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# The development and validation of the Maintenance Environment Questionnaire

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## Introduction

Maintenance is the process of ensuring that a system continues to perform its intended function at its designed-in level of safety and reliability (Kinnison, 2004). Without the intervention of maintenance personnel, equipment used in complex technological systems such as aviation, rail transport, and medicine would drift towards a level of unreliability that would rapidly threaten safety and profitability.

Although maintenance makes an essential contribution to system reliability, the benefits of maintenance come at a price and ironically, maintenance is also a major cause of system failure. The rate of power station outages increases shortly after maintenance (Smith, 1992), maintenance quality is a major concern in the chemical industry (Kletz, 2001), and in aviation there is evidence to suggest that maintenance is contributing to an increasing proportion of accidents (Human Factors Programs, 2002). Furthermore, as automated systems become increasingly common, humans are generally assigned a reduced role as direct controllers of machinery, leaving maintenance as a major remaining point of direct interaction between humans and technology, where human capabilities and limitations can have a significant impact on system safety and reliability.

Obtaining information on maintenance human factors can be notoriously difficult. In many organisations, a punitive culture has discouraged open communication about incidents, and common errors (such as an unsecured oil filler cap) may result in several days without pay, or even instant dismissal. Furthermore, months or years may pass before a maintenance error is detected, making it especially difficult to identify the human factors involved in the events. In some cases investigators have been unable to determine the actions or even the individuals involved in a maintenance irregularity. Unlike pilots or controllers, the activities of maintainers are not recorded for later replay. In this paper we describe the development and validation of a questionnaire that was designed to collect information on maintenance human factors that would be otherwise unobtainable.

## Error producing conditions in the workplace

Although some workplace errors may reflect random variability in human performance, formal models of accident causation are generally based on the notion that errors are related to factors in the workplace (Reason, 1990; International Civil Aviation Organisation, 1993). Reason (1990) and others distinguish between local factors, present in the immediate work environment and higher-level organisational factors.

A relatively limited set of local factors have been associated with maintenance error. Schmidt, Figlock and Lawson (2005) found that the most common factors in a large sample of confidential maintenance incident reports were inadequacies in supervision, coordination, procedures, documentation, training/qualifications and design. Predmore and Werner (1997) asked senior airline mechanics to identify the challenges of their jobs. The most common answers concerned “dealing with people” and time pressures.

Hobbs and Williamson (2003) examined over six hundred maintenance incidents and concluded that the most common local factors were time pressure, equipment deficiencies, inadequate training, coordination breakdowns, fatigue, deficient procedures, and poor supervision. Each factor was associated with a particular set of errors and maintenance outcomes. Time pressure tended to provoke violations such as omitted functional checks, fatigue was associated with memory lapses such as unsecured cowlings, and training deficiencies were (by definition) associated with knowledge-based errors such as incorrect assembly of components.

**Information-gathering approaches**

Safety management systems typically draw on multiple complimentary sources of information including reactive and proactive systems to identify hazards and evaluate the effects of interventions..

A range of reactive investigation approaches can be used to gather maintenance human factors information. These include the Maintenance Error Decision Aid (MEDA) (Rankin & Allen, 1996) and the Human Factors Analysis and Classification System Maintenance Extension (HFACS-ME) developed by Schmidt, Schmorrow, & Hardee, 1998. Maintenance incidents are a potentially rich source of information, despite the difficulties referred to earlier; however, accident and incident databases rarely contain a sufficient number of incidents to provide statistically analysable information on human factors.

Opinion surveys can also be a useful source of safety information. Safety climate has been evaluated on the assumption that maintenance errors reflect high-level organisational characteristics such as process auditing and organisational risk management (Schmidt & Figlock, 2001). The attitudes of maintenance personnel have also been evaluated, in much the same way that attitudes to crew resource management have been assessed among airline pilots (Taylor & Christensen, 1998). The computer-based system Managing Engineering Safety Health (MESH), pioneered at British Airways, gathers information on local factors related to specific tasks (Reason, 1997).

A useful, but sometimes overlooked approach is to use everyday close-calls or minor incidents as the raw material of a safety evaluation system. Long ago Heinrich (1931) noted that for each industrial accident, there are typically hundreds of minor sentinel events. More recently, Helmreich and his co-workers have observed the everyday errors of line pilots as a way of evaluating safety performance (e.g., Helmreich, Wilhelm, Klinect, & Merritt, 2001). In most cases these incidents are resolved before they have any impact on operations, yet they can reveal much about everyday operations.

Self-report behaviour checklists have proven to be a valuable tool for cognitive psychology and safety studies. Checklists such as the Cognitive Failure Questionnaire (Broadbent, Cooper, FitzGerald, & Parkes, 1982) and the Driver Behaviour Questionnaire (Reason, Manstead, Stradling, Baxter, & Campbell, 1990) enable a large amount of data to be gathered on a range of everyday events, and permit naturally occurring behaviour patterns to be identified. Broadbent et al. found that respondents could provide consistent and reasonably accurate reports of their own behaviour. More recently, Burdekin (2004) has found that pilots can provide accurate self-assessments of their behaviour in-flight. Building on Reason's Driver Behaviour Questionnaire, Hobbs and Williamson (2000, 2002) developed a 48-item Maintenance Behaviour Questionnaire (MBQ), designed to explore patterns of unsafe acts in aircraft maintenance. Surveys returned by 1300 aviation mechanics revealed that events such as procedural violations, memory lapses, misunderstandings and incorrect assumptions were relatively common events in aviation maintenance. Importantly, the questionnaire demonstrated that maintenance personnel were prepared to disclose sensitive safety information via an anonymous survey.

**Development of the Maintenance Environment Questionnaire**

The Maintenance Environment Questionnaire (MEQ) was developed to meet the need for a tool to gather information on everyday incidents and near-misses in maintenance in a standardised form that can be statistically analysed to detect trends over time, and enable comparisons with industry norms. The MEQ is intended to supplement the accident and incident data typically gathered as part of a safety management system.

Although it shares some questions with the earlier MBQ, the Maintenance Environment Questionnaire (MEQ) is directed at local workplace conditions that promote unsafe acts, as well as defences designed to manage human-induced hazards. For the current purposes, defences were defined as system elements that are intended to detect maintenance errors. Examples are functional checks and independent secondary inspections. In contrast to the MBQ, aviation-specific terminology is not used in MEQ items, enabling the survey to be applied across industries. The questionnaire prompts the respondent to report the frequency of specific workplace situations using a five-point Likert scale ranging from "Every day" to through "Once a month" to "Never." The 36 questions contribute to eight scales. In addition to items addressing the strength of error defences, items relate to the local factors of: procedures, fatigue, coordination, supervision, equipment, time-pressure, and knowledge.

## Method

The MEQ has been administered anonymously to over 2000 maintenance technicians, including personnel who maintain airliners, military aircraft, rail rolling stock, and air traffic control facilities.

Table 1 displays the items that received the most frequent ratings by 1253 aircraft mechanics. The percentage figures refer to respondents who reported that the situation applied to them once a month or more frequently. As can be seen, the items reflect a range of local conditions, including time pressure, fatigue, equipment difficulties, procedure concerns and coordination breakdowns.

Table 1.
MEQ items with the highest frequency ratings expressed as percentage of respondents who reported the situation occurring once a month or more frequently

| **Item "At work in the last year, on average, how often have you":** | **%*** |
|---|---|
| Been asked to hurry a task. | 68.1 |
| Been interrupted part-way through a task to perform another more urgent task. | 60.6 |
| Performed maintenance tasks between 0200 and 0500 in the morning. | 56.0 |
| Not had enough time to adequately read the documentation before you started a task. | 56.0 |
| Had to rush an inspection. | 55.7 |
| Been delayed on a task because you could not obtain a consumable part (for example, an 'O' ring). | 55.3 |
| Had trouble concentrating because you were tired. | 54.8 |
| Found an error in a maintenance document. | 46.2 |
| Worked more than 12 hours in a 24-hour period. | 44.7 |
| Been delayed on a task because you could not obtain a major part (for example, a wheel or pump). | 44.1 |
| Worked more than two night shifts in a row. | 43.7 |
| Been unable to obtain a special tool or item of maintenance equipment. | 42.0 |
| Done a task a better way than that specified in maintenance documents. | 39.9 |
| Not been aware of maintenance activities done previously, when you needed to know. | 39.6 |
| Referred to an informal source of maintenance data (such as a personal notebook). | 37.9 |
| Had difficulty understanding a maintenance document. | 37.0 |
| Found that somebody else had already started a task you were about to do. | 36.8 |
| Corrected an error made by someone else, without documenting what you had done. | 34.1 |

* Percent of respondents reporting the issue as occurring at least once a month.

The main product of the MEQ is a profile illustrating the average responses on each factor scale, compared with either industry norms or previous administrations of the survey. Figure 1 illustrates results from a rail maintenance organisation alongside normative data from airline mechanics. As can be seen, in comparison to the airline mechanics, the rail maintenance personnel gave lower frequency ratings on questions dealing with error defences, fatigue and time pressure, but reported more frequent problems with procedures and equipment. When a local condition appears to be problematic on the basis of the profile, fine-grained comparisons can be made by referring to item profiles. Attachment 1 shows the responses to eight of the 36

MEQ items for the same sample of airline and rail personnel. The item profiles suggest specific areas where interventions could address error-producing conditions. For example, on the basis of these profiles, a rail maintenance manager may want to look more closely at the problem of non-approved data, and perhaps identify why workers are being interrupted part-way through tasks. In contrast, airline managers may need to address the impact of time pressures on task performance, and the length of duty days.

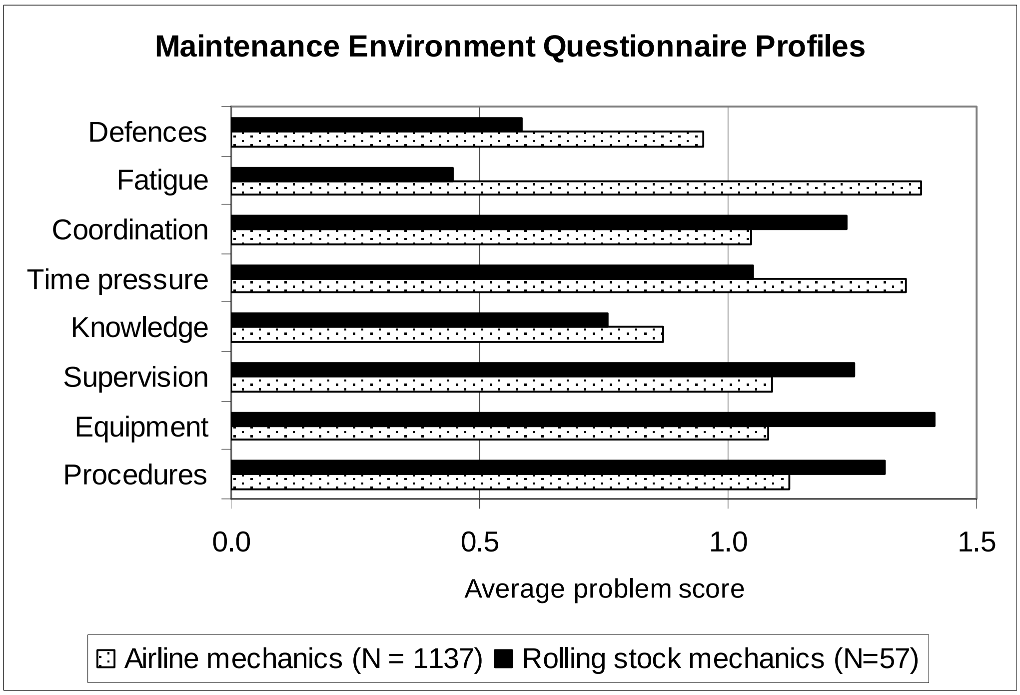
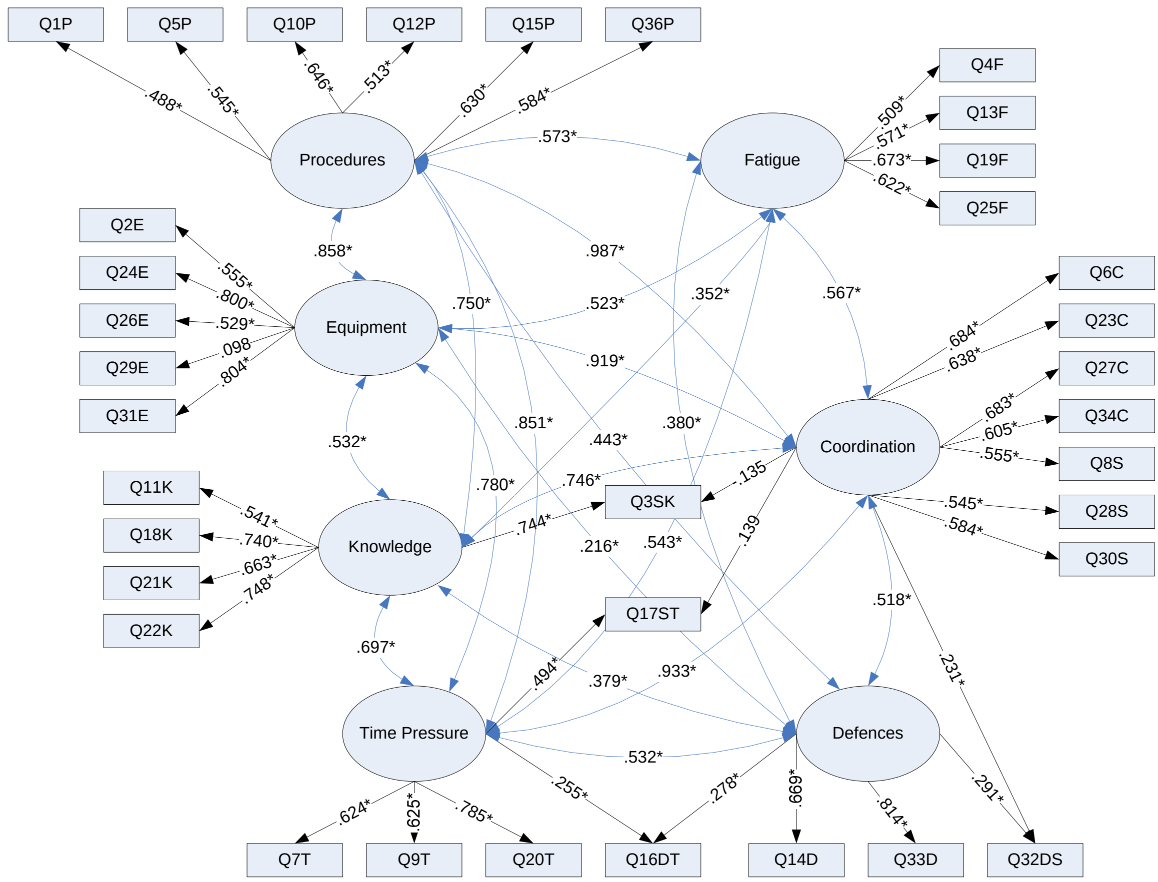



Figure 1. Example of maintenance environment questionnaire local condition profiles.

**Psychometric Properties**

To determine the reliability and construct validity of the MEQ, Cronbach's alpha and confirmatory factor analysis (CFA) were performed on the data collected in 2006 in English speaking countries. Because high correlations were found among coordination and supervision items during a preliminary analysis, supervision items were merged into the coordination scale. Nunnally (1979) considers a Cronbach's alpha of .7 to be an acceptable reliability coefficient. Therefore, internal consistency measures were calculated for seven subscales and found to be satisfactory for all but the fatigue subscale. The fatigue subscale was composed of only four items, and three inter-item correlations were lower than .30, suggesting some items within this scale did not tap into the same dimension of fatigue. Cronbach's alpha for the seven subscales were as follows: defences ($\alpha$ = .71), fatigue ($\alpha$ = .69), coordination ($\alpha$ = .83), time-pressure ($\alpha$ = .78), knowledge ($\alpha$ = .81), equipment ($\alpha$ = .77), and procedures ($\alpha$ = .76).

CFA offers researchers a viable method of evaluating construct validity. Unlike exploratory factor analysis, CFA allows explicit testing of hypotheses concerning the factor structure of the data due to having the predetermined model specifying the number and composition of the factors. The seven-factor model was tested using SYSTAT and produced loadings of over 1.0 on a few items hypothesised to be addressing two underlying constructs. By reducing the model to a simpler structure, the model produced loadings within a permissible range. The overall fit of the resulting model was reasonable, $\chi^2(535, N = 262) = 1136.537$, $p < .001$, RMSEA = 0.066 with a narrow 90% confidence interval of (0.060, 0.071). All of the loadings were statistically significant except two items, Q3 and Q17, which were loaded on both knowledge and coordination scales (see Figure 2). It appeared that although they were good indicators of knowledge and time pressure, respectively, they were not good indicators of coordination.  In addition, some factors were moderately to highly correlated with each other, suggesting that these constructs are not independent.




*p < .05

Figure 2. Path diagram of the seven factor model of the MEQ.

## Conclusions

Maintenance error is a persistent contributor to accidents and incidents in a range of industries. The errors and violations that lead to serious consequences may reflect longstanding system problems that can be identified before they have an opportunity to cause harm.

The MEQ was developed to evaluate the prevalence of key error-producing conditions as an adjunct to other sources of information such as incident investigations or organisational climate surveys. In some cases, the specific MEQ item may appear trivial, such as using an unserviceable piece of maintenance equipment, or referring to an informal personal procedure; however, these apparently routine violations may point to wider system problems in the conduct of maintenance. The MEQ is focused on conditions in the worker’s immediate work environment, without delving into the wider organisational or cultural issues that create these conditions.

MEQ results from a range of industries have demonstrated that errors and routine violations are pervasive, and in some cases, normal aspects of maintenance. We now know for example, that more than 50% of airline mechanics have cut short a functional check at least once in the previous year, that the use of personal “black books” is widespread, that many tasks are performed without reference to procedures, and that maintenance personnel often face obstacles to obtaining the necessary parts and tooling to perform their assigned tasks. The window on maintenance that the MEQ provides enables us to see that maintenance-related accidents (although thankfully rare) often involve actions that occur regularly in normal maintenance activities. Yet in the wake of a major accident, otherwise unremarkable actions may appear to be extreme or even sinister misdeeds.

The data collected so far indicate that many maintenance error-producing conditions such as shortages of spare parts and time pressures, have widespread applicability in a range of industries. Each issue is likely to promote a particular cocktail of errors and violations. Management does not have the power to directly control every action and decision made by maintenance personnel. Identifying and modifying error-shaping factors in the workplace however, is a more achievable goal, and doing so may lessen the chances of incidents. For example, reducing the incidence of equipment deficiencies may address the root causes of some rule violations or workarounds; addressing fatigue may reduce the probability of memory lapses such as tasks left incomplete; while attention to coordination and communication may lessen the frequency of the false assumptions and misunderstandings that lead to many maintenance incidents (Hobbs and Williamson, 2003; Hobbs and Kanki, 2003).

The reliability analysis and the CFA provided support for the factor structure of the MEQ, with some qualifications. A preliminary analysis determined that the factors supervision and coordination were not distinct constructs. At a theoretical level, these two factors are highly related, so it made sense to combine them into a single scale of “coordination”, which includes supervisory issues. Within the resulting seven-factor structure of the MEQ, there remained high correlations between coordination and the scales of procedures, equipment and time pressure. It appears that coordination may represent an overarching construct that influences these other scales. At a practical level, for example, it is likely that poor coordination during the planning of a task could result in time pressures during its execution. So while acknowledging that a hierarchical relation may exist between these factors, there are practical reasons to treat them as separate constructs in the MEQ. In future, it may be appropriate to remove some coordination items, given that the scales of equipment, procedures and time pressure appear to be capturing certain aspects of coordination. It was also apparent that the fatigue factor possessed a lower than desirable internal consistency. Revisions to this subscale will be necessary, and the addition of one or two items that are related to the pre-existing items is likely to improve its reliability.

In conclusion, several cautions must be noted about use of the MEQ. The factor profiles produced from the MEQ are not intended to represent a precise evaluation of the state of the workplace, but rather are intended to provide a rapid “snapshot” of everyday maintenance activities to guide organisational interventions. Responses to survey items may be subject to biases, such as memory effects, a reluctance to report issues, language ability, or differences in the structuring of work across industries. In addition, maintenance quality lapses occur for a variety of factors, not all of which are captured by the MEQ. For these reasons, it would be inappropriate to see the MEQ as a complete maintenance error management system.

It is hoped that the MEQ will provide managers with a practical method to gather data on maintenance human factors across a range of industries. As data collection continues, the questionnaire is already being used to benchmark organisational performance, identify priorities for interventions, and provide a standard method to evaluate interventions.

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***Attachment 1***

At work in the last year, on average, how often have you: