Abstract
This paper introduces the issue of maintenance error, considers the issue of Human Factors in Rail maintenance and inspection. This paper describes a guidance package (a novel web-based human factors support tool) which is available for implementation by train maintenance personnel to improve train maintenance human factors. It is recognised that maintenance error can have a significant impact on safety and therefore the guidance should help to improve overall railway business performance.

Introduction
Maintenance and inspection procedures are largely dependant on humans and although no one intends for errors to happen, psychology informs us that by nature humans are prone to error and it is inevitable that mistakes will be made from time to time. Train maintenance is particularly vulnerable to error because the work is often complex, involving the frequent removal and replacement of a variety of components. Certain tasks also require high levels of vigilance and skill to detect faults that can be infrequent and difficult to spot. Train maintenance is also commonly performed in difficult working conditions and often under time pressure.

Indeed to Quote Jim Reason [1] ‘If an evil genius was given the job of creating an activity guaranteed to produce an abundance of errors they would devise something akin to maintenance work.’

Maintenance errors have been contributory factors in a number of high profile accidents across different industries. The rail industry is no exception, with the accident at Clapham (1988) where a signal failure and subsequent collision was caused by uncorrected poor practices by a signalling technician as a key example.

Errors in Maintenance and Inspection
Table one illustrates the types of errors that can occur in maintenance and inspection tasks.

<table>
<thead>
<tr>
<th>Error</th>
<th>example</th>
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</thead>
<tbody>
<tr>
<td>Omission error</td>
<td>a component or part is not installed or replaced</td>
</tr>
<tr>
<td>Incorrect action error</td>
<td>the wrong component/part installed or replaced; wrong check carried out</td>
</tr>
<tr>
<td>Not restored to operational state error</td>
<td>system not reactivated/deactivated</td>
</tr>
<tr>
<td>Procedural error</td>
<td>failure to carry out inspection</td>
</tr>
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</table>

Table 1: Examples of maintenance errors

Performance on maintenance tasks is heavily influenced by the design of the task and the design of the equipment being maintained. Equipment that is difficult to maintain, or components that can be incorrectly fitted will contribute to maintenance errors. Furthermore, equipment that is not error-tolerant in its design can lead to errors going undetected when they do occur. For example, if it is not possible to visually detect that an error has been made on a maintenance task then it is more likely to be missed during visual inspection.
Maintenance errors are mostly classified as latent failures when thought of in terms of safety. This means that the failure may not be revealed as an equipment, vehicle or system failure until some time after the maintenance error occurred (perhaps not until the equipment or vehicle has been in service for some time). The maintainer often does not directly see the consequences of their error but the effects of maintenance errors or unsafe acts are significant, impacting not only on economic performance but also more importantly on public safety.

**Developing HF Guidance for Train Maintenance**

Understanding maintenance errors has been the focus of considerable work, particularly in the context of Aviation [1] where formal requirements are specified for maintenance human factors [2]. While the importance of human factors for managing maintenance error is generally well understood, the specific application to train maintenance has not been widely researched.

To help the rail industry apply human factors (HF) to rail vehicle maintenance and inspection tasks, a guidance package has recently been developed on behalf of Rail Safety and Standards Board (RSSB). This guidance package is web based (see Figure 1) and provides an archive of HF good practice relevant to maintenance and a 3-step systematic approach to help identify HF issues and then decide upon and apply appropriate HF solutions.

The guidance package has been underpinned by a literature review and field research which has included:

- Identification of good practices using interviews and observations of railway maintenance work across a number of depots;
- Development of an HF framework to bring together HF good practice under a series of generic headings;
- Development of the evidence base for HF issues impacting on maintenance performance and their potential costs if these issues are left unaddressed (collection and analysis of both national and depot data);
- Development of the structure and content of the guidance package;
- Case studies where the guidance was applied to address live issues impacting on depot maintenance. Three of the case studies focused on the following issues at different depots and identified solutions to the issues:
  - Procedures to report work arising.
  - Tools and equipment used.
  - Inspection of critical pipe work under the rail vehicle for signs of damage and fatigue. The design of the rail vehicle made this difficult because the pipe work was housed between the bogie and chassis of the rail vehicle.
- Development of an electronic version of the guidance package;

![Figure 1: The web based toolkit](image-url)
• User testing of the guidance material, which has an intended audience of depot managers.
• Guidance revision and final reporting.

What the guidance package contains
The guidance package is aimed at anyone who has responsibility for managing maintenance operations and/or improving maintenance performance within rail vehicle maintenance depots. It is designed to help address the HF issues that can lead to increased occurrence of human error and poor maintenance performance. The guidance provides a systematic approach that seeks to apply HF knowledge using a 3-step process illustrated in Figure 2.

![Figure 2: 3 step systematic process for applying HF to maintenance operations](image)

This systematic approach seeks to apply HF knowledge at three clearly defined stages. If HF is not applied in this way and at each of these stages, it is less likely that planned intervention (to address an issue affecting maintenance performance, error or rule violation) will be successful.

For example, with consideration of the first step *identifying issues*, it is important that any incident and accident investigation considers the part that HF plays in accident and incident causation. This means understanding that human error is not a cause but in fact a consequence - the cause being a more specific HF issue within the work system such as poor lighting, inadequate procedures or time pressure.

If the role of HF is not understood in causation of regular error occurrence during maintenance work then a proposed solution to address an issue might be to simply re-train the maintenance personnel. However a more detailed investigation that considers the role of HF might reveal that the error was caused primarily by time pressure. This would shift the focus to reviewing the time allocated to complete the work and a more robust solution.

Tools to aid the application of the 3 step process for applying HF
The guidance package goes further than stating what is required; it also provides a series of tools to help those responsible to apply the 3 step approach. These include an event classification system, a maintenance personnel questionnaire, a decision making aid questionnaire, workshop templates, a human factors framework and a good practice guide on designing for maintainability. Each of these tools is described in more detail below.
**Step 1 identifying issues**

*Event classification*
An event classification system was developed, consistent with the principles of MEDA [3]. The use of this tool helps to create a more thorough approach to consider and record the part played by HF in incidents and accidents. Classifying incidents thoroughly and in more detail will ensure that knowledge acquired about incidents is consistent; making comparison between events easier and helping the identification of common trends.

*Maintenance Personnel Questionnaire*
Unlike the event classification tool the maintenance personnel questionnaire supports a proactive approach, identifying issues before they lead to events. This provides a method to seek maintainers’ views on the issues that might impact on their performance and also how their work might be improved. This enables potential problems to be identified early and then addressed potentially before they manifest as an accident. The following table provides some example questions.

<table>
<thead>
<tr>
<th>Communication</th>
</tr>
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<tbody>
<tr>
<td>1. Management are good at keeping me informed about changes to the workplace.</td>
</tr>
<tr>
<td>2. There is enough time for important communication at team briefings and shift handover.</td>
</tr>
<tr>
<td>3. I am regularly consulted about how my workplace might be improved.</td>
</tr>
<tr>
<td>4. It is easy to report to management about problems or issues that I encounter when carrying out work.</td>
</tr>
<tr>
<td>5. Management are quick to act on suggestions for improving how work is carried out (e.g. maintenance tasks, processes and procedures).</td>
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Table 2: examples of Maintenance Personnel Questions

**Step 2 Decision making process**

*Decision Making Aid Questions*
The Decision Making Aid Questions (DMA) provides a method to better understand and refine problems that emerge from the identifying issues phase (results from the questionnaire or incident investigation).

The questions have been designed to help the person responsible for tackling a maintenance issue consider the reasons why the problem might be occurring. They have also been designed to help scope an issue from a broad concern to a more specific HF issue. For example, an issue raised from the questionnaire concerning communication is validated as a genuine problem and scoped to a more specific issue, such as communication between teams at shift hand over. Table 3 provides some example questions. The questions within the DMA link directly to the archive of HF good practice contained in the package.
Communication

1. Are the media/method used to support the communication appropriate for the situation or environment, for example: If communication is verbal does it occur in a noisy environment?

2. Are maintainers kept informed about changes to the workplace?

3. Are maintainers provided with up-to-date information on any current issues that might be affecting their work?

4. Does management provide maintainers with feedback on how well they are doing, for example fleet performance?

5. Are management visible and available for communication?

Table 3: examples of DMA Questions

Workshop templates

The guidance package also contains guidance and advice on using workshops to further support the decision making process. The guidance package not only provides advice on conducting workshops; also detailed are two example workshop templates. These provide two different types of agenda to explore issues concerning a specific task (engine overhaul) or a more general issue (communication).

Each agenda outlines a series of steps beginning with how to introduce the workshop and the topic under discussion through to how to conclude the workshop and how to follow through on the outputs that have emerged from the workshop.

The benefit of the workshop approach is that it involves a cross section of maintenance personnel (managers and supervisors/team leaders and maintainers) deciding upon issues together and if appropriate discussing possible solutions.

Creating a facilitated forum, where maintainers have the freedom to discuss issues in a blame free environment, helps managers to understand why procedures are not always adhered to.

It also provides both managers and maintainers with a chance to put across their side of the story. For example, managers could clarify why they expected work to be carried out in a certain way and the rationale behind this expectation. Maintainers conversely could explain why adherence to working in this way was made difficult by factors not previously realised by management.

Step 3 Selecting solutions

HF framework & HF good practice archive

It has been recognised that HF addresses many different aspects of work, for example, the way work is designed, the way it is communicated and the work procedures that people are required to follow. For the purposes of the developed guidance, these different aspects have been made into a framework of nine key HF topics:

1. Task design
2. Work planning
3. Safety culture
4. Training and competency
5. Procedures and documents
6. Tools and equipment (including housekeeping)
7. Fitness to work
8. Environment
9. Communication
These topics are further sub-divided into more detailed sub categories, for example, communication is split into communication from management and communication between departments and teams. These topics and sub topics are used throughout the guidance, to provide categories for the classification system and to help develop the questions used in the questionnaire and a decision making aid. The framework is also used to provide the headings for an archive of HF good practices. This makes it easier to link identified HF issues such as poor communication at shift handover with potential solutions, for example, improving team briefings by:

- Formalising communication;
- Only presenting key information;
- Developing communication skills;
- Advising of the consequences of miscommunication;
- Using less ambiguous terminology;
- Providing an opportunity for feedback.

**Good practice in designing for maintainability**

A separate section is provided on designing for maintainability which introduces the need to consider maintenance task requirements early on in design stages to ensure better accuracy, safety and economy during maintenance and inspection work. Good practice in designing for maintainability is detailed, including:

- ensuring that the layout of the rail vehicle provides adequate space and access to components and systems;
- ensuring components subject to wear or greater probability of replacement can be easily inspected, accessed, removed and replaced;
- using common or standard replacement parts to improve future availability of spares;
- using common or standard layout of systems and components to reduce the likelihood of incorrect re-wiring;
- ensuring labelling is adequate (legible, easy to read and distinguishable) to support easy identification of components and systems;
- using quick fastening and unfastening mechanisms for regularly serviced items;
- using mistake proof fastenings;
- ensuring that maintenance requires standard tools so as to reduce the range of potentially expensive tools and equipment required;
- using built-in self-test and indicators to support easier and quicker identification and isolation of faults and problems;
- reducing the opportunity for contaminants to enter critical systems and damage electrical systems (swarf debris leading to a wrong side door failure for instance);
- reducing the opportunity for human error by eliminating or reducing the need for system adjustments;
- ensuring that the testing of live working systems comply with H&S regulations (reduce system testing with the engine running leading to improved air quality, for instance);
- providing a feedback loop from depots to manufacturers and infrastructure companies as to how the design of a rail vehicle makes their work more difficult.

**Toolkit validation**

To help validate and improve the guidance package it was piloted at four different maintenance depots around the country testing how well it helped those responsible for train maintenance to tackle HF problems.

A number of benefits were found to be associated with the application of the guidance package:
Applying the proactive questionnaire enabled one depot to identify an issue they were unaware was affecting the performance of their maintainers;

The facilitated workshop helped one depot to better understand why procedures for identifying and recording faulty components were not always adhered to;

One depot was helped to estimate the cost of not addressing a particular HF issue.

A number of additional general benefits from applying the guidance during the case studies included:

- Improved awareness of HF;
- Demonstration of management commitment;
- Encouragement of maintainer participation;
- Improved communication between management and maintainers;
- Development of practical HF solutions.

References

