finding of same-level associations between categories at levels 2 and 3 suggests the existence of 'horizontal' associations at each level in the organisational hierarchy. In practice, same-level associations means that SMS processes targeted at one category will also impact the other category. Consider, for instance, it is likely that departmental SMS interventions to rectify 'Inadequate Supervision' will concurrently rectify 'Supervisory Violations' at level 3; or fixes to 'Adverse Mental States' will help 'Personal Readiness' at level 2. The level of overlap suggests that there is a degree of convergence amongst HFACS categories. The present finding therefore suggests that a merger of associated categories at the same level can improve the reliability of HFACS by reducing duplication.

This corresponds with previous research which recommended making domain specific adaptations to taxonomies, reducing the system size, and taking into account coders' inherent biases to improve system reliability (Krippendorff, 2019; Olsen and Williamson, 2015). Different adaptations are required for different user groups. In the present results, same-level patterns of association differed between the self-funded and ex-military groups (Fig. 3). To illustrate, the 'Adverse Mental States' precondition was significantly associated with 'Personal Readiness' in the self-funded group, whereas for the ex-military group 'Adverse Mental States' was associated with 'Physical Environment'. In practice, what this means is that whilst 'Personal Readiness' interventions will likely help to reduce 'Adverse Mental States' in the self-funded group, the same intervention will not be significant if the users are ex-military.

The selection of which options to remove to reduce duplication should be guided by the coding patterns of target user groups. This is because when domain- or system-specific adaptations to investigative taxonomies (such as the HFACS) are available, it was known that familiarity with 'how things work' within an 'in-group' can enhance the reliability of categorisations (Cohen et al., 2015; Olsen and Shorrock, 2010). This can help to mitigate the problem of 'mitigation myopia', where the attribution of deficiencies and the subsequent suggestion of interventions within the SMS are biased to the investigators' beliefs of what happened and what can be done, rather than an objective

evaluation of relevance (Chan and Li, 2022b; Shappell and Wiegmann, 2007).

4.4. Limitations and potential for future research

Since the present study was designed around the identification of paths of association between and amongst causal conditions, a limitation of the experimental design is that it becomes difficult to assess the reliability of the coding process. To illustrate, the present finding of 'Inadequate Supervision' being linked with 'Supervisory Violations' suggests that the two categories can be compounded with each other. In the context of the research questions, this is a good thing, because the finding suggests that the two closely related categories can be joined to reduce the size of subsequent frameworks (thus improving system reliability). However, the compounding makes it difficult to test the results for inter-rater reliability. If the same factor is categorised by one participant as 'Inadequate Supervision' and another participant as 'Supervisory Violations', then this would indicate poor inter-rater reliability. Although the reliability of the HFACS frameworks has been extensively substantiated (Ergai et al., 2016), a possibility for further research may be to examine the reliability of any future reduced-sized HFACS frameworks that are developed subsequent to this research.

Another limitation of the present study is that the statistical tests employed to answer the three research questions were disjointed. Whilst non-parametric hypothesis testing was used to answer the first research question, the second and third research questions relied on cross-tabulation techniques. To an extent, this separation of statistical analysis amongst the research questions helps to reduce the chance of committing false positive errors. However, a potential for future research is to use other statistical techniques to integrate the multiple variables. This may require another round of data collection to support methods such as multi-criteria decision making or to utilise advanced big data analytics using historical examples. In addition, although the present research utilised expert sampling to ensure the reliability of the responses, in future data collection an increase in the number of demographic variables to include factors such as gender, nationality, or specific airline experience may provide better clarity for the findings in relation to other demographic factors.

The present research focused the participants' attribution of causal factors in relation to a previous incident, and in the safety management process these attributions will, in a large part, inform future safety interventions. Thus, as a logical next step, it will be beneficial to conduct a similar comparison to assess if differences amongst user groups will influence how they perceive subsequent safety interventions. Will airline-sponsored, self-funded, and ex-military pilots rate different interventions differently? This is because safety interventions need to be considered to be relevant by the target users if they are to be successful and well accepted (Chan and Li, 2021). If the same safety intervention is categorised by one group to be 'fixing' a certain condition, whereas another group perceives the intervention to focus on something else, then these differences may affect whether the SMS is relevant and acceptable by the target users.

5. Conclusion

The identification and categorisation of human factors conditions are critical for the development and implementation of safety management systems and safety interventions. Experts' cultural experiences are known to influence how they perceive and categorise human factors issues, but previous research typically considered culture as a combination of distinct homogenous layers surrounding the attitudes and values of workers. A research gap exists in evaluating the spectrum of subcultures within each demographic and employee group. The present study compared qualified airline pilots from three subcultural groups, based on whether their initial pilot training was conducted through either airline-sponsored, self-funded, and ex-military means. It was discovered that the three groups differed in their categorisation of human factors issues using the HFACS framework, with self-funded and ex-military groups more likely to attribute faults to organisational and supervisory-level conditions, in comparison to their airline-sponsored colleagues. This was possibly due to the airline-sponsored group's closer alignment with the prevailing organisational safety culture. Tests of association between the 18 HFACS categories also revealed associations amongst categories at the same level, particularly those related to preconditions of unsafe acts (HFACS level 2). This presents a new perspective in the utilisation and analysis of concerns, influences, and actions in the causal chain using the HFACS taxonomy. The goal of understanding cultural differences in the perception of causal factors is to ensure that relevant SMS objectives and interventions can be created to assimilate people from different backgrounds into the wider systemic safety culture. The findings additionally suggest that domain specific adaptations to the HFACS taxonomy by reducing underused or associated categories may possibly bring about improvements to the reliability of human factors assessments and safety management system frameworks.

CRediT authorship contribution statement

Wesley Tsz-Kin Chan: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Wen-Chin Li:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Conceptualization. **Graham Braithwaite:** Writing – review & editing, Supervision, Methodology, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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APPENDIX A. VII

List of contributing factors in the Uberlingen accident, paraphrased to be survey items:

1. Tupolev crew chose to disregard the Traffic Collision Avoidance System (TCAS) directive, and instead followed the instructions issued by ATC.
2. There was only one ATC controller on duty, and he had to control two positions simultaneously.
3. The other controller on duty was resting in another room.
4. ATC management tacitly tolerated (for years) the practice of allowing one controller to go to rest during quiet periods at night, contrary to regulations.
5. Some ATC facilities were not operational as maintenance work was being undertaken.
6. Effects of the maintenance work was not sufficiently promulgated to the controllers.
7. The short term conflict alert system (STCA) was degraded as a result of the maintenance work, which made the system of little use in situations with high closing speeds.
8. The controller did not remember that the short term conflict alert (STCA) was operating in degraded mode.

9. A delayed A320 aircraft flying into a nearby airport required the controller to operate different frequencies and as a result he missed several radio calls and neglected the control of the two incident aircraft.
10. Whilst the main telephone lines were out of service due to the maintenance work, the back-up line also happened to be defective.
11. The ATC controller failed to notice that the two aircraft were on converging courses at the same level.
12. The controller passed incorrect information concerning the position of the Boeing 757 to the Tupolev crew, causing confusion.
13. As the radio frequency was in use, the crew of the Boeing 757 were unable to inform the controller that they were descending in response to TCAS.
14. The Tupolev crew did not have simulator training on the use of TCAS.
15. The operations manual to which the Tupolev crew operated under lacked clarity on the relative priority of TCAS and ATC instructions.
16. There were key differences between the rules covering the right of way of aircraft between Western/North American rules (the Boeing 757) and those in the Russian Federation (the Tupolev).
17. The Tupolev First Officer, who was uncomfortable with the descent, was not forceful enough in communicating his dissatisfaction with the Captain.

Data availability

Data will be made available on request.

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