Psychological Strain Mediates the Impact of Safety Climate on Maintenance Errors

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Abstract

Maintenance errors are known to be a key cause of aviation mishaps and the search for their causes is now given high priority in the aviation industry. In parallel with the search for causes, research efforts are also focusing on the ways in which various background factors link together to influence safety outcomes. The present study set out to validate a structural model wherein psychological strain is depicted as a major contributor to maintenance errors through the direct influence of strain on maintenance errors and also via its role as a mediator of the effects of safety climate on errors. The Maintenance Environment Survey (MES: Fogarty, 2004) was administered to 150 personnel responsible for maintenance of a large military helicopter fleet. Structural equation modeling was then used to test the fit of the mediation model. The findings support claims that the effect of safety climate on errors is at least partially mediated by individual level factors, such as psychological strain. In our efforts to secure better safety outcomes, we should therefore maintain a dual focus on organizational and individual level variables. Regular administration of safety climate and psychological health surveys can help to achieve this aim.

Psychological Strain Mediates the Impact of Impact of Safety Climate on Aviation Maintenance Errors

The growing literature on safety climate and the proliferation of instruments designed to measure safety climate (see Wiegmann, von Thaden, Mitchell, Sharma, & Zhang, 2003) point to the importance of organisational variables as background causes of error. The various error taxonomies used throughout the aviation industry (e.g., HFACS: Shappell & Wiegmann, 1997) emphasise the role of organisational as well as individual variables. From a more general perspective, following Reason's (1990) seminal publication on the bases of human error, descriptive models of accident causation suggest that individuals err because of latent organisational pathogens that create conditions wherein human weaknesses are unnecessarily exposed. Within the context of human error, it is now generally acknowledged that it is the interaction of organisational and individual variables that lead to error.

Having reached this point, researchers must turn their attention to teasing out the nature of this interaction. Structural equation modelling (SEM), a technique that combines factor analysis with regression analysis, is well-suited to this purpose because of its ability to accommodate both organizational climate and individual differences approaches. The present study employed SEM to cross-validate a structural model reported in Fogarty (2004) that depicts organisational factors as impacting on psychological health, which in turn impacts on maintenance errors. The rationale for the model is spelled out in the earlier publication. What follows here is a brief summary of the relevant literature and a description of the parts of the model that are to be tested in the present study.

Most safety climate studies have relied on regression techniques and bivariate correlations to demonstrate the existence of a relationship between safety climate and safety performance without attempting to explain the bases of the observed correlations. However, a small group of studies outside the aviation domain have used path analysis or SEM to address this issue. Two of these studies are of particular interest in the context of the present validation study. In the first of these, Tomas, Melia, and Oliver (1999) employed path analysis to examine the effect of safety climate on accidents. Contrary to their expectations, safety climate did not have a direct effect on workers' safety behavior. Instead, organizational variables influenced group processes (supervisors' and co-workers' safety response), "which in turn influenced workers' safety attitudes and behaviors, usually reported as the 'main' direct cause of accidents" (p.57).

In a second study, Oliver, Cheyne, Tomas, and Cox (2002) collected data from a wide range of industrial sectors in the Valencia region of Spain using structured interviews and employed SEM to test models depicting the influence of organizational and individual variables on accidents. They found that individual level variables, including safe behavior and general health, mediated the indirect effects of the organizational variables. Stress, in particular, was an important mediator of both organizational and environmental variables.

Working within an aviation maintenance context, Fogarty (2004) found support for a structural model that showed organizational factors influencing individual factors such as psychological health and morale, which in turn had an impact on self-reported workplace errors and job turnover intentions. Specifically, organizational factors accounted for 67% of the variance in a construct called Morale and 44% of the variance in a construct called (psychological) Health. The organizational variables did not have a direct effect on Errors or Job Intentions but they did have a significant indirect effect through Morale and Health. Morale, Fatigue, and Health, between them, accounted for 45% of self-reported maintenance errors and

27% of turnover intentions. The Fogarty (2004) study therefore supports the findings of these other researchers and demonstrates the relevance of the findings to the aviation industry. However, because the data were cross-sectional in nature and drawn from a single sample, it is important that the structural model developed by Fogarty be cross-validated. If it can be established that the primary influence of organizational variables is on the psychological health of the individual worker, rather than on errors per se, and if it can be established that individual factors have a direct link with errors, then we will have a better idea of the likely efficacy of interventions directed at different parts of the error chain. The primary purpose of the present study was to attempt this cross validation.

To provide the full context for the present study, the Fogarty (2004) model is reproduced in Figure 1.

Insert Figure 1 about here

For the purposes of the present study, the key parts of this model are those linking Climate with Health and Errors. Morale was included in the earlier study as a predictor of turnover intentions and it also made a contribution to the prediction of maintenance errors. However, both morale and turnover intentions are omitted in the present cross-validation study which was concerned primarily with the construct of psychological strain and its direct impact on errors and its role as a mediator of the effects of safety climate. In this model (see Figure 2) Recognition, Safety Focus, Supervision, Feedback, and Training were treated as aggregate variables (Gribbons & Hocevar, 1998) serving as reflective indicators of an underlying construct labelled Safety Climate (the same construct labeled as Climate in the earlier study). Stress and

GHQ were also treated as aggregate variables serving as reflective indicators of an underlying construct called Psychological Strain. Errors was treated as a single indicator latent trait that forms the main outcome in this study. In accordance with standard SEM practice (Jöreskog & Sörbom, 1989), the factor loading of the single indicator was set to 1.0 and the residual variance is set to (1-reliability)*variance. Finally, Psychological Strain is conceptualized as a variable that entirely mediates the influence of Safety Climate on Errors .

A competing model with a direct link between Safety Climate and Errors was also tested on the grounds that a significant direct pathway would rule out the possibility of full mediation.

Method

Participants

A total of 150 maintenance engineers (146 males) working at a major helicopter repair base for the Australian Army responded to the survey, representing a response rate of over 92%. The survey was targeted primarily at trainees (36.7%), tradespersons (33.3%) and supervisors (30%). The average age of the respondents was 30.5 years and most respondents (82.4%) had been working as a maintenance engineer or a trainee engineer for at least one year.

Materials

A slightly modified version of the Maintenance Environment Survey (MES: Fogarty, 2004) was used to measure safety climate. Modifications consisted of an additional item for the Supervision scale, a reduction of three items for the Training Standards scale, and an increase of nine items in the Error scale. The scales are described below under the headings of the constructs for which they were intended to act as markers. The Cronbach alpha internal consistency reliability estimates obtained from the present study are reported for each scale.

A. Safety Climate (MES scales)

1. Recognition for doing good work (5 items). This scale assessed the extent to which people feel that they are rewarded and recognised for doing good work. Sample item: In this job, people are rewarded according to performance. Alpha = .78.
2. Safety focus of the organization (5 items). This scale assessed the perception that the organisation has a strong concern for safety issues. Sample item: This unit regards safety as a major factor in achieving its goals. Alpha = .72.
3. Supervision standards (7 items). The items in this scale focused on the expertise of the supervisor and the extent to which the supervisor assisted the worker. Sample item: My immediate supervisor really understands the maintenance task. Alpha = .86.
4. Feedback on work performance (4 items). These items assessed workers’ perceptions of the amount and quality of feedback they received. Sample item: The quality of our work is rated or evaluated frequently. Alpha = .73.
5. Training standards and appropriateness (5 items). The items in this scale covered a number of different aspects of training, including adequacy of training for the job, encouragement to undertake further training, and opportunities for on-the-job training. Sample item: My training and experience have prepared me well for the duties of my current job. Alpha = .62.

B. Psychological Strain (MES plus GHQ)

6. Exposure to workplace stressors (9 items). The questions comprising this scale tapped the actual feelings and consequences of stress, rather than background factors that might be causing the strain. Sample item: I get anxious when I work to strict deadlines. Alpha = .84.

7. Health. The abbreviated, 12-item form of the General Health Questionnaire (GHQ: Goldberg and Williams, 1988) was used. The GHQ explores four aspects of psychological health: somatic symptoms; anxiety and insomnia; social dysfunction; and severe depression. High scores indicate poor psychological health. Alpha = .88.

C. Outcome Variable (MES)

8. Maintenance errors (13 items). The revised MES included 13 questions that asked the respondents to indicate whether they made maintenance errors on the job. These included errors that they detected themselves and those picked up by their supervisors. Sample item: I make errors in my job from time to time. Alpha = .82.

All items, except for those involving the GHQ and the PANAS scales, employed a five-point (1-5) Likert scale format where 1 indicated strong agreement and 5 strong disagreement. High scores on all Safety Climate variables were desirable whilst low scores were regarded as desirable on Stress, GHQ, and Errors. [A copy of the version of MES used in this study can be found at http://www.usq.edu.au/users/fogarty/]

Procedure

The procedure was identical to that followed by Fogarty (2004). The survey was sponsored by Army Aviation Headquarters and survey forms were included in the pay envelopes of all maintenance personnel along with a covering letter explaining the purposes of the survey. To ensure anonymity, self-addressed envelopes were included so that the forms could be returned directly to the investigator. At the completion of the study, feedback sessions on the main findings of the study were conducted by the investigator and a research assistant.

Results

All scales, except for Training, had satisfactory reliability estimates with alpha estimates above .70 (Nunnally & Bernstein, 1994). The low reliability of the Training scale (.62) was not of concern given that it acted as just one of five markers for the Safety Climate construct. It could also be argued that the components of a training program are not necessarily correlated and should therefore be treated as an index rather than a scale (see Diamantopoulos & Winklhofer, 2001). SPSS (version 11.0.1) was used to calculate means, standard deviations, and scale intercorrelations. The results are shown in Table 1.

Summary Statistics and Correlations for MES Scales (N = 150)

Scale	M	SD	Correlations						
			1	2	3	4	5	6	7
1. Recognition	2.90	.52							
2. Safety Focus	3.58	.60	.25						
3. Supervision	3.59	.61	.32	.23					
4. Feedback	2.99	.48	.46	.29	.43				
5. Training	3.07	.64	.32	.29	.36	.52			
6. Stress	3.05	.59	-.32	-.36	-.20	-.31	-.32		
7. GHQ	1.94	.46	-.40	-.30	-.21	-.37	-.35	.60	
8. Errors	2.57	.57	-.05	-.27	-.06	-.09	-.11	.34	.25

Note. Correlations above ± .18 are significant at the .01 level

The bottom row of Table 1 shows the correlations of the Errors scale with all other scales. It can be seen that the only significant correlations involving Errors were with Safety Focus, a Safety Climate marker, and the two Psychological Strain variables, Stress and GHQ. It can also be seen that the Safety Climate variables were all correlated with both of the Psychological Strain markers. These findings support those reported by Fogarty (2004) and are in keeping with the proposition that safety climate acts primarily on the psychological health of the individual workers and that psychological strain is a primary determinant of maintenance errors. This proposition is tested in the next section by using path analysis.

Maximum likelihood procedures from Version 5.0 of the AMOS structural equation modelling (SEM) package (Arbuckle, 2003) were employed to test the hypothesized model of the relations among the MES variables. Because of the unfavourable ratio of free parameters to cases, a partially aggregated model (Gribbons & Hocevar, 1998) was used wherein subscales represented the various first-order constructs in the conceptual model. Three fit indices are reported. The first is the traditional χ^2 goodness of fit test where *p* values above .05 can be taken to indicate good fit. One incremental fit index was used; the comparative fit index (CFI: Bentler, 1990) which is considered to be reasonably robust against violations of assumptions and where a value above .95 was considered to indicate satisfactory fit. The third index used was the root mean square error of approximation (RMSEA: Steiger, 1990), which indicates the mean discrepancy between the observed covariances and those implied by the model per degree of freedom, and therefore has the advantage of being sensitive to model complexity. A value of .05 or lower indicates a good fit and values up to .08 indicate an acceptable fit (Kline, 1998).

A test of the path model shown in Figure 2 yielded acceptable fit indices with χ^2 (19, N = 150) = 23.29, *p* = .23; CFI = .98; RMSEA = .04. The model predicted 39% of the variance in Psychological Strain 15% of the variance in Errors. All factor loadings and regression pathways were significant. A second model with a pathway from Safety Climate to Errors was also fitted. However there was no improvement in model fit and the direct pathway was not significant. Accordingly, the more parsimonious model is the preferred solution.

Figure 1. Fogarty's (2004) model depicting interactions among Climate, Morale, Health, Fatigue, Turnover, and Errors

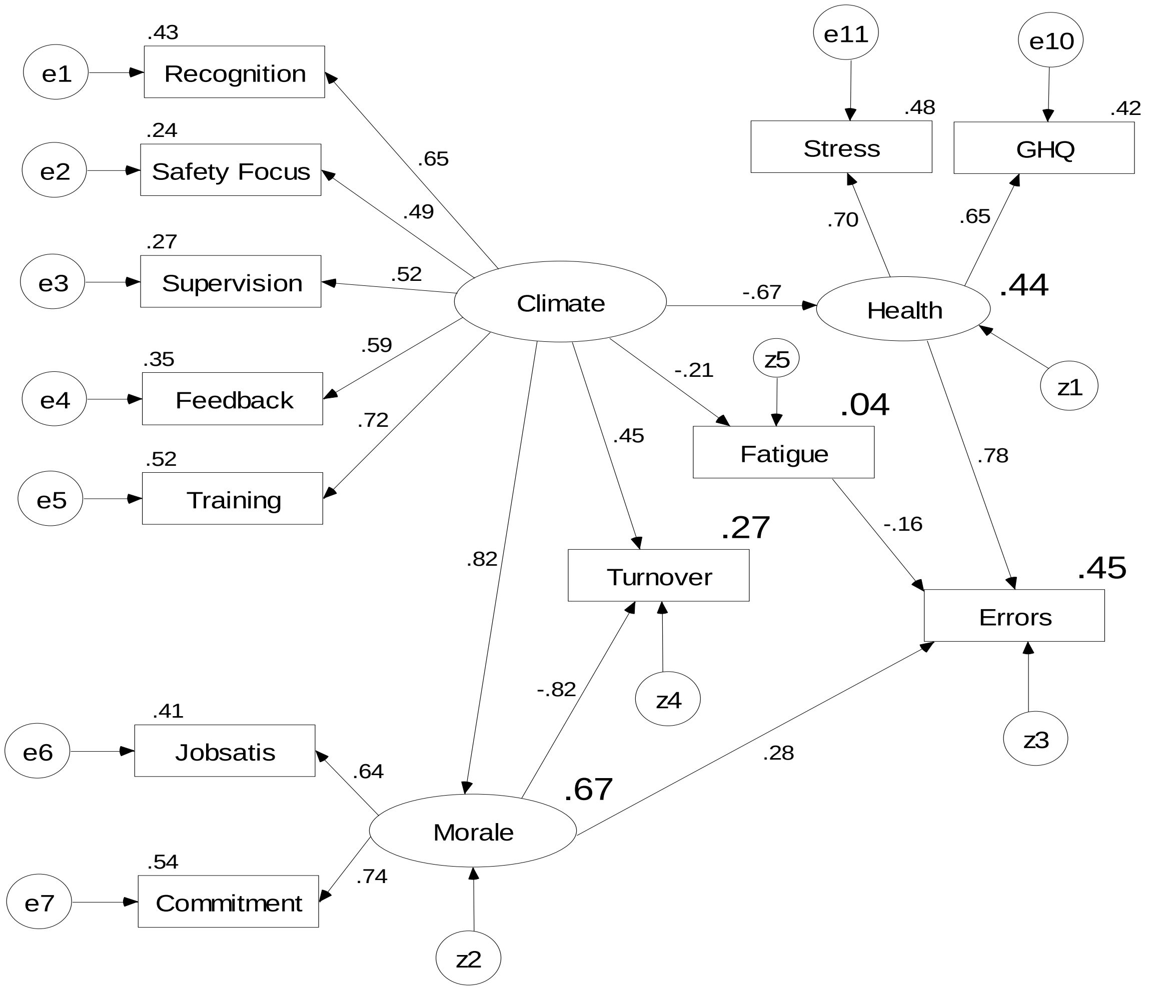
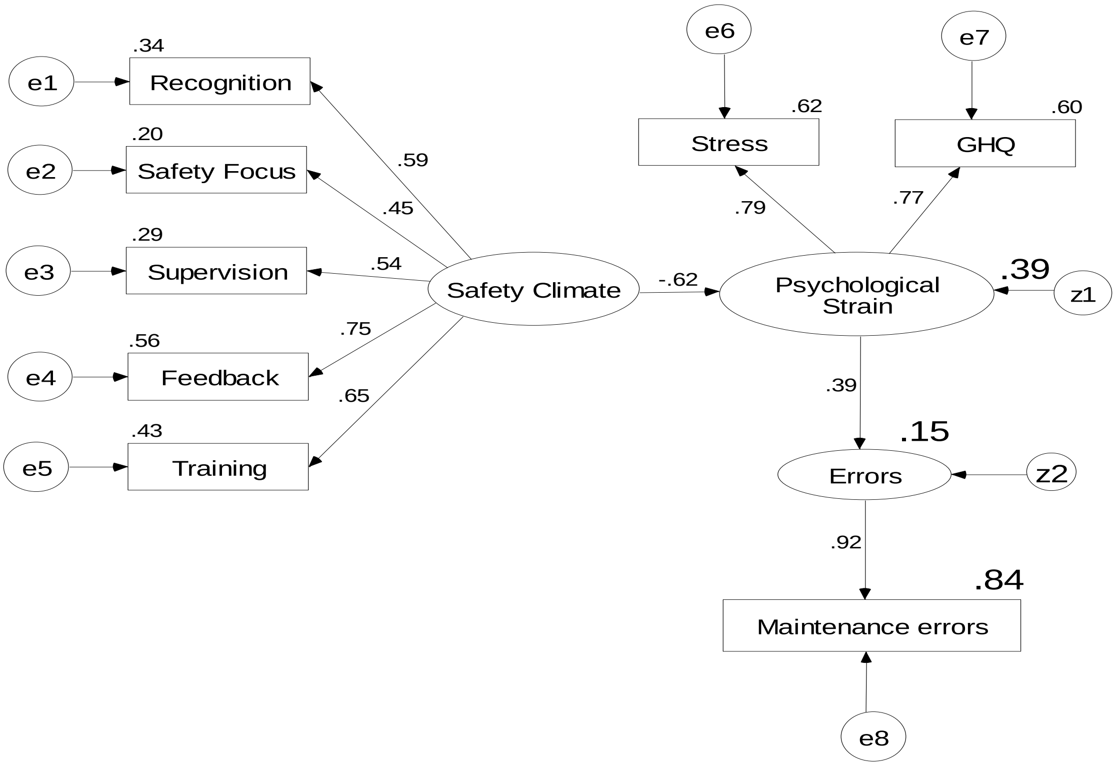


Figure 2. Model depicting interactions among Safety Climate, Psychological Strain, and Errors



Discussion

The main aim of the present study was to test Fogarty's (2004) proposition that the link between safety climate and errors is mediated by psychological health and to confirm the important role of psychological strain in particular as being among the immediate causes of maintenance errors. The study was successful in these aims. The bivariate correlations reveal a significant association between safety climate and psychological strain and a further significant association between psychological strain and maintenance errors. The path model establishes that the linkage between safety climate and errors is a mediated one.

These results replicate the Fogarty (2004) findings and support claims by researchers working in other high risk industries (Oliver et al., 2002; Tomas et al., 1999) that organizational and individual level variables cannot be regarded as having additive effects on safety performance. As other researchers have asserted, many errors result from interacting causes involving physical, cognitive, social, and organizational factors. To understand this interaction requires a model of how the components of the system work together to influence outcomes. The model tested in the current research program is conceptually driven and already validated on a military population (Fogarty, 2004). Its cross-validation in the present study suggests that we have a way of measuring and quantifying some of the main sources of error.

The implications of these findings are spelled out in Fogarty (2004) but I will summarise them again here. The demonstration of indirect links between climate and errors (via psychological strain) suggests that the mere presence of unfavourable perceptions of organizational factors is not sufficient in itself to lead to errors. Unfavourable organizational conditions place pressure on the individual and when the individual begins to succumb to these pressures, errors begin to occur. From a management perspective, it is therefore important to monitor both safety climate and individual health variables on a regular basis to ensure that there are no problems of this kind developing. Studies such as the present one therefore lend strong support to initiatives designed to measure climate and individual health (e.g., Wiegmann et al., 2003; Cival Aviation Authority, 2003). Such measures will be even more useful if benchmark comparisons within and across organizations become possible (Mearns, Whitaker, & Flin, 2001).

Limitations and Future Research Directions

In closing, it is important to recognize the theoretical and methodological shortcomings of the approach followed in the original Fogarty (2004) study and, hence, in the present validation study. From a theoretical point of view, it could be argued that the set of markers used for Safety Climate in the present study was not truly representative of the safety climate construct and that a different set of variables may define a factor that is directly related to errors. The earlier paper justifies the selection of marker variables but it is certainly true that this proposition needs to be tested. The fact that Safety Focus was correlated with Errors in the present study ($r = -.27$, $p < .01$) is an indication that some aspects of climate may have a direct relationship with errors. In ongoing research, we are extending the error scale in an attempt to capture the various dimensions of this construct and to search for evidence of direct links between organizational variables and specific types of error.

A further limitation of the current research program is that it is confined to the military environment. Maintenance engineers working in this setting face some challenges (e.g., demands of military duties) that are not faced by those working in commercial settings. The converse also holds true. It is also possible that military settings impose a uniformity of working conditions not found in the commercial environment. If safety climate is reasonably uniform throughout an organization such as Army Aviation, the consequent restriction in range will have the effect of suppressing correlations with other variables. The model therefore needs to be tested in different organizational settings. Against this criticism, it must be noted that there was sufficient variability in the safety climate construct in both of these studies to enable it to account for a significant proportion of the variance in psychological health.

Conclusion

There is also still much work to be done in identifying the contributors to both psychological health and errors. The restricted model tested in the present study explained 15% of the variance in errors. The Fogarty (2004) study included morale and fatigue as additional predictors and succeeded in capturing 45% of the variance in errors. The aim of the present study was to clarify the pathways by which organizational and psychological variables contribute to errors, rather than to maximize the prediction, but we should not lose sight of the fact that both aims are important. When the predictor space has been well defined using these self-report measures of error, the challenge will then be to see if these findings can be applied to real-life measures of error gathered in actual work settings. A growing number of studies examining the relationship between psychological variables such as stress and actual accident data (e.g., Fogarty & Shardlow, 2004; Hoffman & Stetzer, 1996; Zohar, 2000) suggest that this will be the case and that we already have a good platform for designing interventions that will assist in error reduction.

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Figure 2. Model depicting interactions among Safety Climate, Psychological Strain, and Errors