Australian Government

Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY REPORT

Aviation Research and Analysis Report – AR-2008-036

Final

Evaluation of the Human Factors Analysis and Classification System as a predictive model

Australian Government

Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY REPORT

Aviation Research and Analysis Report

AR-2008-036

Draft

Evaluation of the Human Factors Analysis and Classification System as a predictive model

Published by:	Australian Transport Safety Bureau
Postal address:	PO Box 967, Civic Square ACT 2608
Office location:	62 Northbourne Ave, Canberra City, Australian Capital Territory, 2601
Telephone:	1800 020 616, from overseas +61 2 6257 4150
	Accident and incident notification: 1800 011 034 (24 hours)
Facsimile:	02 6247 3117, from overseas +61 2 6247 3117
Email:	atsbinfo@atsb.gov.au
Internet:	www.atsb.gov.au

ISBN and formal report title: see 'Document retrieval information' on page v

CONTENTS

DOCUMENT RETRIEVAL INFORMATION

Report No.	Publication date	No. of pages	ISBN
AR-2008-036	December 2010	52	978-1-74251-120-7

Publication title

Evaluation of the Human Factors Analysis and Classification System as a predictive model

Prepared By

Australian Transport Safety Bureau
PO Box 967, Civic Square ACT 2608 Australia
www.atsb.gov.au

Reference Number

NOV10/ATSB151

Authors

Inglis, M., Smithson, M. J., Cheng, K., Stanton, D. R., Godley, S. T.

Abstract

The Human Factors Analysis and Classification System (HFACS) is a hierarchical taxonomy that describes the human factors that contribute to an aviation accident or incident that is based on a chain-of-events theory of accident causation and was derived from Reason's (1990) accident model.

The objectives of this exploratory study were to identify relationships between the factors of the HFACS taxonomy and to assess the usefulness of HFACS as a predictive tool. The associations found in this study may assist investigators in looking for associated factors when contributing factors are found. Also, when using the HFACS taxonomy to identify areas for intervention, the relationships found may also guide intervention in associated areas for a holistic, systems approach to improvement.

This exploratory study found a number of strong positive relationships between factors at different levels of the model. However, based on the amount of variation explained by the logistical regression statistical models, it appears that HFACS is a more effective predictive framework when used to predict *unsafe acts* than when used to predict higher levels within the taxonomy.

The Australian Transport Safety Bureau (ATSB) formalised the concept of *outside influences* and added five factors within this grouping to the HFACS model in this study. The *outside influences* factors proved to be important additions to the HFACS model as they were associated with factors at all levels of the HAFCS taxonomy.

The results have also shown that it is not always the case that higher-level factors predict only the lower-level factors directly below them. For example, *inadequate supervision* predicted *precondition for unsafe acts*, such as *adverse mental states* and *crew resource management issues*, as well as *skill-based errors* (two levels down).

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The Bureau is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; and fostering safety awareness, knowledge and action.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

EXECUTIVE SUMMARY

The Human Factors Analysis and Classification System (HFACS) is a hierarchical taxonomy that describes the human and other factors that contribute to an aviation accident or incident. It is based on a chain-of-events theory of accident causation that was derived from Reason's (1990) accident model. It was originally developed for use within the United States military, both to guide investigations and to analyse accident data. The HFACS classification system has four levels: *organisational influences*, *unsafe supervision*, *preconditions for unsafe acts*, and *unsafe acts*. Based on Australian civil aviation accidents, the Australian Transport Safety Bureau (ATSB) formalised the concept of *outside influences* and added five associated factors outside of the original HFACS model.

The HFACS model assumes that higher levels in the model influence the presence of lower-level factors. Thus, the objectives of this exploratory study were to identify relationships between the factors of the HFACS taxonomy and to assess the usefulness of HFACS as a predictive tool. The associations found in this study may assist investigators in looking for associated factors when contributing factors are found. Also, when using the HFACS taxonomy to identify areas for intervention, the results of this study may also guide intervention strategies in associated areas for a holistic, systems approach to improvement.

This study is based on the analysis of 2,025 Australian aviation accidents reported to the ATSB for the period 1 January 1993 to 31 December 2003. A total of 3,525 contributing factors were included in the analysis. Logistic regression was used to analyse the associations between HFACS factors from different levels.

At the higher levels of HFACS, it appears that *regulatory influence* predicts *organisational process* and *inadequate supervision*. *Inadequate supervision* was also predicted by *organisational process* issues. *Inadequate supervision*, in turn, predicted all *precondition for unsafe acts* factors, with the exception of the *physical environment* factor. The presence of *crew resource management issues* were affected by *regulatory influences* and *other person involvement.* The *physical environment* factor was positively predicted by *other person involvement* and *airport/airport personnel*. The odds ratio suggests that maintenance issues negatively predicted the *physical environment* factor.

There were 11 higher-level HFACS factors that predicted the presence of at least one *unsafe act*, regardless of whether they were *skill-based errors*, *decision errors*, *perceptual errors*, or *violations*. In predicting the presence of each *unsafe act* individually, it was found that *adverse mental states* predicted all *unsafe acts* and that all *unsafe acts* were predicted by at least another three higher-level HFACS factors, including *outside influences*.

Based on the amount of variation explained by the predictive statistical models, it appears that HFACS is a more effective predictive framework when used to predict *unsafe acts* than when used to predict higher levels within the taxonomy. The results have also shown that it is not always the case that higher-level factors predict only the lower-level factors directly below them. *Outside influence* factors are important when applying HFACS to civil aviation accidents at the national level, as the *outside influences* factors were associated with factors at all levels of the HAFCS taxonomy. These factors are not a formal part of the HFACS taxonomy, yet significantly increased the odds of these factors occurring.

TERMINOLOGY USED IN THIS REPORT

Terminology used in this report is based on terminology used for the Human Factors Analysis and Classification System (HFACS) (e.g. Wiegmann & Shappell, 2003). It differs to the standard Australian Transport Safety Bureau (ATSB) terminology. The table below outlines the HFACS terminology used in this report for each level of the HFACS taxonomy, along with the equivalent ATSB terminology used in investigation reports.

HFACS terminology	ATSB terminology
Event	Occurrence event
Factor	Contributing safety factor
Unsafe acts	Individual actions
Preconditions for unsafe acts	Local conditions
Unsafe supervision	Risk controls
Organisational influences	Organisational influences

1 INTRODUCTION

The Human Factors Analysis and Classification System (HFACS) is a taxonomy that describes the human and other factors that contribute to an aviation accident or incident. The HFACS taxonomy was developed to provide a framework for identifying and analysing human error. In turn, this examination of underlying human factors can help develop data driven intervention strategies and track the effectiveness of prevention strategies (Shappell & Wiegmann, 2000; Wiegmann & Shappell, 2003).

The HFACS model is a hierarchical model that proposes that higher levels in the model influence the presence of lower level factors. While the model has been widely employed to describe the contributing factors to safety occurrences, little has been published on the relationships or pathways between the HFACS levels.

This study reviews the assumptions made with regards to the relationships between HFACS factors and attempts to assess the value of the model as a predictive tool.

1.1 Overview of HFACS

The Human Factors Analysis and Classification System is based on a sequential or chain-of-events theory of accident causation and was derived from Reason's (1990) accident causation model (Wiegmann & Shappell, 2003). It was originally developed for use within the United States military, both to guide investigations when determining *why* an accident or incident occurred, and to analyse accident data (Shappell & Wiegmann, 2000). Since its development, the classification system has been used in a variety of military and civilian transport and occupational settings, including aviation, road, and rail transport (e.g. Federal Railroad Administration, 2005; Gaur, 2005; Li & Harris, 2005; Pape et al., 2001; Shappell, 2005), and has also been used by the medical, oil, and mining industries (Shappell, 2005).

The HFACS classification system has four hierarchical levels. These are akin to those in the Australian Transport Safety Bureau (ATSB) safety factor classification taxonomy (as described in Walker & Bills, 2008), although different terminology is used (see page viii for a comparison).

The hierarchical levels in the HFACS model are named:

1) organisational influences

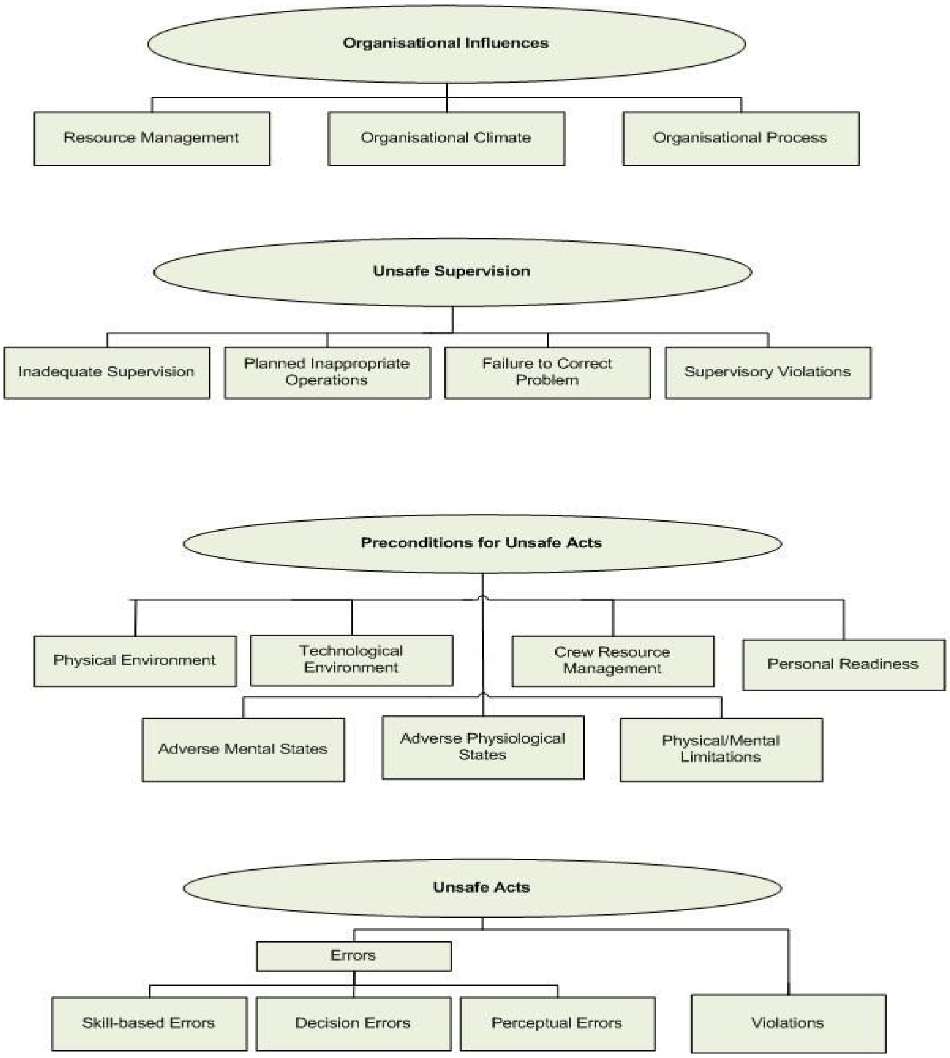
2) unsafe supervision

3) preconditions for unsafe acts

4) unsafe acts of operators.

The model assumes that each level above influences the level below it. As shown in Figure 1, within each level there are numerous specific types of contributing safety factors.

Figure 1: Flow diagram of the Human Factors Analysis and Classification System (HFACS)



Source: adapted from Shappell (2005).

The HFACS taxonomy was designed as a way of identifying factors that help explain why errors and violations by flight crew were made. Therefore, there is an implicit assumption that any predictive relationships between higher level factors to lower level factors will be positive. That is, if one type of factor is present, it is more likely that the other factor type will also be present.

Wiegmann and Shappell (2003) recognised that there are contributing factors outside the flying organisation. However, HFACS was originally developed for the US military where there were no or little outside influences (for example, maintenance and air traffic control (ATC) are carried out by military personnel). To classify civil aviation accidents, the ATSB formalised an *outside influence* group by including it in this current study. The *outside influence* group is not a hierarchical level as it can link to any of the four levels of the original HFACS model.

2 METHODOLOGY

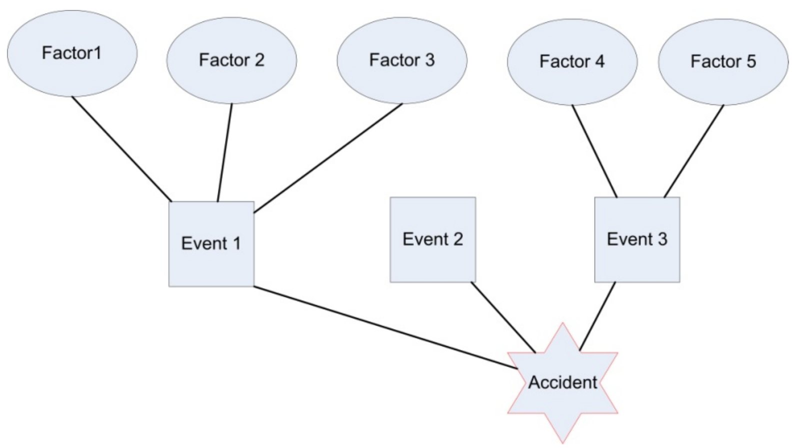
2.1 Accident sample

This study is based on the analysis of 2,025 Australian civilian aviation accidents reported to the ATSB for the period 1 January 1993 to 31 December 2003. Details were extracted from the ATSB aviation safety occurrence database for accidents that occurred over Australian territory and involved VH-registered powered aircraft (both rotary and fixed-wing).

To eliminate redundancy, only data from one of the aircraft involved in multi-aircraft collisions, such as mid-air or ground collisions, were included.

For any one accident, there may be one or more occurrence events that explain *what happened* in the accident (for example, hard landing and noise gear collapse). For each event, there may be one or more factors (or none at all) that is considered to have contributed to the event. The relationship between accidents, events and factors can be seen in Figure 3.

Figure 3: HFACS factors in relation to events and accidents



A team of researchers applied HFACS factor codes to the safety factors that were identified as contributing to the accident through an ATSB accident investigation. In total, there were 4,555 occurrence events stemming from the 2,025 accidents. There were 3,547 factors contributing to these events that were each coded into one of the 18 HFACS factors or the five *outside influence* factors.

Further details of the coding process and of the quality assurance process can be obtained from the ATSB report *Human factors analysis of Australian aviation accidents and comparison with the United States* (B2004/0321) by Inglis, Sutton and McRandle (2007) which used the same data set as the present report.

2.2 Method of analysis

To achieve the overarching objectives of the study, a number of analysis sub-goals were identified. These sub-goals are presented below.

Analysis sub-goals

1. Predicting *organisation influences*: identify any relationships between *outside influences* and *organisational influences*.
2. Predicting *unsafe supervision*: identify any relationships between both the *outside influences* and *organisational influences* and the *unsafe supervision* level of HFACS.
3. Predicting *preconditions of unsafe acts*: predicting preconditions by higher-level HFACS factors and *outside influences*. Within the limitations imposed by the dataset, the analysis was not confined to adjacent HFACS levels. Instead, predictors across more than one level were also investigated.
4. Predicting *unsafe acts*: identifying factors, including *outside influences*, that predict particular types of *unsafe acts*. The strategies used depended on the findings of the preparatory analysis (described below).

Preparatory analysis

Preparatory analyses were required before designing the data models in order to construct predictive models.

The purpose of the preparatory analysis was to:

- determine if there were sufficient instances of each HFACS factors to include in predictive models
- identify any associations between factors at the same level of the HFACS taxonomy.

The purpose of the latter point was to determine whether the co-occurrence of within-level factors was random. If so, then predictive models could be developed for each factor independent of the others. If not, then an understanding of the relationships among the factors would be needed to inform further analyses of this kind (see Section 2.3 for the results of the preparatory analysis).

2.2.2 Strategies and statistical models

As factors are binary (present or absent) for each accident, logistic regression was used to analyse the associations between HFACS factors and make predictions based on these associations. Briefly, logistic regression predicts the presence and absence of a category via a model of the probability of that category's occurrence.

Log-linear analyses were used to investigate multi-way associations among categorical variables at the same HFACS level in the preparatory analysis.

Candidate predictors for the models were identified by generating contingency tables and using either chi-square tests or Fisher's exact test. Fisher's exact test was used when the assumptions for the chi-square test were not met. The results showing the candidate predictors are not presented in this report. The models with final predictor(s) are presented.

2.3 Preparatory analysis

2.3.1 Number of HFACS factors

Table 1 shows the frequency count of each factor in the HFACS taxonomy and in the additional *outside influences* group.

Table 1: Frequency count of all HFACS factors

HFACS level	HFACS factor	Cases
Outside influences	Maintenance issues	81
	Regulatory influence	29
	Other person involvement	25
	Airport/ airport personnel	21
	ATC actions/issues	6
Organisational influences	Organisational process	16
	Resource management	1
	Organisational climate	1
Unsafe supervision	Inadequate supervision	87
	Supervisory violation	8
	Planned inappropriate operations	7
	Failure to correct problem	1
Preconditions for unsafe acts	Physical environment	444
	Physical/ mental limitations	323
	Adverse mental states	306
	Crew resource management issues	75
	Technological environment	41
	Adverse physiological states	38
	Personal readiness	7
Unsafe acts	Skill-based error	1,333
	Decision error	493
	Violation	117
	Perceptual error	87

The data analysis of factors required sufficient cases of each factor to include it in a predictive model. Factors with less than 15 cases were considered to be of low frequency and so were excluded from analysis. Table 2 shows the excluded HFACS factors.

Table 2: Excluded HFACS factors

HFACS level	HFACS factor	Cases
Preconditions for unsafe acts	Personal readiness	7
Unsafe supervision	Planned inappropriate operations	6
	Failure to correct problem	1
Organisational influences	Resource management	1
	Organisational climate	1
Outside influences	ATC actions/issues	6

Of the original 3,547 HFACS factor cases, 3,525 factor cases were included in the analysis after the above factors were excluded. Since not all accidents reported to the ATSB were investigated, information on the contributing factors, and hence the number of HFACS codes for these accidents, were limited. In addition, without investigation, identification of higher order factors is made more difficult.

Figure 4 shows the HFACS factors, including those in the *outside influence* grouping that were excluded from analysis. Unfortunately most of the excluded factors were from the *unsafe supervision* or *organisational influence* levels, thereby hindering the evaluation of predictors from those levels.

Figure 4: The HFACS taxonomy with the excluded factors crossed out

Although there were only eight cases of *supervisory violations* (and hence should have been excluded), it was kept in the exploratory analyses as a predictor. This was done to take the emphasis off *inadequate supervision* as the only factor for *unsafe supervision*. Any interpretation involving *supervisory violations* should be made with caution due to the low number of cases.

2.3.2 Associations between HFACS factors

The HFACS factors at the same level were analysed in the preparatory analysis in order to examine associations among these factors. Any associations should be taken into account when analysing and interpreting prediction models as these associations may affect the strength of associations.

Associations were found within the level of *unsafe acts*. A backward-elimination log-linear analysis revealed a model with a 3-way interaction and two 2-way interactions. The 3-way interaction was between *skill-based errors*, *perceptual errors* and *violations*. The two 2-way interactions were between *decision errors* and *violations*, and *skill-based errors* and *decision errors*. The cell counts, residuals and cross tabulation table for these models are presented in Appendix B.

As a result, two predictive models were used to predict *unsafe acts*. These were:

- logistic regression predicting at least one *unsafe act*, regardless of the type
- logistic regressions predicting each kind of *unsafe act* on its own while taking the associations into account.

The first model predicted the presence of any *unsafe act* (regardless of its factor code), and the second predicted the presence of each *unsafe act* factor (*skill-based error*, *decision error*, *perceptual error* and *violation*).

Similarly, an association was found between *inadequate supervision* and *supervisory violations*. However, due to the small cases of *supervisory violations*, this factor was not predicted. Rather, this was used to predict lower-level HFACS factors.

In contrast, none of the *preconditions for unsafe acts* factors were significantly associated with one another. As a result, it can be expected that the factors for *preconditions for unsafe acts* would behave as relatively independent predictors, and it was reasonable to evaluate separate prediction models for each of them.

The *organisational influence* level contained only one factor (*organisational process*) once factors with inadequate cases were removed, so no such analysis was required for this level.

There were no associations between any of the *outside influence* factors.

2.4 Interpreting results

R^2

To provide an evaluation of the goodness-of-fit for each statistical model, pseudo-R^2 values are provided in logistic regression as an approximate R^2 value, which would apply in linear regression models. The R^2 value provides a measure of how well future outcomes are likely to be predicted by the model. A low R^2 value suggests that there may be other predictors (not in the model) that would also explain the variability in the data. The R^2 value thus allows the evaluation of how powerful at prediction the model is. It is possible that the model can fit the data well (as indicated by the significance value for the model), but have very low predictive power (as evaluated by the R^2).

The pseudo-R^2 values are an estimate of the proportion of the variability accounted for by the prediction model. For the logistic regression models presented in this report, the pseudo-R^2 values are shown using methods devised by Cox and Snell and Nagelkerke. As the Cox and Snell pseudo-R^2 cannot reach the value of one, the more useful interpretation of variation accounted for is through the Nagelkerke R^2 correction of the Cox and Snell statistic, which has a range from zero to one.

Odds ratio

For this study, the odds ratio indicates the likelihood of a factor occurring in the presence of another factor. An odds ratio greater than one indicates that the presence of the predictor factor is likely to increase the odds of the predicted factor occurring. However, an odds ratio less than one indicates that the presence of the predictor factor decreases the odds of the predicted factor occurring. An odds ratio of one indicates that the predictor factor has no influence on the presence or absence of the predicted factor.

Attention should also be given to the confidence intervals for the odds ratios when interpreting the statistics presented. A large confidence interval should be treated with some degree of caution when interpreting the results (Lenné et al, 2008).

Factors in the higher-levels of the HFACS model were used to predict lower-level factors in this study. Thus, the predicted outcomes can be viewed as being directional as it is assumed that the higher-level factors of HFACS exist before the lower-level factors. Along the same lines, the effects of *outside influences* on the HFACS factors are also directional as *outside influences* generally occur before any of the HFACS factors.

3 RESULTS

3.1 Predicting *organisational influence*

Outside influences factors were used to predict the *organisational process* factor, which was the single remaining factor in the *organisational influences* level. The *regulatory influence* factor was the only *outside influence* factor that predicted *organisational process* and the model accounted for 35 per cent of the variance. The range in the odds ratio confidence interval indicates that issues with regulation increases the odds of *organisational process* factor issues by at least 72 times.

Table 3: Logistic regression predicting *organisational process* from *outside influences*

Predictors	Odds ratio	95% C.I. for odds ratio		Sig.
		Lower	Upper	
Regulatory influence	231.90	72.19	744.89	<0.001

Note R^2 =0.02 (Cox and Snell), 0.35 (Nagelkerke). Model χ^2 (1) = 73.97, p< 0.001.

3.2 Predicting *unsafe supervision*

There were four factors at the *unsafe supervision* level of HFACS, but only *inadequate supervision* had sufficient cases to reliably identify relationships with other HFACS levels. The results for the logistic regression predicting *inadequate supervision* from *organisational process* and *outside influences* factors are displayed in Table 4.

Table 4: Logistic regression predicting *inadequate supervision* from *organisational process* and *regulatory influence*

Predictors	Odds ratio	95% C.I. for odds ratio		Sig.
		Lower	Upper	
Organisational process	19.29	5.24	71.03	<0.001
Regulatory influence	5.77	1.66	20.08	0.006

Note R^2 =0.01 (Cox and Snell), 0.06 (Nagelkerke). Model χ^2 (2) = 46.79, p< 0.001.

The *organisational process* factor (from *organisational influences*) and *regulatory influence* factor (from *outside influences*) were both positively associated with the *inadequate supervision* factor. The odds of *inadequate supervision* factor occurring were 19 times higher when the *organisational process* factor was present and nearly six times higher when *regulatory influence* was present. This finding must be treated with caution due to the wide range of the confidence interval, which can be attributed to the low number of cases in the *organisational process* category, as well as the low variance (6 per cent) explained by the model.

3.3 Predicting *preconditions for unsafe acts*

Table 5 presents the HFACS factors predicting each of the six *preconditions for unsafe acts* factors. Note that the models only explain a small amount of the variance, with the most predictive model of the set only accounting for up to 8 per cent of the variability in the dataset.

Table 5: Logistic regressions predicting *preconditions for unsafe acts*

Predictors	Odds ratio	95.0% C.I. for odds ratio		Sig.
		Lower	Upper	
Physical environment				
Airport/ airport personnel	30.63	11.17	84.01	<0.001
Other person involvement	4.54	2.04	10.10	<0.001
Maintenance issues	0.12	0.02	0.86	0.04
R^2 =0.02 (Cox and Snell), 0.03 (Nagelkerke). Model χ^2 (3) = 73.86, p< 0.001.				
Technological environment				
Inadequate supervision	7.45	2.84	19.55	<0.001
Maintenance issues	4.43	1.32	14.82	0.02
R^2 =0.00 (Cox and Snell), 0.03 (Nagelkerke). Model χ^2 (2) = 14.82, p< 0.001.				
CRM issues				
Regulatory influence	11.16	4.18	29.76	<0.001
Inadequate supervision	8.01	3.91	16.81	<0.001
Other person	6.41	1.41	20.83	0.01
R^2 =0.01 (Cox and Snell), 0.08 (Nagelkerke). Model χ^2 (3) = 58.03, p< 0.001.				
Adverse mental states				
Inadequate supervision	4.99	3.03	8.21	<0.001
R^2 =0.01 (Cox and Snell), 0.02 (Nagelkerke). Model χ^2 (1) = 30.41, p< 0.001.				
Adverse physiological states				
Supervisory violations	41.77	8.16	213.94	<0.001
R^2 =0.01 (Cox and Snell), 0.02 (Nagelkerke). Model χ^2 (1) = 10.35, p< 0.001.				
Physical/ mental limitations				
Inadequate supervision	8.92	5.68	14.01	<0.001
Maintenance issues	0.15	0.02	1.01	0.06
R^2 =0.02 (Cox and Snell), 0.04 (Nagelkerke). Model χ^2 (2) = 76.44, p< 0.001.				

Physical environment

The *outside influence* factors of *airport/airport personnel* and *other persons* both predicted the presence of the *physical environment* factor. In contrast, the presence of the *maintenance issues* factor lowered the odds of a *physical environment* factor also being present. None of the higher level HFACS factors predicted *physical environment*.

Technical environment

Inadequate supervision was the only factor from the higher level of *unsafe supervision* to positively predict the occurrence of *technical environment* factors. From the *outside influence* factors, *maintenance issues* were positively associated with this factor category.

Crew resource management (CRM) issues

Inadequate supervision, *other person involvement* and *regulatory influence* were all significant, positive predictors of *CRM issues*.

Adverse mental states

When considering only the higher levels of the HFACS model, the only predictor of *adverse mental states* was *inadequate supervision* with an odds ratio of 4.99. However, this model only accounted for between 1 and 2 per cent of the variance. Given the poor predictive power of the model, a second model included other *preconditions for unsafe act* factors. However, the model only improved marginally and so the results are not presented.

Adverse physiological states

Instances of *adverse physiological states* are not well predicted by the higher level HFACS categories. The only significant predictors were *supervisory violations*- a finding that should be interpreted with caution given the low frequency of this factor. The odds ratio showed that an *adverse physiological state* was 42 times more likely in the presence of a *supervisory violation*. However, the very large confidence interval for the odds ratio along with the small number of *supervisory violation* cases suggests that the results should be interpreted with caution.

Physical/ mental limitations

The significant predictors of *physical/mental limitations* included *inadequate supervision* and *maintenance issues* with odds ratios of 8.92 and 0.15 respectively. Thus, the presence of *inadequate supervision* increased the odds while *maintenance issues* lowered the odds of *physical/mental limitations* occurring.

3.4 Predicting *unsafe acts*

Outlined in the preparatory analysis section were a number of strategies for predicting *unsafe acts*. The strategies were to predict at least one *unsafe act* and to predict each *unsafe act* individually, while taking the associated *unsafe acts* into account.

The first step modelled at least one *unsafe act* (ALOUA). That is, a model was constructed to include HFACS factors that predicted the presence of at least one *unsafe act* regardless of whether it was a *skill-based error*, *decision error*, *perceptual error* or *violation*. As in the preceding subsections, the models included predictors from all higher levels of HFACS rather than restricting candidate predictors to the adjacent level.

3.4.1 Predicting at least one *unsafe act*

The 11 factors that were significantly associated with ALOUA are outlined in Table 6. A logistic regression analysis using backward elimination to eliminate redundant or unviable predictors arrived at the model shown below. The R^2 values indicate that the model is a robust one as it explains about a third of the variance in the dataset.

Table 6: Logistic regression predicting at least one *unsafe act*

Predictors	Odds ratio	95% C.I. for odds ratio		Sig.
		Lower	Upper	
Adverse mental states	45.97	26.09	81.00	<0.001
Physical/mental limitations	34.98	21.18	57.79	<0.001
Inadequate supervision	18.07	7.01	46.58	<0.001
CRM issues	6.84	3.37	13.87	<0.001
Physical environment	5.95	4.67	7.57	<0.001
Maintenance issues	0.22	0.09	0.52	0.001
Airport/ airport personnel	0.08	0.02	0.33	<0.001

Note R^2 =0.28 (Cox and Snell), 0.37 (Nagelkerke). Model χ^2 (7) = 1337.78, p< 0.001.

In this model, *adverse mental states* and *physical/mental limitations* were the most influential predictors of ALOUA. The presence of *adverse mental states* or *physical/mental limitations* increased the odds of ALOUA occurring by 46 and 35 times respectively.

Cross-tabulations of these two factors with ALOUA demonstrated that 96 per cent of *adverse mental states* cases co-occurred with at least one *unsafe act*, and *physical/mental limitations* co-occurred with at least one *unsafe act* in 95 per cent of cases. The next most influential predictor was *inadequate supervision*, with an odds ratio of 18.1. In 94 per cent of cases, *inadequate supervision* co-occurred with ALOUA.

Crew resource management issues and *physical environment* also positively predicted ALOUA. *Maintenance* and *airport/airport personnel*, on the other hand, negatively predicted ALOUA. That is, if *maintenance* or *airport/airport personnel* issues were identified, ALOUA by aircrew were less likely to be coded.

3.4.2 Predicting individual *unsafe acts*

Separate models were also used to predict each individual *unsafe act* factor.

Recall that the preparatory analysis identified a three-way interaction and two 2-way interactions among the three error types and single violation within the *unsafe acts* level. Thus, where statistically significant, the associated *unsafe acts* were included into the prediction model. Predicting errors/violations should be interpreted with these associations in mind.

Skill-based errors

Logistic regression analyses were conducted to determine the best predictors of *skill-based errors*. The predictors are presented in Table 7. All but *maintenance issues* were positive predictors of *skill-based errors*. *Physical/mental limitations*, *adverse mental states*, and *inadequate supervision* exerted the strongest influence on the presence of a *skill-based error*. Conversely, the presence of *maintenance issues* reduced the probability of a *skill-based error*.

Compared to the models predicting other *unsafe acts*, this model accounted for the most variance in the dataset by explaining about a third of the variability.

Table 7: Logistic regression predicting *skill-based errors*

Predictor	Odds ratio	95% C.I. for odds ratio		Sig.
		Lower	Upper	
Physical/mental limitations	13.37	9.68	18.48	<0.001
Inadequate supervision	11.33	5.68	22.61	<0.001
Adverse mental states	11.06	8.07	15.17	<0.001
Physical environment	3.74	2.99	4.67	<0.001
Decision error	2.15	1.70	2.72	<0.001
Maintenance issues	0.11	0.03	0.36	<0.001

Note R^2 = 0.22 (Cox and Snell), 0.31 (Nagelkerke). Model χ^2 (6) = 1114.58, p<0.001

Decision errors

Six factors were identified as significant predictors of *decision errors* in the logistic regression model. The parameter estimates for the model are displayed in Table 8.

Table 8: Logistic regression predicting *decision errors*

Predictor	Odds ratio	95% C.I. for odds ratio		Sig.
		Lower	Upper	
CRM issues	6.25	3.76	10.37	<0.001
Violations	4.63	3.05	7.02	<0.001
Adverse mental states	4.04	3.08	5.32	<0.001
Physical environment	2.98	2.32	3.83	<0.001
Physical/mental limitations	2.79	2.10	3.69	<0.001
Skill-based error	2.37	1.89	2.97	<0.001

Note R^2 = 0.09 (Cox and Snell), 0.18 (Nagelkerke). Model χ^2 (6) = 432.57, p< 0.001

All six predictors increased the probability of a *decision error* occurring. The presence of a *CRM issue* increased the odds of a *decision error* by up to 6 times. The model accounts for 18 per cent of the variability in the dataset.

Perceptual errors

The most influential predictor was *adverse physiological states* (see Table 9), which increased the odds of a *perceptual error* occurring by 34 times. Other significant predictors of *perceptual errors* included *physical environment*, *adverse mental states*, *physical/mental limitations*, *adverse mental states*, and *other person involvement*. The prediction model accounts for 18 per cent of the variability in the dataset.

Table 9: Logistic regression predicting *perceptual errors*

Predictor	Odds ratio	95% C.I. for odds ratio		Sig.
		Lower	Upper	
Adverse physiological states	34.04	16.24	71.32	<0.001
Other person involvement	10.65	3.66	30.99	<0.001
Physical/ mental limitations	2.83	1.61	4.98	<0.001
Physical environment	2.73	1.62	4.61	<0.001
Adverse mental states	2.26	1.24	4.14	0.008

Note R^2 = 0.03 (Cox and Snell), 0.18 (Nagelkerke). Model χ^2 (5) = 141.41, p< 0.001

Violations

In the final model, presented in Table 10, the presence of *skill-based* and *decision errors* increased the odds of a *violation* by 2.13 times and 5.16 times respectively. Three *preconditions for unsafe acts'* factors (*adverse mental states*, *adverse physiological states*, and *physical/mental limitations*) and *supervisory violations* positively predicted violations. The strongest predictor of *violations* was *adverse physiological states* with an odds ratio of 9.57. Similar to the models predicting *decision errors* and *perceptual errors*, this model accounts for 19 per cent of the variance.

Table 10: Logistic regression predicting *violations*

Predictor	Odds ratio	95% C.I. for odds ratio		Sig.
		Lower	Upper	
Adverse physiological states	9.57	3.7	24.75	<0.001
Supervisory violations	6.11	1.09	34.44	0.04
Decision error	5.16	3.43	7.75	<0.001
Adverse mental states	2.44	1.53	3.90	<0.001
Skill-based error	2.13	1.38	3.90	<0.001
Physical/ mental limitations	1.88	1.14	3.07	0.01

Note R^2 = 0.04 (Cox and Snell), 0.19 (Nagelkerke). Model χ^2 (6) = 188.23, p< 0.001

4 DISCUSSION

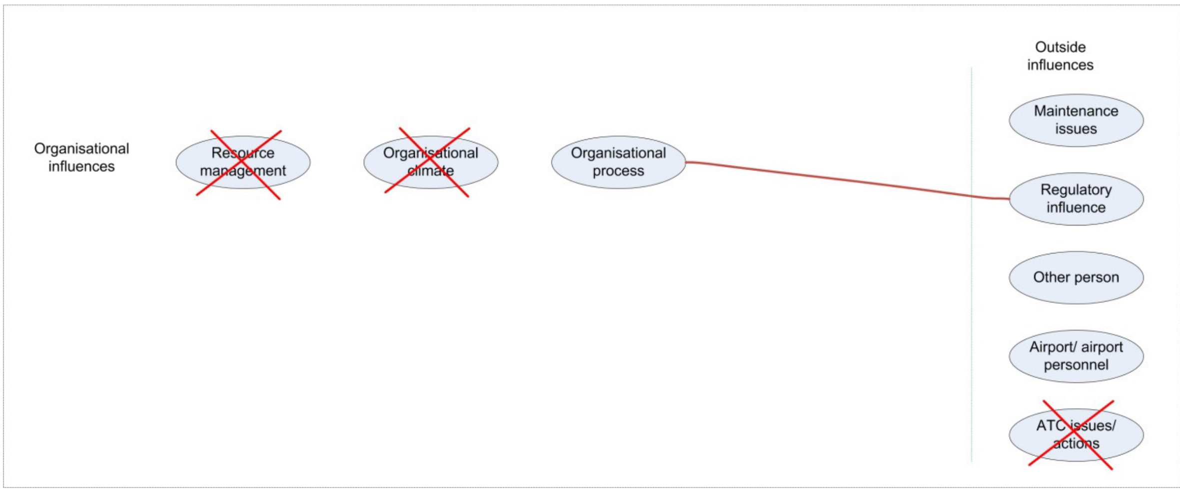
The analysis revealed a rich set of relationships between the hierarchical levels of HFACS. Many relationships were identified, with the majority increasing the odds of the associated factor occurring. These relationships provided some support for the argument that higher levels of the model do predict lower levels. For example, *organisational process* predicted *inadequate supervision* which in turn predicted both *preconditions for unsafe acts* and *unsafe acts*.

4.1 Summary of relationships and illustrative examples

4.1.1 Relationships between *organisational influences* and *outside influences*

It is not surprising that a relationship was found between the only *organisational influence* factor, *organisational process*, and the *outside influence* factor *regulatory influence* (Figure 5), as organisational systems and processes are bound by regulation, especially with regards to safety. The following case is a salient example of the effects of *regulatory influence* on *organisational processes*. An aircraft, operated by a company described by the then Civil Aviation Authority (CAA) (now known as the Civil Aviation Safety Authority) as having a tendency to explore the grey areas of the rules, crashed killing seven people. The CAA's Safety Regulations and Standards Division was responsible for the surveillance of air operators to ensure safety standards were met. Investigations revealed that the CAA was often under-resourced to carry out surveillance and checks, and a review of audit files gave an impression that the CAA often gave sub-standard operators second chances.

Figure 5: Associations between *organisational influences* and *outside influences*



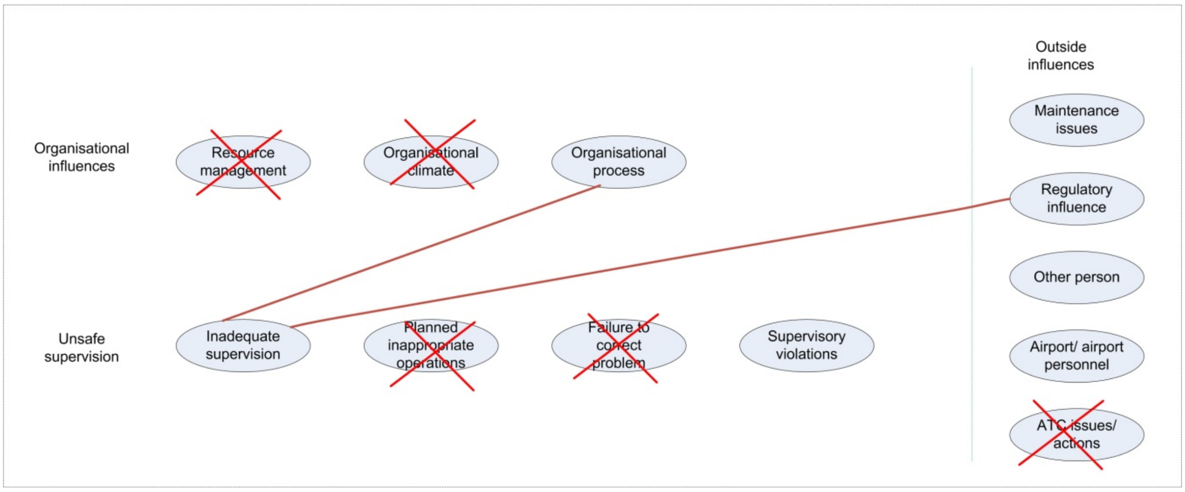
4.1.2 Relationships between *unsafe supervision* with *organisational influences* and *outside influences*

Two factors had positive relationships with the *inadequate supervision* factor at the *unsafe supervision* level - *organisational process* and *regulatory influence*. These relationships are shown in Figure 6.

Organisational process increased the likelihood of *inadequate supervision*. For example, a chief pilot, with limited floatplane experience and without formalised support from appropriately experienced floatplane pilots, was made responsible for all of a company's floatplane operations. This lack of experience and support contributed to shortcomings in the floatplane endorsement training received by the accident pilot.

The same accident can illustrate the relationship between *regulatory influence* and *inadequate supervision*. In this example, the minimum separation required under marine regulations was inadequate to provide a safe margin between the seaplane and the impacted yacht. Aviation regulations and supporting advisory material did not provide any guidance for the aircraft operators and pilots regarding appropriate lateral separation from moored vessels or other obstacles during takeoff and landing operations. Regulations have since changed.

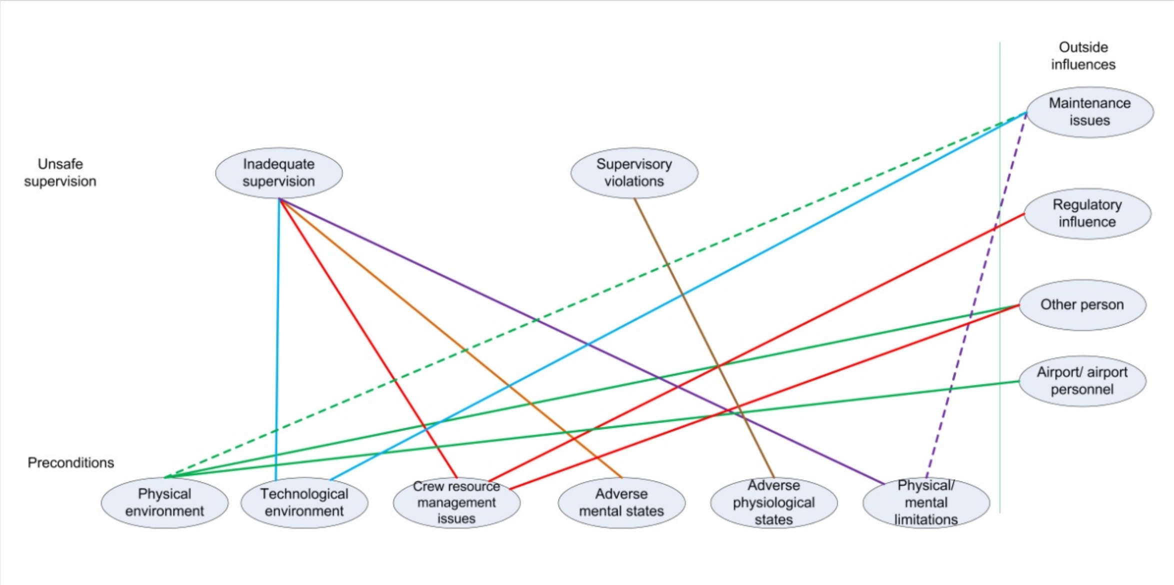
Figure 6: Associations between *unsafe supervision*, *organisational process*, and *regulatory influence*



4.1.3 Relationships between *preconditions for unsafe acts* and *unsafe supervision*, *organisational influences* and *outside influences*

There were a number of significant relationships between *preconditions for unsafe acts* and higher levels of HFACS (see Figure 7). However, there were no relationships between the *organisational influences* level and the *preconditions for unsafe acts* level.

Figure 7: Associations between *preconditions for unsafe acts*, *unsafe supervision* and *outside influences*[1]



Physical environment

Physical environment was not significantly related to any of the higher level factors in HFACS. This is not surprising as the higher-level factors identified in HFACS have little influence on the weather or physical objects, such as trees or fences.

Significant relationships were found between the *physical environment* factor and the *outside influences* factors. The positive relationships were with *airport/airport personnel* and *other persons*. These relationships reflected problems with runway or landing surfaces, animals on the runway, or perimeter fences that airport personnel or other personnel could have influenced. The *physical environment* factor was unlikely to be present in accidents where *maintenance issues* also occurred.

Technological environment

Technological environment co-occurred with *inadequate supervision*. For example, the design of a cockpit display or control was sometimes identified as a contribution to the same accident as *inadequate assessment* of the accident pilot's skills.

Maintenance issues also co-occurred with *technological environment*. For instance, at 1,000 ft above ground level, the engine of a de Havilland aircraft lost power and then stopped completely. The pilot conducted an emergency landing and the aircraft sustained substantial damage. Investigations found a substantial amount of water in the fuel system. It was revealed that it was the aircraft's first flight after a periodic servicing.

1 Dotted lines indicate negative relationships.

Crew resource management issues

The presence of *CRM issues* was positively predicted by *inadequate supervision*, *regulatory influence*, and *other person involvement*.

For example, a flight instructor simulated a left engine failure without a clear pre-takeoff briefing (*CRM issue*). Subsequently, the student pilot did not detect the engine failure and selected an incorrect response to the aircraft's performance. This response was in direct conflict to the corrective action being attempted by the flight instructor (*inadequate supervision*).

Another accident demonstrates the link between *regulatory influence* and *CRM issues*. At the time of the accident, there were no regulations requiring airlines to train their crew in CRM and investigations revealed that the accident airline had no CRM policy on two-crew operations. No evidence was found that the pilot monitoring was encouraged to fulfil copilot duties to reduce the workload of the pilot in command.

Other persons involvement and *CRM* is demonstrated in the following. Due to language barriers between the pilot and a foreign film crew, there were numerous communication problems. The pilot spotted a powerline running across the planned filming area and deemed the area unsuitable for low-level flight. However, the film crew persisted and the pilot eventually agreed to conduct the flight. During the low flight sequence, the helicopter struck the powerline and impacted the ground.

Adverse mental states

The *adverse mental states* factor was positively associated with *inadequate supervision*. For example, a wheels-up landing investigated by the ATSB found that a combination of student pilot fatigue (which may have contributed to the failure to complete the pre-landing short final check) and the failure of the instructor pilot to also compete his checks meant that neither crew realised that the landing gear was not extended.

Adverse physiological states

Adverse physiological states were positively associated with *supervisory violations*. In one instance, a student who was relatively inexperienced in dark night operations and had not completed the training specified in the operator's syllabus was allowed by his instructor to conduct night solo circuits (*supervisory violation*). The student pilot became disorientated upon landing (*adverse physiological state*) and the aircraft's nose impacted the runway.

Physical/ mental limitations

Physical/mental limitations were associated with *inadequate supervision*, but were unlikely to be present in accidents where *maintenance issues* also occurred.

The inadequate checking of line pilots coupled with the pilot's low experience or recency was a common example of the relationship between *physical/mental limitations* and *inadequate supervision* contributing to an accident.

The absence of *physical/mental limitations* when *maintenance issues* were present was not surprising. Accidents related to mechanical failures generally do not include pilot-related *preconditions for unsafe acts*.

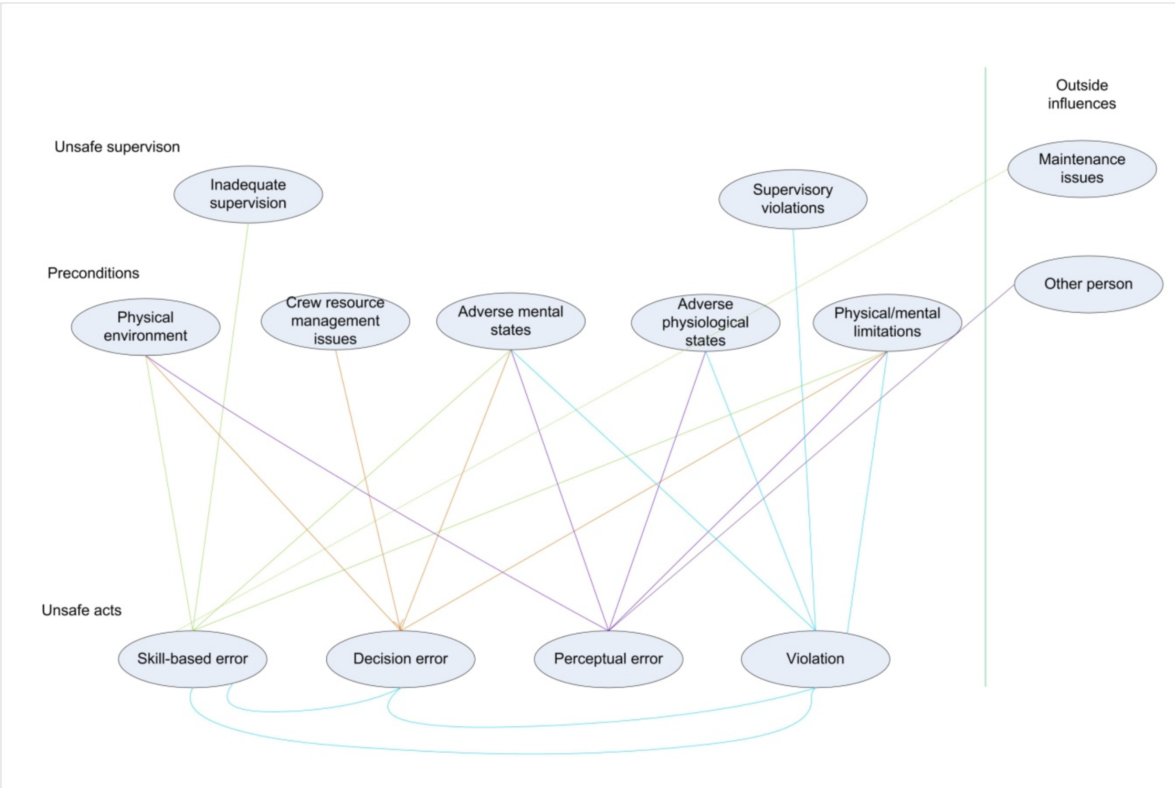
4.1.4 Relationships between *unsafe acts*, upper HFACS levels and *outside influences*

The strongest predictors of *unsafe acts* were the *preconditions for unsafe acts*. There were also two relationships between *unsafe acts* and the *unsafe supervision* level. However, there were no direct relationships identified with the *organisational influences* level.

A salient finding was that *adverse mental states* and *physical/ mental limitations* raised the odds of at least one *unsafe act* occurring by 46 and 35 times respectively. *Inadequate supervision* also increased the odds by 18 times of an *unsafe act* occurring. Smaller, but still significant influences were *CRM* issues and *physical environment*, both of which increased the odds of an *unsafe act* by nearly 7 and 6 times, respectively.

The relationship between specific *unsafe acts*, upper HFACS predictors and *outside influences* are summarised in Figure 8.

Figure 8: Associations between *unsafe acts* and higher levels of HFACS



Skill based errors

Skill-based errors were more likely to occur if *inadequate supervision*, *physical/ mental limitations*, or *adverse mental states* were present (increased odds of 11, 13 and 11, respectively) and, to a lesser extent, if *physical environment* issues, or a *decision error* were present (increased odds of 4 and 2, respectively). Accidents from the Australian dataset used in the analysis are provided below to illustrate these relationships.

The relationship between *skill-based error* and *inadequate supervision* included an instance where the instructor took over control of the aircraft to demonstrate to the student how much excess speed the aircraft had after initial touchdown. At the end of the demonstration, the student reached forward to check that the carburettor heat was off and in error activated the landing gear lever. The nose gear retracted and the aircraft came to rest on the runway in a nose down attitude.

A pilot's inexperience or lack of recency is a typical example of how *physical/ mental limitations* can contribute to a *skill-based error*, such as selecting an incorrect radio frequency.

Pilot overconfidence, distraction, or the pressure to continue flight despite adverse weather, are some examples of how *adverse mental states* can induce *skill-based errors*. In one wheels-up landing accident, the pilot reported that she was distracted during approach by abnormal traffic and the presence of a strong crosswind.

The *physical environment* can also influence the presence of *skill-based errors*. For example, weather conditions, such as thunderstorms, widespread cloud, or crosswind, can contribute to a *skill-based error*, such as a hard landing, an unstable approach resulting in a go-around, or not achieving adequate aircraft performance leading to a rejected takeoff.

An example of the association between *skill-based* and *decision errors* is highlighted in the following accident. During the take-off roll, when the pilot applied back-pressure to rotate, the aircraft would not lift off the ground. The pilot subsequently tried to reject the takeoff, but could not stop the aircraft prior to it leaving the flight strip and overturning. The aero club president reported that the aircraft had too much nose-down trim applied. The trim indicator had a mark near it and the pilot is believed to have used that mark to set the take-off trim. As a result, the forces required to rotate the aircraft were not as expected by the pilot.

The presence of *maintenance issues* reduced the probability of a *skill-based error* occurring.

Decision errors

Decision errors were more likely to be present when *CRM* issues, *violations*, *adverse mental states*, *physical environment issues*, *physical/ mental limitations* or *skill-based errors* were also present.

Accidents where *decision errors* and *CRM* issues were present typically involved poor communication and inadequate pre-flight planning followed by a poor in-flight decision. A common example includes instances where the pilot did not gather current weather information and then chose to continue to fly in adverse weather.

There is often a fine line between a *decision error* and a *violation*. The interaction between these factors is commonly illustrated by accidents where the pilot decides to depart later than planned, without the certainty that the flight could be completed in the required daylight conditions and without the relevant night-time flying qualifications or equipment.

A pilot's overconfidence, considered an *adverse mental state*, can influence his or her decision to conduct high risk manoeuvres. Succumbing to pressure to continue flight despite adverse weather is another example of the interaction between *decision error* and *adverse mental states*. Other *adverse mental states* such as fatigue, distraction, and anxiety can also unfavourably affect decision-making skills.

The interplay between *decision errors* and the *physical environment* is illustrated by accidents where the pilot took off on unsuitable terrain or landing areas. This interplay is also reflected in decisions to continue into adverse weather conditions, such as flying into instrument meteorological conditions (IMC) or landing in high crosswinds.

A pilot's inexperience or lack of recency is an example of how *physical/mental limitations* can contribute to a *decision error*. In one accident, the pilot, inexperienced with the aircraft type and the local area, incorrectly planned the fuel required for the flight.

The interplay between *decision errors* and *skill-based errors* is shown in the following accident. The pilot in command, who was engaged in a night freight operation, had elected to conduct a practice NDB (non-directional beacon) approach[2] on arrival. He used fuel from the auxiliary fuel tanks and had elected not to change to the main tanks at the top of descent, as required by the checklist. He intended to change to the main tanks during the latter part of the approach. During the instrument approach, he failed to change the fuel selection. Shortly after commencing the outbound leg of the approach, the left engine failed. The pilot discontinued the approach and elected to land the aircraft without feathering the left engine. During the final approach, the right engine failed and the aircraft impacted the ground short of the runway. The pilot sustained minor injuries and the aircraft was substantially damaged.

Perceptual errors

The odds of a *perceptual error* being involved in the accident were markedly increased by the presence of the *adverse physiological states* factor being present (34 more likely). The probability of *perceptual errors* was also increased by the presence of actions by *other persons*, *physical environment* issues, *adverse mental states*, and *physical/ mental limitations*. Accidents from the Australian dataset are provided below to illustrate the various relationships.

The association between *adverse physiological states* and *perceptual errors* is illustrated in an accident where a pilot suffering from visual impairment, as a result of hypoxia, mistook a flight control for another and improperly used that flight control. In another accident, a pilot, experiencing a combination of high mental workload, fatigue, and pressure to continue the flight, flew his aircraft into an undetected object. A further example of the relationship between *adverse mental states* involved an overconfident pilot who attempted a low altitude manoeuvre where the clearance distance was misjudged.

The relationship between *other persons* and pilot *perceptual error* is illustrated in an accident where ground personnel provided the pilot with inaccurate information and the pilot subsequently misjudged speed/distance and conducted a hard landing.

An example of the relationship between *perceptual errors* and *physical environment* was reflected in collisions where: the pilot was unable to detect an object or animal; the pilot misjudged the distance to an obstacle/terrain; or the pilot misjudged the strength of a crosswind.

---

2 A ground-based non-precision approach.

The relationship between *perceptual errors* and *physical/mental limitations* included an accident where the pilot, lacking in low-level flying experience, flew into a powerline. It was likely that the oblique angle of approach to the wires limited the pilot's ability to detect the wires. The pilot subsequently lost control of the aircraft.

Violations

Violations were more likely to occur if *adverse physiological states*, *supervisory violations*, or *decision errors* were present and to a lesser extent, if *adverse mental states*, *skill-based errors* and *physical/mental limitations* were present.

Common examples of the relationship between *violations* and *adverse physiological states* usually involved a visual flight rules pilot flying in instrument meteorological conditions or at night without the appropriate rating. The pilot subsequently experiences spatial disorientation and loses control of the aircraft.

Supervisory violations and *violations* on the part of the pilot usually involved the operator or flight instructor allowing the pilot to conduct flights that he or she was not rated or authorised to conduct. For example, the pilot contracted to conduct mustering flights was not endorsed to conduct low-level flying or mustering operations. The operator knew of this requirement and stated that despite the pilot's lack of endorsement, hired him because the pilot had arranged to do training for a mustering endorsement.

In an accident where the aircraft exceeded the maximum take-off weight (*violation*), reducing its climb performance, the pilot also used 10 degrees of wing flap (*decision error*), which also would have reduced the climb performance. The combination of these factors meant that the aircraft would have been flying slower for any given nose attitude.

A common example of a *violation* and a *skill-based error* contributing to an accident usually involved aircraft being overloaded and thus unstable. This overloading may lead to loss of aircraft control, which typically results in collision with terrain.

Incorrect aircraft weight and balance, lack of certification for the type of flying, low altitude manoeuvres, and inadequate fuel supply are examples of *violations* that were typically coupled with *physical/mental limitations*, such as insufficient training or experience.

4.2 Comparisons with other studies

Li & Harris (2006)

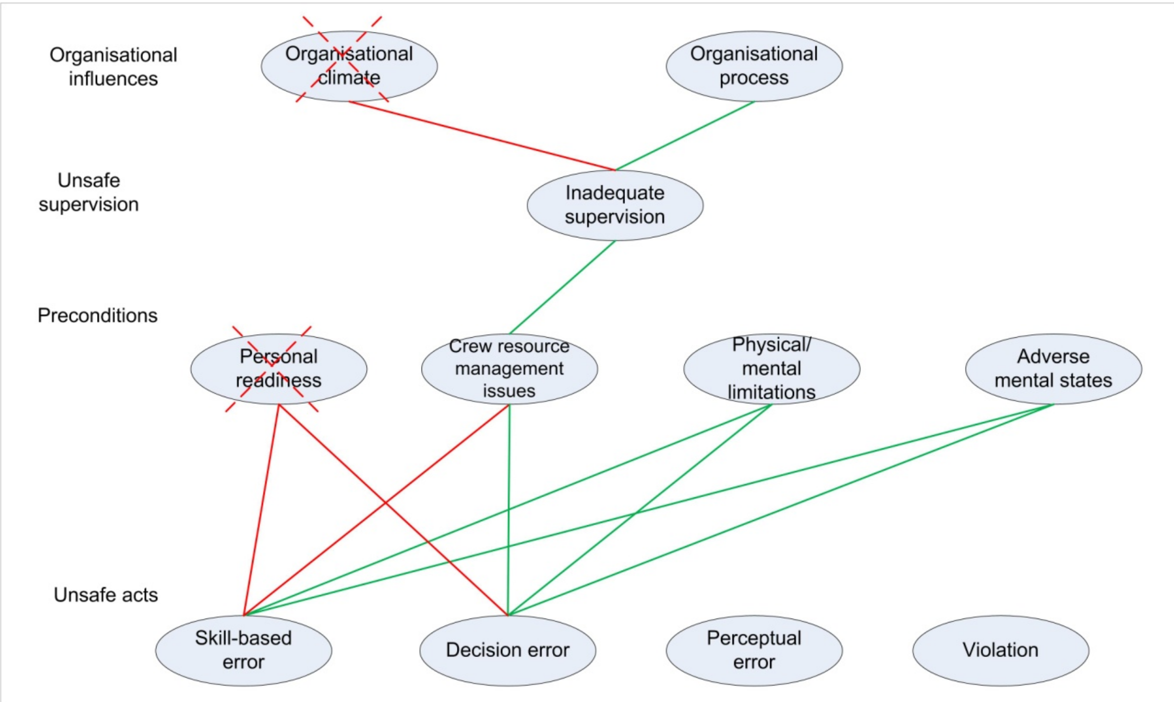
The current results suggest a substantially richer set of associations and predictive models than the one that emerged from Li and Harris's (2006) findings.

A total of 38 relationships were identified between the HFACS factors in the present study. Seven of these relationships replicated those found by Li and Harris (2006). The difference in the number of associations found were probably due to the fact that this study did not limit associations to adjacent levels, had a larger sample size and/or used more powerful statistical techniques.

The results of this study also deviated from Li and Harris's, with inclusion of the *outside influence* factors. The *outside influence* factors are more important to the current study as civil aviation has many different organisations providing services. On the other hand, all the services in military aviation are generally provided by the military itself (one organisation).

Figure 9 shows the relationships between HFACS factors that Li and Harris (2006) found in their study. Of the 11 relationships found in Li and Harris's study, seven were also replicated in the current study. The replicated relationships are highlighted in green. With the exception of the relationship between *CRM issues* and *skill-based errors*, the additional relationships found by Li and Harris (2006) could not be tested in the present study as there was insufficient number of cases in those factors to include in the analysis (shown as cross-out in Figure 9).

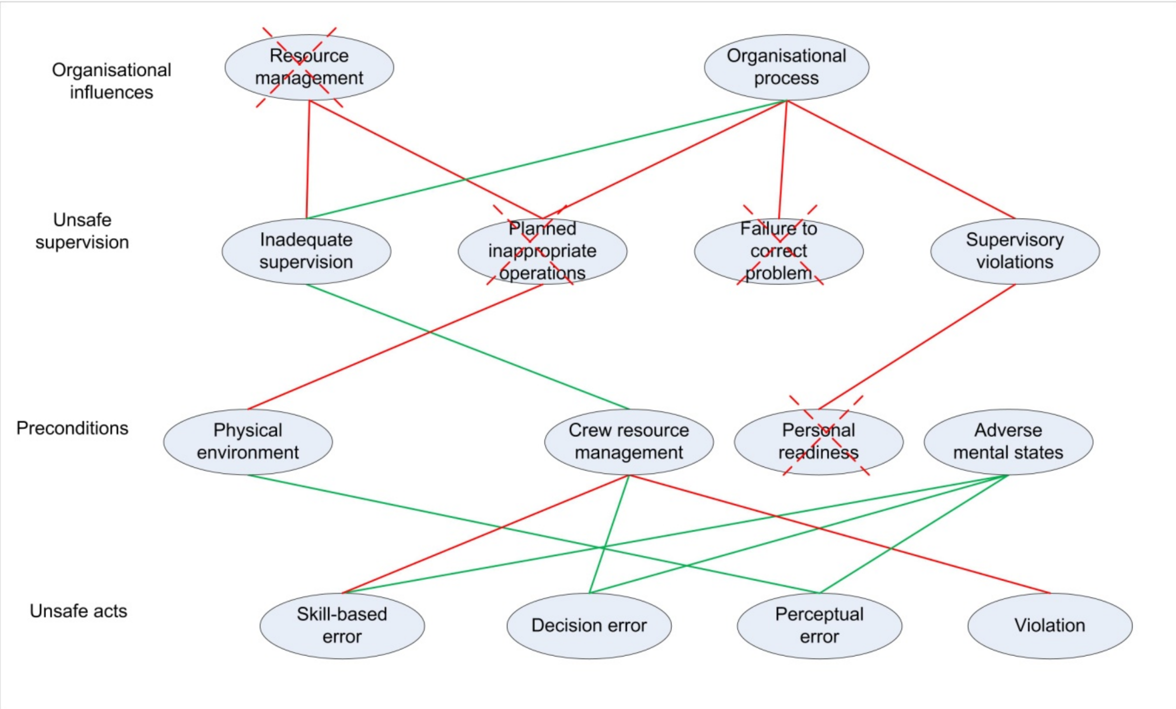
Figure 9: Relationships between HFACS factors in Li & Harris (2006)



Li, Harris & Yu (2008)

Li et al (2008) found similar results to the above study using civilian aviation accidents from China. They found 16 relationships, only 7 of which were replicated by the present study (shown as green lines in Figure 10). However, when removing those that could not be replicated in the present study due to insufficient cases within particular factors (cross-out factors in Figure 10 and *supervisory violations*), only two relationships found in their study were not replicated in the present study. These were the relationships between *CRM issues* and both *skill-based errors* and *violations*.

Figure 10: Relationships between HFACS factors in Li & Harris (2006)

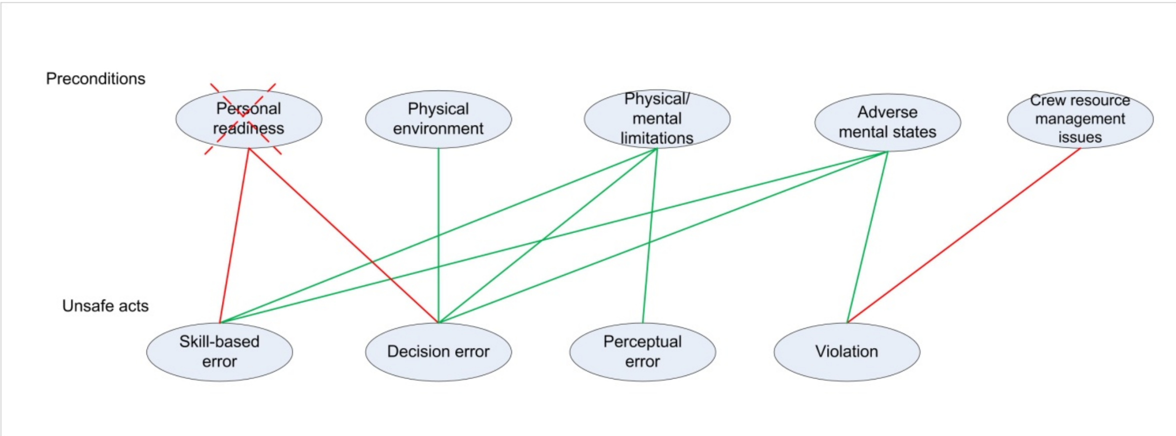


__Lenné, Ashby & Fitzharris (2008)__

Similar to the comparisons above, some of the relationships identified by Lenné et al. (2008) were replicated. Seven of the 10 relationships identified by Lenné et al. were reproduced. That study only analysed relationships between *preconditions for unsafe acts* and *unsafe acts* as Lenné et al. only had sufficient data for those levels.

Figure 11 below shows the relationships between HFACS factors Lenné et al (2008) found in their study. The replicated relationships are highlighted in green. Of the three relationships not replicated, two involved the precondition of *personal readiness*, which was excluded from the current analysis due to insufficient cases. The third relationship not replicated in the current study was the link between *CRM issues* and *violations*. This was also found by Li et al. (2008) above.

Figure 11: Relationships between HFACS factors in Lenné et al (2008)



5 CONCLUSION

This exploratory study evaluated the HFACS framework as a predictive tool.

There were 38 relationships found within the HFACS model, which included the added *outside influences* factors. Some of these relationships had large odds ratios and were mostly consistent with previous studies. However, when taking into account the amount of variation explained by each statistical model, it appears that HFACS may have limited effectiveness as a predictive framework.

The models predicting individual *unsafe acts* had between 18 and 31 per cent of their variability accounted for from within the HFACS taxonomy. Although these are not large proportions, they are large enough to show there is some robustness about the HFACS taxonomy to predict *unsafe acts*.

In contrast, the models predicting *preconditions for unsafe acts* and *unsafe supervision* only accounted for between 2 and 8 per cent of the variation. This suggests that HFACS is a poor predictor of these upper levels of the model.

However, given that the dataset used had limited cases in a number of the upper level factors, it is possible that an equivalent sized dataset with a higher proportion of accidents coded at the higher levels of HFACS may result in predictive models with higher levels of explained variation. This would require a dataset based around either passenger transport civil aviation, or military aviation accidents only, as accident investigations from general aviation tend to have minimal factors identified above the *preconditions for unsafe acts* level. It should be noted that previous studies have not reported the amount of variation explained by their statistical models.

Adverse mental states and *physical/mental limitations* were found to predict all *unsafe acts*. *Inadequate supervision* predicted the most *preconditions for unsafe acts* (four) as well as *skill-based errors*. *Outside influences* factors predicted nine HFACS factors, including *organisational process*, *inadequate supervision*, *physical/ mental limitations*, *CRM issues*, *technical environment*, *skill-based errors*, and *perceptual errors*.

Very large odds ratios (greater than 30 times) were found for a small number of predictions. These included:

- *regulatory influences* predicting *organisational processes*
- *organisational processes* predicting *inadequate supervision*
- *airport/airport personnel* predicting *physical environment*
- *supervisory violations* predicting *adverse physiological states*
- *adverse physiological states* predicting *perceptual errors*
- *adverse mental states* predicting *at least one unsafe act*
- *physical/mental limitations* predicting *at least one unsafe act*

The findings from this study also provide evidence for two implicit assumptions of HFACS. The first assumption is that all of the HFACS factors are positively associated, that is, the presence of higher-level factors increased the likelihood of the lower-level factors also appearing. Most of the prediction models conformed to this assumption. However, two factors - *maintenance issues* and *physical* *environment* - negatively predicted other factors downstream. The negative predictions are where an accident investigation taxonomy and a predictive model of accident causation must divert.

The second assumption is that higher-level factors predict only the lower-level factors directly below them. The results of this study have shown that this is not always the case. For instance, *inadequate supervision* was found to predict *skill-based errors*, bypassing the *preconditions for unsafe acts* level.

Outside influence factors are important when applying HFACS to civil aviation accidents. The *outside influence* factors added to the model were associated with factors at all levels of the HAFCS taxonomy. Furthermore, the model predicting *organisational influences* from *outside influences* factors accounted for 35 per cent of the variation. These factors are not a formal part of the HFACS taxonomy, yet significantly increased the odds of four of the *preconditions for unsafe acts*, one of the *unsafe supervision* factors, and two of the *unsafe act* factors occurring. Thus, *outside influences* are an imperative addition to the existing HFACS model when investigating factors that contribute to civil accidents at a national level. Used within an airline or in a military setting for classifying contributing factors to aviation accidents and incidents during investigations, the *outside influences* group is probably not required to the same extent. This is because although *outside influences* do affect all accidents and incidents, occurrence investigations routinely stop at the level at which the organisation can actually influence. For an airline for example, this usually means internal investigations stop at the *organisational influences* level. The *outside influence* factors derived for this study were based on accidents in the ATSB database. Other accident databases may yield a more comprehensive or different list of *outside influences*.

Despite finding limited predictive validity with the HFACS framework at higher levels of the taxonomy, the associations found in this exploratory study nonetheless may help investigators to look into associated factors when contributing factors are found. Also, when using the HFACS taxonomy to identify areas for intervention, the results of this study may also guide intervention in associated areas for a holistic, systems approach to improvement.

6 REFERENCES

Federal Railroad Administration. (2005). *Human factors root cause analysis of accidents/incidents involving remote control locomotive operations* (No. RR05-05). Washington, DC: US Department of Transportation.

Gaur, D. (2005). Human Factors Analysis and Classification System applied to civil aircraft accidents in India. *Aviation, Space and Environmental Medicine, 76*(5), 501-505.

Inglis, M., Sutton, J., & McRandle, B. (2007). *Human factors analysis of Australian aviation accidents and comparison with the United States* (Aviation Research and Analysis Report B20040321). Canberra: Australian Transport Safety Bureau.

Lenné, M. G., Ashby, K., & Fitzharris, M. (2008). Analysis of general aviation crashes in Australia using the Human Factors Analysis and Classification System. *The International Journal of Aviation Psychology, 18*(4), 340-352.

Li, W.C., & Harris, D. (2005). HFACS analysis of ROC Air Force aviation accidents: Reliability analysis and cross-cultural comparison. *International Journal of Applied Aviation Studies, 5*(1), 65-81.

Li, W.C., & Harris, D. (2006). Pilot error and its relationship with higher organizational levels:HFACS analysis of 523 accidents. *Aviation, Space and Environmental Medicine, 77*(10), 1056-1061.

Li, W.C., Harris, D., & Yu, C.S. (2008). Routes to failure: Analysis of 41 civil aviation accidents from the Republic of China using the human factors analysis and classification system. *Accident Analysis & Prevention, 40*, 426-434.

Pape, A. M., Wiegmann, D. A., & Shappell, S. A. (2001). *Air traffic control (ATC) related accidents and incidents: A human factors analysis.* Paper presented at the 11th International Symposium on Aviation Psychology, The Ohio State University, Columbus OH.

Reason, J. (1990). Human Error. Cambridge University Press: Cambridge, UK.

Shappell, S. A. (2005). Assessment and development of safety programs targeting human error in general aviation: Clemson University, Clemson, SC.

Shappell, S. A., & Wiegmann, D. A. (2000). *The Human Factors Analysis and Classification System-HFACS* (No. DOT/FAA/AM-00/7). Oklahoma City, OK: Civil Aeromedical Institute, Federal Aviation Administration.

Walker, M.B., & Bills, K.M. (2008). *Analysis, Causality and Proof in Safety Investigations.* (Research and Analysis Report AR-2007-053). Canberra: Australian Transport Safety Bureau.

Wiegmann, D. A., & Shappell, S. A. (2003). *A human error approach to aviation accident analysis: The Human Factors Analysis and Classification System*. London, UK: Ashgate Publishing Company.

APPENDIX A: HFACS CATEGORY DEFINITIONS

The descriptions were adapted from Wiegmann and Shappell (2003). The adaptation involved changing the language to Australian English and adding a description of the outside influence category.

Unsafe acts of operators

The *unsafe acts* of operators (aircrew) can be loosely classified into one of two categories - *errors* and *violations* (Reason, 1990). While both are common within most settings, they differ markedly when the rules and regulations of an organisation are considered. That is, while *errors* represent authorised behaviour that fails to meet the desired outcome, *violations* refer to the wilful disregard of the rules and regulations. It is within these two overarching categories that HFACS describes three types of *errors* (*decision*, *skill-based*, and *perceptual*) and two types of *violations* (*routine* and *exceptional*).

Errors

Decision errors

One of the more common error forms, *decision errors* represent intentional behaviour that goes on as planned yet the plan proves inadequate or inappropriate for the situation. Often referred to as 'honest mistakes', these errors typically manifest itself as poorly executed procedures, improper choices, or simply the misinterpretation and/or misuse of relevant information.

Skill-based errors

In contrast to *decision errors*, *skill-based errors* occur with little or no conscious thought. Indeed, just as *decision errors* can be thought of as 'thinking' errors, skill-*based errors* can be thought of as 'doing' errors. For instance, little thought goes into turning one's steering wheel or shifting gears in an automobile. Likewise, basic flight skills such as stick and rudder movements and visual scanning refer more to how one does something. The difficulty with these highly practiced and seemingly automatic behaviours is that they are particularly susceptible to attention and/or memory failures. As a result, *skill-based errors* frequently appear as the breakdown in visual scan patterns, inadvertent activation or deactivation of switches, forgotten intentions, and omitted items in checklists. Even the manner (or skill) with which one flies an aircraft (aggressive, tentative, or controlled) can affect safety.

Perceptual errors

While *decision* and *skill-based errors* have dominated most accident databases and have been included in most error frameworks, *perceptual errors* have received comparatively less attention. No less important, these 'perceiving' errors arise when sensory input is degraded or 'unusual' as is often the case when flying at night, in bad weather, or in other visually impoverished environments. Faced with acting on imperfect or incomplete information, aircrew run the risk of misjudging distances, altitude, and descent rates, as well as responding incorrectly to a variety of visual or vestibular illusions.

Violations

In the present study, both routine and exception violations were included as a single factor of *violations*.

Routine *violations* tend to be habitual by nature and are often enabled by a system of supervision and management that tolerates such departures from the rules (Reason, 1990). Often referred to as 'bending the rules', the classic example is of the individual who drives their automobile consistently 3 km/ hr faster than allowed by law. While clearly against the law, the behaviour is, in effect, sanctioned by police who often may not enforce the law until speeds in excess of 5 km/ hr over the posted limit are observed. An aviation example includes one where the pilot consistently flies in marginal weather when only authorised for visual flight rules.

Exceptional *violations*, on the other hand, are isolated departures from authority, neither typical of the individual nor condoned by management. For example, while authorities might overlook driving 58 in a 55 km/ hr zone, driving 85 km/ hr in a 55 km/ hr zone would almost certainly result in a speeding ticket. It is important to note that, while most exceptional *violations* are appalling, they are not considered 'exceptional' because of their extreme nature. Rather, they are regarded as exceptional because they are neither typical of the individual nor accepted by authority.

Preconditions for unsafe acts

Simply focusing on *unsafe acts*, however, is like focusing on a patient's symptoms without understanding the underlying disease state that caused it. As such, investigators must dig deeper into the *preconditions for unsafe acts.* Within HFACS, the three major subdivisions of *preconditions for unsafe acts* and the factors within them are described below.

Conditions of operators

The condition of an individual can, and often does, influence performance on the job. It is often the critical link in the chain of events leading up to an accident. The three conditions of operators that directly impact performance are described below.

Adverse mental states

Being prepared mentally is critical in nearly every endeavour; perhaps it is even more so in aviation. With this in mind, the *adverse mental states* category was created to account for those mental conditions that adversely affect performance and contribute to unsafe acts. Principal among these are the loss of situational awareness, mental fatigue, task fixation, distraction, and attitudes such as overconfidence, complacency, and misplaced motivation.

Adverse physiological states

Equally important, however, are those *adverse physiological states* that preclude the safe conduct of flight. Particularly important to aviation are conditions such as spatial disorientation, visual illusions, hypoxia, illness, intoxication, and a whole host of pharmacological and medical abnormalities known to affect performance. It is important to understand that these conditions, such as spatial disorientation, are physiological states that cannot be turned on or off — they just exist. As a result, these *adverse physiological states* often lead to the presence of *unsafe acts* like *perceptual errors*. For instance, it is not uncommon in aviation for a pilot to become spatially disoriented (*adverse physiological state*) and subsequently misjudge the aircraft's pitch or attitude (*perceptual error*), resulting in a loss of aircraft control.

Physical/mental limitations

The third category of substandard operator conditions, *physical/mental limitations* refers to those instances when operational requirements exceed the capabilities of the pilot. It also include instances when necessary sensory information is either unavailable or, if available, individuals simply do not have the aptitude, skill, or time to safely deal with it. There are instances when an individual simply may not possess the necessary aptitude, physical ability, or proficiency to operate safely.

Personnel factors

At times, things that we do to ourselves will lead to undesirable conditions and unsafe acts. Referred to as personnel factors, these preconditions have been divided into two general factors: *CRM issues* and *personal readiness*.

Crew resource management issues

Crew resource management issues, as it is referred to here, includes the failures of both inter- and intra-flight deck communication, as well as communication with ATC and other ground personnel. This category also includes those instances when crew members do not work together as a team, or when individuals directly responsible for the conduct of operations fail to coordinate activities before, during, and after a flight.

Personal readiness

Individuals must, by necessity, ensure that they are physically and mentally prepared for flight. Consequently, the category of *personal readiness* was created to account for those instances when rules such as disregarding crew rest requirements, violating alcohol restrictions, or self-medicating, are not adhered to. Note that these instances are not considered *violations* (an *unsafe act*) as these activities do not typically occur in the flight deck, nor are they necessarily active failures with direct and immediate consequences. However, even behaviours that do not necessarily violate existing rules or regulations (for example, running 10 kilometres before piloting an aircraft or not observing good dietary practices) may reduce the operating capabilities of the individual and are, therefore, captured here as well.

Environmental factors

Although not human factors per se, *environmental factors* can also contribute to the substandard conditions of aircrew. Very broadly, these environmental factors can be captured within two general factors- the *physical environment* and the *technological environment.*

Physical environment

The term *physical environment* refers to both the operational environment (for example, weather, altitude, terrain) as well as the ambient environment, such as heat, vibration, lighting, and toxins in the cockpit. For example, flying into adverse weather reduces visual cues, which can lead to spatial disorientation and perceptual errors. Other aspects of the *physical environment* such as heat can cause dehydration, reducing a pilot's alertness level, which then can slow the decision-making processes or even render the pilot ineffective in controlling the aircraft. Likewise, a loss of pressurisation at high altitudes can result in hypoxia which can then lead to delirium, confusion, and a host of *unsafe acts*.

Technological environment

Within the context of HFACS, the term *technological environment* encompasses a variety of issues that can impact pilot performance. The *technological environment* includes the design of equipment and controls, display/interface characteristics, checklist design, and automation. Indeed, one of the classic design problems first discovered in aviation was the similarity between the controls used to raise and lower the flaps and those used to raise and lower the landing gear. Such similarities often caused confusion among pilots, resulting in the frequent raising of the landing gear while still on the ground. Likewise, automation designed to improve human performance can have unforeseen consequences, for example when interacting with multiple modes in modern flight management systems. The pilot may experience 'mode confusion'. The confusion may result in the pilot making *decision errors* and consequently fly a 'good' aircraft into the ground.

Unsafe supervision

Clearly, aircrews are responsible for their actions and, as such, must be held accountable. However, in some instances, they are the unwitting inheritors of latent failures attributable to those who supervise them. To account for these latent failures, the overarching category of *unsafe supervision* was created with the following four factors.

Inadequate supervision

This category refers to failures within the supervisory chain of command as a direct result of some supervisory action or inaction. At a minimum, supervisors must provide the opportunity for individuals to succeed. It is expected, therefore, that individuals will receive adequate training, professional guidance, oversight, and operational leadership, and that all will be managed appropriately. When this is not the case, aircrew can become isolated, thereby increasing the risks associated with day-to-day operations.

Planned inappropriate operations

The risks associated with supervisory failures come in many forms. Occasionally, for example, the operational tempo and/or schedule are planned such that individuals are put at unacceptable risk and, ultimately, performance is adversely affected. As such, the category of *planned inappropriate operations* was created to account for all aspects of improper or inappropriate crew scheduling and operational planning, such as inappropriate crew pairing, inadequate crew rest, and managing the risk associated with specific flights.

Failed to correct known problems

The remaining two factors of *unsafe supervision*, the *failure to correct known problems* and *supervisory violations*, are similar, yet considered separately within HFACS. *Failure to correct known problems* refers to those instances when deficiencies among individuals, equipment, training, or other related safety areas are known to the supervisor, yet are allowed to continue uncorrected. For example, the failure to consistently correct or discipline inappropriate behaviour certainly fosters an unsafe acceptance of risk but is not considered a violation if no specific rules or regulations are broken.

Supervisory violations

This category is reserved for those instances when supervisors wilfully disregard existing rules and regulations. For instance, permitting aircrew to operate an aircraft without current qualifications or license is a blatant violation.

Organisational influences

Where decisions and practices by front-line supervisors and middle management can adversely impact aircrew performance, fallible decisions of upper-level management may also directly affect supervisors and the personnel they manage. The HFACS framework describes the three latent organisational failures below.

Resource management

This category refers to the management, allocation, and maintenance of organisational resources, including human resource management (for instance, selection, training, staffing), monetary safety budgets, and equipment design (ergonomic specifications). In general, corporate decisions about how such resources should be managed centre around two distinct objectives — the goal of safety and the goal of on-time, cost-effective operations. In times of prosperity, both objectives can be easily balanced and satisfied. However, there may also be times of fiscal austerity that demand some give and take between the two. Unfortunately, history tells us that safety is often the loser in such battles as safety and training are often the first to be cut in organisations experiencing financial difficulties.

Organisational climate

The concept of an organisation's climate has been described in many ways; however, here it refers to a broad class of organisational variables that influence worker performance. One telltale sign of an organisation's climate is its structure, as reflected in the chain-of-command, delegation of authority and responsibility, communication channels, and formal accountability for actions. Just like in the flight deck, communication and coordination are vital within an organisation. However, an organisation's policies are also good indicators of its climate. Consequently, when policies are ill-defined, adversarial, or conflicting, or when they are supplanted by unofficial rules and values, confusion abounds, and safety suffers within an organisation.

Operational process

Finally, *operational process* refers to formal processes (for instance operational tempo, time pressures, production quotas, incentive systems, schedules), procedures (such as performance standards, objectives, documentation, instructions about procedures), and oversight within the organisation (for example organisational self-study, risk management, and the establishment and use of safety programs). Poor upper-level management and decisions concerning each of these organisational factors can also have a negative, albeit indirect, effect on operator performance and system safety.

Outside influence

In Australian civil aviation, many agencies play a role in the performance and regulation of aviation. For example, there is an organisation that develops and enforces regulations (Civil Aviation Safety Authority), a separate organisation that provides air services and air traffic control (Air Services Australia), another organisation that investigates aviation safety occurrences (ATSB), and many business entities that provide airport services and aircraft maintenance. The HFACS model cannot distinguish between these agencies making it impossible to determine which organisational factors present in the accident related to which aviation agency.

The *outside influence* category was added to the HFACS to capture any influence on the accident from organisations that were external to the flying organisation. *Outside influence* codes could reflect an individual *unsafe act* or *unsafe supervision* or an *organisational influence*, but because it is associated with a person outside the flying organisation it is coded as *outside influence*.

The ATSB identified the following factors of outside influence.

- ***Maintenance issues***: includes any actions by maintenance personnel (both employees of the flying organisation and employees of contracted maintenance organisations) that contributed to the accident.
- ***Airport/ airport personnel***: this category includes instances of inadequate runway/landing area maintenance, inadequate provision of information about the runway/landing area conditions, inadequately securing the landing area. Airport personnel include airport management, maintenance personnel, drivers of airside vehicles, and ground crew.
- ***Regulatory influence***: this includes occurrences where aviation rules and regulations had an impact on the accident.
- ***ATC issues/ actions***: includes occurrences where an aircraft was cleared to the wrong runway, there was an error in the provision of a clearance, breakdown in co-ordination, or inadequate air traffic service was provided.
- ***Other person involvement***: includes the involvement of passengers on the flight, meteorological personnel, and personnel from other institutions with a role in aviation.

APPENDIX B: ASSOCIATIONS BETWEEN HFACS FACTORS

Table 11: Observed and expected frequencies for Log-linear model of *unsafe acts*

Skill-based error	Decision error	Perceptual error	Violation	Observed count	Observed per cent	Expected count	Expected per cent	Residuals	Standardised Residuals
Yes	Yes	Yes	Yes	3	0.10	3.11	0.10	-0.11	-0.06
			No	10	0.20	13.73	0.30	-3.73	-1.01
		No	Yes	34	0.80	37.80	0.90	-3.80	-0.62
			No	240	5.80	232.37	5.60	7.63	0.50
	No	Yes	Yes	1	0.00	0.88	0.00	0.12	0.13
			No	26	0.60	22.33	0.50	3.67	0.78
		No	Yes	32	0.80	27.96	0.70	4.04	0.76
			No	981	23.60	988.79	23.80	-7.79	-0.25
No	Yes	Yes	Yes	4	0.10	4.12	0.10	-0.12	-0.06
			No	10	0.20	6.04	0.10	3.97	1.61
		No	Yes	15	0.40	11.00	0.30	4.00	1.21
			No	172	4.10	179.84	4.30	-7.84	-0.58
	No	Yes	Yes	4	0.10	3.90	0.10	0.10	0.05
			No	29	0.70	32.88	0.80	-3.88	-0.68
		No	Yes	23	0.60	27.24	0.70	-4.24	-0.81
			No	2571	61.90	2563.01	61.70	7.99	0.16

The associations can be dissected by examining cross tabulations and odds-ratios.

The model fit was acceptable and the residuals were consistent throughout the entire table (Table 11). Aside from the cases where no *unsafe acts* occurred, the most common *unsafe acts* were *skill-based errors* alone (981), *decision errors* alone (172), and combined *skill-based* and *decision errors* (240). It is also of interest that *violations* frequently co-occurred with *skill-based errors*, *decision errors*, or a combination of both. Of the 93 *violations* that co-occurred with an *error* (*skill*, *decision* or *perceptual*), 81 of these *violations* co-occurred with a *decision error*, *skill-based error* or both.

Table 12: Chi-square analysis of *inadequate supervision* and *supervisory violations*

	Supervisory violations	No supervisory violations	Total	Chi-square	Significance
Inadequate supervision	2	85	87		
No inadequate supervision	6	4462	4468	22.8	<0.001
Total	8	4547	4555		

The relationship between *perceptual errors* and *skill-based errors* varied with the presence or absence of a *violation* (Table 13). When *violations* were absent, the presence of a *perceptual error* increased the probability of a *skill-based* error by two times. When a *violation* was present, a *perceptual error* reduced the chance of a *skill-based error* occurring.

Table 13: Three-way association of *unsafe acts*: *skill-based errors*, *perceptual errors* and *violations*

			Perceptual error		**Total**	**Odds ratio**
			Yes	**No**		
Violation	Skill-based error	Yes	4	66	70	0.3
		No	8	38	46	
	Total		12	104	116	
No violation	Skill-based error	Yes	36	1221	1257	2.1
		No	39	2743	2782	
	Total		75	3964	4039	

There were also two 2-way interactions: *decision errors* by *violations*, and *skill-based errors* by *decision errors* (Table 14). *Violations* had 7.8 times higher odds of occurring if there was a decisional error than if there wasn't a decision error. *Skill-based errors* had 3.6 times higher odds of occurring when there was a decisional error than when it was absent.

Table 14: Odds ratio of *decision error* and *violations* and *decision error* and *skill-based error*

	Decision error	**No decision error**	**Total**	**Odds ratio**
Violation	56	60	116	7.8
No violation	432	3607	4039	
Total	488	3667	4155	
Skill-based error	287	1040	1327	3.6
No skill-based error	201	2627	2828	
Total	488	3667	4155	

Evaluation of the Human Factors Analysis and Classification System as a predictive model