HUMAN FACTORS GUIDANCE FOR MAINTENANCE

D. J Pennie and N. Brook-Carter Greenstreet Berman, UK
W.H Gibson, RSSB & University of Birmingham, UK

SUMMARY

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. Maintenance is also commonly performed in difficult working conditions and often under time pressure.

Maintenance errors have been contributory factors in a number of high profile accidents across different industries. The maritime industry is no exception, with the accident on-board Erika (2000) as a key example.

Attention to Human Factors (HF) is a proven way to enhance performance and reduce the risks of accidents and incidents. HF takes a human centred approach when considering the design and operation of the workplace. This helps to control the factors that influence and shape behaviour which can lead to error and rule violation.

Applying HF is not always straightforward and anecdotal evidence suggests that workplace interventions to address HF issues may not always be successful. To help the rail industry apply 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 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 is currently under review and is due to be published in the near future.

This paper introduces the issue of maintenance error, considers the issue of HF in maritime maintenance and inspection, describes the HF guidance package developed for the rail industry and then discusses how such an approach might be of benefit to the maritime sector. It also explores the issue of “designing for maintainability” which is using HF principles to improve the design or refurbishment of ships to make it easier for engineers to carry out maintenance.

NOMENCLATURE

M&I Maintenance and Inspection
HF Human Factors
RSSB Rail Safety and Standards Board
HSE Health and Safety Executive

1. INTRODUCTION

1.1 ERRORS IN MAINTENANCE AND INSPECTION

Maintenance and inspection procedures are largely dependant on humans and although no one intends for errors to happen, psychology informs us that by our nature humans are prone to error and it is inevitable that mistakes will be made from time to time.

Civil Aviation Authority (CAA) Safety Regulation Group (2002) [1] goes further stating:

“It is an unequivocal fact that whenever men and women are involved in an activity, human error will occur at some point”

Maintenance and inspection work 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. Maintenance and inspection work is also commonly performed in difficult working conditions, and often under time pressure. James Reason, a leading authority on human error, comments that 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 [2]. This is evidenced by the many ways in which error may occur, for example:

- Omission error (component/part not installed or replaced);
- Incorrect action error (wrong component/part installed or replaced; wrong check carried out);
- Not restored to operational state error (system not reactivated/deactivated);
- Procedural error (failure to carry out inspection).

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. Further, 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 as illustrated by these high profile safety critical events:

- 1988 Clapham Rail collision – signal failure caused by uncorrected poor practices by a signalling technician leading to a wrong-side failure of the signalling system (a disused wire was allowed to cause a short-circuit);
- 1988 Piper Alpha explosion – maintenance error led to the leak that caused the explosion, due to a number of technical and organisational failures;
- 1984 Union Carbide Bhopal – a cloud of toxic chemical was released as a result of operator error, poor maintenance and failed safety systems;
- 2000 Erika – a 25-year-old tanker which broke up and sank off the Brittany coast, causing one of Europe's worst ever oil spills - contributing factors included poor organisation of maintenance tasks and procedures, and rule violations within maintenance tasks.

As illustrated by these examples, it is not just the design of the maintenance and inspection tasks themselves which influence the likelihood of maintenance errors occurring; wider organisational issues can also have an impact on maintenance performance. These can include, for example, poor communication between the maintenance personnel and across the organisation, and inadequate systems to monitor and learn from maintenance errors. Cultural issues can also have an impact, for example, senior management failing to appreciate the importance of managing maintenance operations and allowing commercial pressures to affect the quality and robustness of maintenance work. Other factors which can influence maintenance performance include the environment in which maintenance tasks are performed, the suitability of equipment provided to carry out maintenance tasks and the adequacy of training and procedural documentation provided to support maintenance personnel.

1.2 HUMAN FACTORS, MAINTENANCE AND THE MARITIME INDUSTRY

Maritime, as with other safety critical industries, has established the significant role played by HF (otherwise termed a Human Element issue) in incident and accident causation. Rothblum [3] notes that 75-96% of maritime casualties are caused, at least in part, by some form of human error and identified one of the HF issues to be poor maintenance, which can result in a dangerous work environment, lack of back-up systems and crew fatigue from the need to make emergency repairs.

Maintenance, particularly where a ship is required to be out of service, can be subject to commercial pressures. This in turn can lead to time pressures and an increased likelihood of errors and violations and, although not the highest contributor, maintenance error has been identified as a causal factor in a number of shipping accidents [4]. In addition, there can be significant economic impacts from maintenance error, such as delays in operations, even if most instances of maintenance error do not lead to injuries or loss of life.

Awareness of these issues has led to an increasing realisation of the influence that HF has on maintenance performance. Earthy and Sherwood-Jones [5] observed that the training of ship surveyors should include greater awareness of the human element (Human Factors) components of maintenance and ship maintainability (otherwise known as ease of maintenance) in order for surveyors to more effectively test ship procedures and equipment.

The Maritime industry is impacted by the generic HF issues common in other safety critical industries, for example, fatigue caused by poor shift scheduling. It also faces, however, other specific HF issues. These include communication and cultural differences between multinational crew members, the challenge of communication between on-shore and off-shore maintenance operations, training provision for off-shore maintenance engineers on equipment when they are frequently moved from ship to ship and spend long periods of time at sea, and the challenging environment in which maintenance is carried out on-board ships when at sea and a long way from port. The design of ships and ease with which they can be maintained is also a key issue. Not considering HF during the design or refurbishment of a ship could have a negative impact on future maintenance performance.

A recent CHIRP\(^\text{1}\) report [6] identified several issues associated with the provision of maintenance manuals,

\(^{1}\) Confidential Human Factors Incident Reporting Programme
including problems with the style and presentation and the lack of clarity of the documented procedures. This in turn can lead to an increased risk of human error or of seafarers adhering to their own ways and violating maintenance procedures. The importance of good manuals is particularly high in the maritime industry as seafarers will move from ship to ship and often encounter equipment with which they are not familiar. A further issue is the language in which the manuals are supplied, which may not be the native language of the seafarer.

There are therefore numerous HF maintenance and inspection issues within the maritime industry which can lead to errors and, potentially, incidents or accidents onboard ships. Many of the HF issues in maintenance and inspection are latent issues which can be addressed, but a systematic approach for identifying and addressing them is required. Attention to issues of maintainability during ship design is also fundamental.

1.3 LEARNING FROM OTHER INDUSTRIES

Any organisation involved in maintenance and inspection work should seek to understand and control HF issues to reduce the impact of human error and rule/procedural violations. Anecdotal evidence suggests, however, that although many industries and organisations understand the importance of controlling human error and rule violation, interventions may not always be successful.

This would imply that there is benefit in seeking guidance on how to better tackle the factors influencing human performance and, where applicable, draw upon advances and approaches made in maintenance and inspection HF within other industries.

Industries seen to be doing more to address HF maintenance issues include: aviation, offshore and onshore oil and gas, and nuclear. For example, the Civil Aviation Authority Safety Regulation Group publication CAP 716 [7] provides good practice regarding the training of maintenance personnel in HF issues and the factors that can lead to error and poorer maintenance performance, such as fatigue.

Useful approaches for managing maintenance error have also been developed by Health and Safety Executive (HSE), for example, ‘Improving maintenance a guide to reducing error’ [8].

Although the technical operations associated with the various safety critical industries can at times be quite different, the HF issues which influence operational and maintenance performance are frequently the same, and the techniques, methods and approaches for identifying and addressing HF issues are highly transferable. Further, the importance of learning from other industries is increasingly being recognised in the maritime industry, as is the benefit that sharing HF good practice knowledge across industries can bring.

2. DEVELOPING HF GUIDANCE FOR TRAIN MAINTENANCE

2.1 BACKGROUND

Significant work has been undertaken to understand and manage the HF issues affecting maintenance issues, for example, Reason and Hobbs 2003 [2]. Anecdotal evidence, however, suggested that rail vehicle maintenance had received less HF input in comparison with other sectors (aviation) or other areas of rail safety, for example: driver cab design.

The aim of the research project, commissioned by RSSB, was therefore to address this need by considering the HF issues impacting on Rail Vehicle M&I and then develop practical HF guidance to address these issues.

The overriding requirement was to deliver a:

“Useable and tested product that can be readily applied to M&I operations”

It is the belief that because this guidance was developed based on good practice from across safety critical industries it is therefore highly applicable to other sectors, including the maritime industry.

2.2 ACTIVITIES TO DEVELOP THE GUIDANCE

Importantly the work undertaken was conducted in close collaboration with a steering group representing the interests of the rail industry.

A number of key activities were undertaken to develop the guidance, for example:

- Identification of good practices using interviews and observations of work using contacts within the rail industry;
- 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 (applied the guidance using a paper version of the guidance to address live2 issues impacting on depot maintenance);

2 ‘Live’ issues are current key HF issues identified by the depots engaged in the research that are considered, by them, to impact on their maintenance performance.
• Development of an electronic version of the guidance package;
• User testing;
• Guidance revision and final reporting.

3. APPROACHES TO ADDRESSING HUMAN FACTORS IN MAINTENANCE AND INSPECTION

As mentioned above, part of the research to develop this HF guidance package included a literature review and interviews to identify HF good practice from within the rail industry and other industries.

From this review a number of key publications were identified and used to help develop the guidance.

The HSE publication 'Improving maintenance a guide to reducing error' [8] helped to develop the concept for the three stage structured approach.

HF good practice in maintenance and inspection was also developed with reference to the Civil Aviation Authority Safety Regulation Group publication CAP 716 [7]. For example, it provided good practice regarding the training of maintenance personnel in HF issues and the factors that can lead to error and poorer maintenance performance such as fatigue.

Most significantly, much of the identified HF good practice and HF approaches were derived from the interviews and observations with key personnel at different rail vehicle depots around the country.

One approach that was very popular and included in the guidance was called ‘Lean’. This was used by several depots to identify and eliminate wasteful practices during maintenance work.

Finally, attention to design for maintainability was recognised as a key issue from the interviews. Designing for maintainability seeks to reduce human error and improve performance by considering future maintenance and inspection requirements in the design of new equipment and by considering the ease with which maintenance tasks can be performed.

4. 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 package provides both an archive of HF good practice and a formal 3-step process to identify and tackle HF issues - illustrated in Figure 1. The guidance package also contains a number of tools to aid the application of the recommended approach.

4.1 A SYSTEMATIC APPROACH TO HF

Figure 1: 3 step systematic process for applying HF to maintenance operations

The 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.

The guidance package goes further than stating what is required; it also provides a series of tools to help those responsible to apply the recommended approach.

4.2 TOOLS TO AID THE APPLICATION OF HF

This section summarises the tools provided in the guidance.
4.2 (a) Event Classification System

An event classification system was developed, consistent with the principles of MEDA [8] (used in the aviation industry). This recommends that event investigators take a more thorough approach to find out what happened and consider the part played by HF rather than simply determining who made the error and then administering disciplinary procedures. 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.

4.2 (b) Maintenance Personnel Questionnaire

Improving event classification and understanding the role of HF in accident and incident causation enables a better understanding of events once they have occurred. This is a reactive approach but administering questionnaires can proactively identify issues before they lead to events. Within the guidance package a Maintenance Personnel Questionnaire is provided. Its aim is to seek maintainers’ views on the issues that might be impacting 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>
</thead>
<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>
</tr>
</tbody>
</table>

Figure 2: examples of Maintenance Personnel Questions

The guidance package also provides help and guidance on how to administer the questionnaire and how to interpret the results.

The benefits of applying this questionnaire were demonstrated during the case studies used to validate the guidance – see Case Study 2 in the case study section.

4.2 (c) Decision Making Aid Questions

One of the key outcomes from the research to develop the guidance package was that there was often awareness about HF issues but chosen interventions were frequently unsuccessful.

Often what is required is more time at the outset to explore an issue in more depth before applying a solution. The Decision Making Aid Questions (DMA) help to facilitate this by providing 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. The following table provides some example questions:

<table>
<thead>
<tr>
<th>Communication</th>
</tr>
</thead>
<tbody>
<tr>
<td>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?</td>
</tr>
<tr>
<td>2. Are maintainers kept informed about changes to the workplace?</td>
</tr>
<tr>
<td>3. Are maintainers provided with up-to-date information on any current issues that might be affecting their work?</td>
</tr>
<tr>
<td>4. Does management provide maintainers with feedback on how well they are doing, for example fleet performance?</td>
</tr>
<tr>
<td>5. Are management visible and available for communication?</td>
</tr>
</tbody>
</table>

Figure 3: examples of DMA Questions

The questions also link directly to the archive of HF good practice. Reference to this archive is recommended during decision making to derive a better understanding of why an issue might exist and what solutions might be applied to overcome it.

Guidance and advice on using workshops to further support the decision making process is also provided.

4.2 (d) Workshop templates

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.

4.2 (e) Human Factors Framework

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 guidance, these different aspects have been made into a framework of nine key HF topics, for example:

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 subdivided into more detailed sub categories, for example, communication is split up 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 DMA. The framework is also used to provide the headings for the 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:

- Advising of the consequences of miscommunication;
- Using less ambiguous terminology;
- Providing an opportunity for feedback.

4.2 (f) 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.

4.3 PRESENTATION OF THE GUIDANCE

In order to make the guidance package accessible to those responsible for managing maintenance operations and to ensure that it is easy to navigate and find information of interest, it was developed as an electronic...
application which will shortly be made available on the RSSB website.

The following screenshot provides an example of the appearance of the guidance.

![Figure 4: Introduction guidance overview](image)

The user can navigate through the guidance using either the internal links provided in the main body of the text or with the menu provided on the left of the guidance.

The menu has been developed to work in a similar way to ‘Windows Explorer’. This allows the user control to close or open as much or as little of the menu using the plus and minus symbols. They can also open a page by clicking directly on the menu.

![Figure 5: The navigation menu](image)

There are a number of benefits associated with providing the guidance package as an electronic application, for example:

- Easily updated - keep up-to-date with changes to rail vehicle maintenance and inspection routines;
- Improved navigation – direct links can be provided for relevant information within the guidance package;
- Better referencing – links to external relevant websites;
- Print out and keep tools provided (questionnaire, workshop template)

5. CASE STUDIES

Case studies involving a number of rail vehicle maintenance depots were used to validate the guidance by testing how well it helped those responsible for train maintenance to tackle HF problems.

Overall there was positive feedback from the depots taking part in the case studies and the guidance package was considered to be an effective way to help apply HF good practice.

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.

The case study visits were also used to develop a list of recommendations for the revision of the guidance, with the aim of making the guidance package more effective. Three of these case studies are detailed below.

5.1 CASE STUDY 1

5.1 (a) Issue

An audit had identified that there was an issue concerning the procedures to report work arising.
5.1 (b) Method

Maintenance personnel, team leaders and managers were interviewed using the process and tools provided in the guidance package. A workshop was then held with a cross section of the workforce to discuss the possible underlying causes of this issue.

5.1 (c) Key Outcomes

The interviews highlighted the critical role of the team leader and the inadequacy of current resource. Team leaders did not have the time to supervise their teams or complete paperwork because of the other demands on their time.

The case study also highlighted how maintainers were left to use their own discretion for reporting and recording work arising, with some relying on their memory.

5.1 (d) Recommended Solutions

- Review procedures for collating documentation and provide administrative support to reduce team leader workload;
- Review documentation (consider re-designing default recording sheets so they are fit for the purpose – delete obsolescent columns and provide more space for detailing the nature of the defect);
- Review the process for reporting and recording defects – identify the most appropriate method and formalise the procedure;
- Review and update the component cataloguing process.

5.2 CASE STUDY 2

5.2 (a) Issue

Administering the maintenance personnel questionnaire identified an issue concerning tools and equipment.

5.2 (b) Method

Maintenance personnel, team leaders and managers were interviewed using the process and tools provided in the guidance package. A workshop was then held with a cross section of the workforce to discuss the possible underlying causes of this issue.

5.2 (c) Key Outcome

The questionnaire proactively identified an HF issue which management had been unaware of and highlighted serious concerns with tools and equipment. For example, maintainers reported: “Not correct tools, tend to struggle all the time” “Tools and equipment are not up to standard” “Low quality tools” “Lack of proper equipment”. Following the results of the questionnaire, the issue was discussed with maintenance personnel and an audit conducted. This identified a number of areas for improvement.

5.2 (d) Implemented Solutions

- Calibrated equipment is clearly identified and labelled with its last calibration date;
- Record keeping of the use of calibrated equipment is now more comprehensive and rigorous;
- The tool request form has been revised;
- An improved storage facility for new equipment has been introduced;
- New shadow boards have been introduced;
- The stores manager conducts depot tours.

Following the implementation of these solutions, the questionnaire was re-administered indicating a reduction in concerns regarding tools and equipment.

5.3 CASE STUDY 3

5.3 (a) Issue

As part of the case study visits, a maintainer described how, as part of their job, they were required to inspect 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. Maintenance work could only be conducted to a desired standard if the bogie was removed.

5.3 (b) Implemented Solutions

The manufacturer was made aware of this issue and when the fleet was overhauled the location of the pipe work was changed. This made the inspection task much easier, reducing the opportunity for leaking of damaged pipe work to go un-detected.

6. DISCUSSION

The maritime industry, as with all other safety critical industries, is faced with the challenge of addressing HF issues concerning maintenance and inspection.

Working with RSSB to develop the guidance has clearly demonstrated that much HF knowledge and approaches derived from other industries, such as aviation, is directly relevant to the rail industry. It is likely therefore that such knowledge and approaches are equally applicable to the maritime industry.

There is also a clear advantage in using the knowledge and experience from other industries, particularly those industries which have considered the HF issues that impact on maintenance performance in depth. It would seem both practical and cost effective to take the
successful approaches and techniques derived elsewhere and then adapt them to suit maritime requirements.

In terms of the guidance package presented in this paper, it is possible to take the key framework issues described and show how they are equally applicable across other safety critical industries, including maritime, for example:

- **Task design** - ensuring ship design supports maintainability during both on-shore and off-shore maintenance activities;
- **Tools & equipment** - providing appropriate maintenance tools and equipment both on-shore and off-shore;
- **Communication** - supporting communication between on-shore and off-shore maintenance operations;
- **Procedures** - providing clear and usable procedures in the appropriate languages of all maintenance personnel;
- **Training** - ensuring staff, who are frequently at sea for long periods of time and being moved from ship to ship, are up to date with all relevant maintenance training;
- **Work planning** - identifying and managing issues of commercial pressure and placing priority on ship maintenance operations;
- **Safety Culture** developing a strong safety culture where it is not appropriate to violate maintenance procedures;
- **Fitness to work** – managing crew fatigue;
- **Environment** – addressing issues associated with the challenging environment due to possible outdoor working in inclement weather.

A key issue is designing for maintainability. The challenge is to ensure that maintainers’ requirements are considered during the design and construction of ships and shipping equipment with the aim of improving the ease with which maintenance tasks can be carried out and limiting the occurrence of maintenance errors. Ideally, the design should be error-tolerant, recognising that some predictable errors are difficult to prevent and that when they occur, the design is such that they can be easily detected and therefore recovered without unacceptable consequence. Alternatively the design can prevent unavoidable errors by recognising their likelihood and through the inclusion of a prevention measure such as interlocks.

In addition to the HF framework issues, it is also possible to see how there can be an advantage in applying adapted versions of the:

- **Questionnaire**
- **Classification system**
- **Decision making aid**
- **Workshop approach**
- **HF good practice**

Undoubtedly the application of the advocated systematic approach, to identify issues and develop solutions to tackle them, would also bring great benefits to individual shipping companies and to the industry as a whole.

There is no doubt that the maritime industry faces some particular challenges associated with ship maintenance and inspection work. For example, maritime maintenance is complex as some maintenance tasks will be carried out by seafarers whilst a ship is in operation. The hierarchical command structure on-board ships may in some cases be a barrier to worker consultation. It is also necessary to consider the overall maturity and awareness of HF in maritime maintenance. For example, is it necessary to do more to promote and sell the benefits of HF?

It may be important therefore to consider and address these additional challenges and possible obstacles prior to applying a similar HF approach.

A next step may be to develop the evidence base for HF issues impacting on maintenance performance in the maritime industry and the potential costs of these issues if they are left unaddressed. A similar case study approach could be used to help test and validate adapted HF guidance.

7. CONCLUSIONS

Maintenance error has been identified as a causal factor in a number of shipping accidents. The maritime industry, as with all other safety critical industries, could benefit from addressing HF issues in ship maintenance and inspection.

A breadth of HF issues, including task design, environment and organisational issues, has the potential to impact on maintenance performance. The maritime sector also faces specific challenges due to the nature of shipping and ship maintenance activities.

This paper has presented an approach developed for the rail industry for addressing HF in rail vehicle maintenance and inspection. The approach was developed based on good practice taken from other safety critical industries and has been demonstrated to effectively tackle rail vehicle maintenance issues.

Undoubtedly, the application of a similar systematic approach in the maritime sector to identify HF maintenance issues and develop solutions to tackle them would bring great benefits to individual shipping companies and to the industry as a whole. It is important to ensure that design for maintainability is considered in ship design.
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9. REFERENCES


10. AUTHORS’ BIOGRAPHIES

David Pennie is a Senior Consultant at Greenstreet Berman. He joined in September 2004 having previously worked at HSE where he provided technical information and support on a wide range of Human Factor issues. These included shiftwork and fatigue, mental workload, Work with Display Screen Equipment and Musculoskeletal Disorders. David has an MSc in Human Computer Interaction & Ergonomics from UCL and is a member of the Ergonomics Society and British Psychology Society. He is currently responsible for a range of Human Factors projects in the rail, nuclear and petroleum industries.

Nikki Brook-Carter is a Principal Consultant at Greenstreet Berman, where she is responsible for a wide range of Human Factors projects and has over 8 years experience in research consultancy across a range of transport sectors. Nikki recently managed an MCA research project investigating organisational structures in the Maritime Industry and has worked in the rail industry investigating good practice in organisational issues, such as safety culture. Areas of interest include human performance, distraction, workload and impairment, as well as alarms and alerts and more generally the safety and usability of interfaces. Nikki has an MSc in Human Computer Interaction with Ergonomics, a BSc in Psychology, and is a Registered Member of the Ergonomics Society.

W.H Gibson works for the Rail Safety and Standards Board Human Factors team and part-time at The University of Birmingham. Huw’s research interests particularly relate to human errors and human reliability in transportation. Huw has an MSc(Eng) in Work Design and Ergonomics, a PhD in Air Traffic Control communications, and is a Member of the Ergonomics Society.