Modelling Errors and Violations in High-Risk Industries

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Abstract

The present paper summarises a series of studies aimed at identifying the individual and organisational factors that contribute to aviation maintenance errors, violations, and reporting behaviour. The first study in the series concentrated on errors. The second study was essentially a replication of the first study with some minor extensions to the predictor set and refinements to the criterion variable. The third study introduced an additional criterion variable called violations and a variable that we labeled willingness to commit violations. The implications of our findings are discussed in the context of aviation maintenance and high risk industries in general.

Introduction

Whenever the probable causes of aircraft accident are listed, maintenance-associated deficiencies invariably hold a prominent place. Rankin (1997), in examining the experience of the Boeing organisation, reported that improper maintenance contributed to 15% of commercial jet accidents. Based on Boeing's experience, Marx (1998) calculated that in the USA alone the number of commercial aircraft dispatched each year with a maintenance error was roughly 48,800. This rather alarming figure is tempered when the number of maintenance actions performed each day is taken into consideration; nevertheless, it is evident that maintenance is having an impact on flight not merely in terms of safety but also in operational costs.

Despite this, until recently, empirical research into the nature of maintenance incidents and their related human factors has been negligible. The literature tends to be dominated by descriptive models based on qualitative data, usually originating from accident reports. The present research programme represents a concerted effort to make up for our relative lack of knowledge concerning the causes of maintenance incidents. We will demonstrate that the area does lend itself to quantitative study and that the findings provide much-needed empirical backup for the popular models of accident causation.

Study 1

The first study (Fogarty, Saunders, & Collyer, 1999) was designed to explore the role of individual and organizational variables in maintenance performance. Specifically, the objectives of the study were to: a) examine a number of organisational, job and individual factors that were considered likely to impact on maintenance performance; b) explore the relations among these variables; and c) develop a model for predicting self-reported maintenance errors.

Following two phases of qualitative research incorporating analysis of an incident database and two series of focus group interviews, a survey methodology was used to develop a structural model linking predictor variables with self-reported errors. Because this study served as the platform for the three that followed, it will be described in some detail. The scales themselves were not always the same across the different studies, but the underlying constructs were essentially the same.

Participants

The survey was administered to Australian Army Aviation personnel working on aircraft maintenance. A total of 448 individuals responded, 95% of whom were male. In terms of work specialities, 11% were trainees, 41% tradespersons, 22% supervisors, 11% independent inspectors, and 15% in other categories. Median time spent in maintenance work was approximately five years.

Materials

A questionnaire was developed to measure a range of variables considered to be related to maintenance performance. The variables comprising the questionnaire, which we called the Maintenance Environment Survey Scale (MES), are described below.

- Rewards, Recognition. This variable assesses the extent to which people feel that they are rewarded and recognised for doing good work. Example: *In this job, people are rewarded according to performance.*
- Physical Conditions. Measures the quality of the actual physical surrounds of the workplace. Example: *The physical conditions make working here unpleasant.*

- Attitude To Safety. Assesses the perception that the organisation has a strong concern for safety issues. *Example: This unit regards safety as a major factor in achieving its goals.*
- Efficiency. There are many aspects to efficiency; here we looked at the tendency of the work units to emphasise improvement in work practices. *Example: In my unit, management actively supports our efforts to improve*.
- Training. 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. *Example: My training and experience has prepared me well for the duties of my current job.*
- Documentation/Procedures. Poor documentation is often cited as a reason for maintenance errors. Documentation refers to manuals, not log books or the like. *Example: Maintenance procedures are accurately described in our technical manuals.*
- Family Pressures. Maintenance personnel in the armed forces are often required to be absent from home. It was expected that the absences would result in personal strain, which may in turn affect work performance. *Example: The demands of my work interfere with my home and family life.*
- Stress. The questions comprising this scale tended to tap actual feelings and consequences of stress, rather than background factors that might be causing the stress. *Example: Workload pressures have at times affected the quality of my work.*
- Fatigue/Sleep. Given the difficulty of adequately assessing fatigue in a self-report measure, the questions in this scale focussed on the quality of sleep. *Example: My overall sleep quality is extremely poor*.
- General Health. The General Health Questionnaire (GHQ: Goldberg and Williams, 1988), an instrument already widely used in the armed services, was included as part of the survey of maintenance personnel. The GHQ explores four aspects of psychological health: somatic symptoms *(e.g., Have you been getting any pains in your head?)*; anxiety and insomnia *(e.g., Have you found everything getting on top of you?)*; social dysfunction *(e.g., Have you felt that you are playing a useful part of things?)*; and severe depression *(e.g., Have you felt that life isn't worth living?)*. An abbreviated, 12-item version of the GHQ was used here.
- Job Satisfaction. The questions in MES targetted the actual feeling of satisfaction, rather than why they might or might not feel this way. *Example: I like maintenance work.*
- Responsibility. When employees enjoy a sense of responsibility for their work, it is reasonable to expect that they will exercise more care and diligence. *Example: I feel I have little input into the decision-making at work*. (Reverse-scored item).
- Supervision. The quality of work supervision was brought forward as a problem in a number of our interviews with management in the early stages of this project. *Example: My immediate supervisor really understands the maintenance task.*
- Support from Coworkers. It is difficult to operate effectively in a work environment unless there is a feeling of support from one's colleagues. In the present instance, questions focussed on expectations that - if needed - workers would receive assistance from coworkers. *Example: Most of my workmates can be relied upon to do what they say they will do.*
- Feedback. Many maintenance personnel are in the early stages of their careers and still learning the trade. Their effectiveness is likely to be shaped by the amount and quality of feedback they receive. *Example: The quality of our work is rated or evaluated frequently*.
- Organisational Commitment. Again, interviews with management highlighted concerns with the level of organisational commitment in today's maintenance workforce. Such concerns were fuelled by the outsourcing of maintenance tasks, the mixing of civilians and service personnel in the same workplace, and a possible shift in values among service personnel. *Example: I am proud to tell others that I am part of this unit*.
- Turnover Intentions. One item asked about the job intentions of staff, whether they intended to keep working in the maintenance industry, leave the industry, or whether they were uncertain. High turnover leads to manpower shortages and greater pressure on existing staff to keep up with the workload.
- Errors. MES included four 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.

All items employed a five-point (1-5) Likert scale format where 1 indicated strong agreement and 5 strong disagreement.

Results

To establish whether the questionnaire succeeded in measuring the aspects it set out to measure, the items were subjected to factor analysis. As a result of these analyses, some items were discarded. The remaining items were used to form scales that in general conformed to those intended to be captured by MES. All scales had satisfactory reliability estimates (α > .70). Structural equation modelling (SEM), using version 4.01 of Arbuckle's (1999) AMOS program, was then employed to test models of the relations among the MES variables. A two-step approach was followed wherein a second order measurement model was derived from the composite variables followed by testing of a structural model linking the input and output variables. Without going into details of various competing models that were tested, a simplified version of the final model is shown in Figure 1.

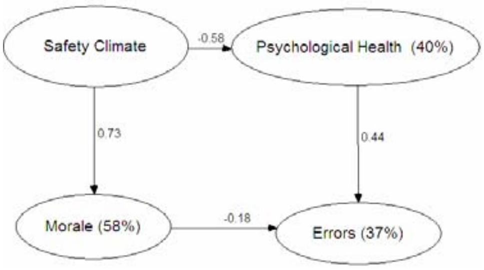

Figure 1. Effect of workplace climate on morale, psychological health, and errors (indicator variables not shown).

Fit statistics for this model were acceptable (χ^2, 74 = 152.07 .14, $p < .01$; TLI = .93; RMSEA = .04).

Discussion
Apart from the demonstration of strong links among the latent constructs and also the robust R-Square values, the main feature of this model was the lack of a direct pathway between climate and errors. Further discussion is deferred until the presentation of Study 2, which was basically a replication of Study 1.

Study 2
The Fogarty et al. (1999) study provided strong empirical support for a model that is implicit in the theories of Reason (1990, 1997) and embedded in a number of error taxonomies (e.g., HFACS: Shappell & Wiegmann, 1997). As such, the study represents an important contribution to the literature on human error. However, one limitation of the study by Fogarty and colleagues was the small number of items (4) used to construct the error scale. To improve this aspect of the design and to cross-validate the model obtained in Study 1, a revised version of MES was administered to a fresh sample of maintenance engineers (Fogarty, Saunders, & Collyer, 2001).

Participants
A total of 106 maintenance engineers (mostly males) working at one of two main helicopter repair bases for the Australian Army responded to the survey, representing a response rate of over 90%. Of the 106 respondents, 48% were tradespersons and 52% trainees. The average age of the respondents was 28.5 years and most (84%) had been working as a maintenance engineer for at least one year but less than four years.

Materials
A revised version of the Maintenance Environment Survey (MES), was used. The contents of the first version of MES (see Study 1) can be taken as a good guide to the scales included in Study 2.

Results
All scales had satisfactory reliability estimates ($\alpha >$ .70). Inspection of Pearson Product Moment correlation coefficients indicated that four of the organisational variables were related to the Error scale. The relevant variables were: Safety ($r = -.27$), Communication ($r = -.30$) Co-Worker Support ($r = -.33$), and Documentation ($r = -.21$). As expected, these correlations were all negative, indicating that low scores on these organisational variables were associated with high error rates. All three variables defining the Individual factor were correlated with Errors: Stress ($r = .38$), Fatigue ($r = .25$), GHQ ($r = .28$). As expected, these correlations were positive, indicating that high levels of stress, fatigue, and health problems were associated with high error rates. An abbreviated form of the full structural model is shown in Figure 2.

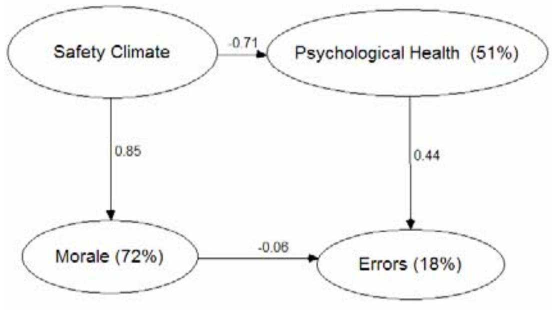

Figure 2. Replication of model showing effect of workplace climate on morale, health, and errors.

The salient points of the model were as follows:

- Fit statistics were again acceptable, thus cross-validating the model reported in Study 1.
- The link between Morale and Errors was not significant.
- The drop in R-Square value for errors was probably due to the fact that this sample of maintenance engineers was more restricted, consisting mostly of newer recruits who had only recently completed basic theoretical training.

Discussion
Taken together, the findings from these two studies support the claims of other researchers who point to the role that social and organizational factors can have on

human error (e.g., Reason, 1990). As these researchers assert, 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. We have provided such a model.

Study 3

The third study in the series introduced two new variables: willingness to violate and actual violations. The first of these variables was suggested by Ajzen's (1991) Theory of Planned Behaviour, a theory that attempts to explain the link between attitudes, intentions, and actual behaviour by examining the contribution of norms and the individual's perceptions of his or her control over behavioural options. The introduction of violations as a variable of interest in this research programme was in response to claims in the literature that violations are often immediate predecessors to errors (Reason, 1990; Lawton, 1998; Flin et al., 2000). Violations are also more amenable to change than errors which, by definition, are not intentional. It was hypothesized that willingness to violate would be influenced by safety climate and that willingess, in turn, would exert a major influence on actual violation behaviour. Violations were also expected to contribute to errors.

Method

The methodology was identical to that used in the first two studies. Some changes were made to the measurement scales for the Safety Climate construct. Otherwise, apart from the addition of the new variables, the model remained essentially unchanged.

Participants

A total of 307 maintenance engineers from the Australian Defence Force (105 Army, 86 from Navy, and 116 from the Air Force) responded to a revised Maintenance Environment Survey admininistered in conjunction with an in-house survey developed by the Directorate of Flying Safety of the Australian Defence Force. The combination of two surveys (209 items in total) resulted in a total testing time somewhere between 30-45 minutes.

Results

As was the case in the first two studies, exploratory factor analysis was used to establish the factor structure of the questionnaire and to confirm that hypothesized constructs were represented in the data. There were no problems in this regard and a simplified representation of the full structural equation model is shown in Figure 3. Fit statistics for this model were acceptable (e.g., CFI = .94; RMSEA = .05).

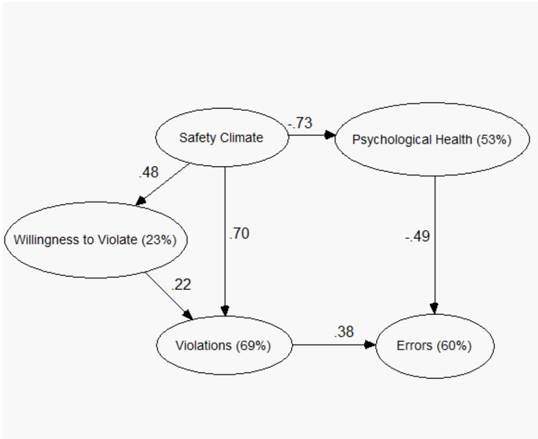

Figure 3. Model showing the precursors to errors and violations in aviation maintenance.

Discussion

Three features of the model shown in Figure 3 are worthy of comment. Firstly, violations appear to occur whether or not the individuals concerned are actually willing to commit these violations. Focus group interviews with respondents confirm this impression: they see themselves as often forced to work outside strict procedural guidelines because of resource shortages, work pressures, and the like. Interestingly, the interviews reveal that they do not see themselves as working unsafely when using these shortcuts, relying on their knowledge and skill level to achieve a safe outcome using non-standard procedures. McDonald et al. (2000) made a similar observation when noting that the impact of the organisation safety system is mediated by a professional sub-culture in which maintenance engineers see their role as not necessarily blindly following procedures but exercising their knowledge, skills, and professional values to enable them to maintain the overall safety of the aircraft.

A second feature of this model is the significant link between violations and errors, suggesting that – despite the above belief – violations are often a precursor to errors. The third feature is the further confirmation that the link between safety climate and errors is entirely indirect. This is now a well-replicated finding.

The finding that errors and violations have different origins is something that needs to be conveyed to practitioners in the safety industry. Too often these qualitatively different safety outcome variables are linked together as though they are indistinguishable. Indeed, some definitions of error include violations as a type of error. We reject that point of view entirely. Although violations are less under the control of the individual than we supposed at the outset of this research programme, they are nevertheless directly influenced by safety climate. Errors are also influenced by safety climate but only in an indirect way. Attempts to reduce error must therefore aim at both individual and organisational levels.

Conclusions

The safety literature tends to be dominated by discussions of error taxonomies and descriptive models of accident causation, such as that provided by Reason (1990). We see these contributions as valuable but we also believe that they must be supported by empirical research. Structural equation modeling is a technique that can be used to test nomological networks embedded in popular descriptions of accident causation. Through these three studies, we have developed, tested, and cross-validated a model that explains how errors can occur in safety-conscious industries. We have also shown how they are linked with violations. The basic model that we have presented is capable of elaboration and further testing. In ongoing research, we are seeking to extend the model to include incident reporting, another key variable in the quest to achieve safer and more productive working environments.

Acknowledgments

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