

IMPROVING MAINTENANCE BY REDUCING HUMAN ERROR

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1.1 EXECUTIVE SUMMARY

Human error in maintenance can impact on safety and performance in a number of ways. Poor repairs, for example, can increase the amount of breakdowns which in turn can increase the risks associated with equipment failure and personal accidents. The influence of the human factors associated with maintenance operations on safety was recognised by members of the Human Factors in Reliability Group (HFRG), however, only limited guidance was available for managers and engineers to identify the many issues which could detract from safe and reliable maintenance in their own organisation and assist in generating practical actions to reduce these problems. The HFRG initiated a sub-group of members with experience in this area and produced a managers' guide to reducing human error in maintenance operations. The guide identifies 18 important factors which need to be addressed and provides a methodology to identify key areas of concern among these factors. It also provides a number of practical suggestions for managers to use to improve the human factor aspects of their maintenance operations. It has recently been published by the Health and Safety Executive (HSE) and has value to the Aviation Industry.

This paper overviews this work and introduces further methodologies which can also be used to reduce errors in aviation maintenance and thereby promote safety. The author was involved in the development of these methodologies. They are all solution driven, and were developed to be used by the non-human factors specialists. Many were developed to specifically address maintenance issues, however, some are general purpose tools with applications in both maintenance and operational areas. These methodologies are summarised below:

1.2 BACKGROUND

Maintenance has a major relevance to the business performance of industry. Whenever a machine stops due to a breakdown, or for essential routine maintenance, it incurs a cost. The cost may simply be the costs of labour and the cost of any materials, or it may be much higher if the stoppage disrupts production.

A maintenance operator who is motivated, well trained, under no time pressure, given the correct information, and working with equipment which has been designed to be maintenance friendly, will likely complete all specified maintenance work to a high standard. However, the more these requirements are not met, the less likely it becomes that the maintenance work will receive the desired attention and short cuts in work methods become increasingly probable. As a result, equipment can become poorly maintained causing reduced reliability/availability or

direct damage to the plant. In turn, these consequences can increase the safety risk to the maintenance operator and also to other employees and the public.

As with most types of work, the scope for human error in maintenance operations is vast. These can range from becoming distracted and forgetting important checks to knowingly deviating from a permit to work procedure in order to save time or to get the job done in unexpected circumstances. Some types of human error can be so frequent that they almost become the accepted custom and practice. For example, fitters may have got into the habit of omitting final checks during a routine maintenance procedure. Other forms of human error may only occur rarely during exceptional circumstances. For example, crews may mis-diagnose the cause of a novel failure.

There are therefore a number of factors which influence the behaviour of maintenance crews and the likelihood of human error (eg references 1, 2, 3) and human error needs to be considered both in terms of its effect on safety of people and also in terms of its effect on damage to plant or equipment or reduced reliability and subsequent breakdown.

1.3 REDUCING HUMAN ERROR

It should be readily apparent that the solutions to address human error in maintenance will be very different for different types of error. Errors can be broadly considered in terms of the following three types (from Reason):

Slips & Lapses

A maintainer may be distracted or lose concentration and inadvertently undo the wrong hydraulic hose. He knew what he wanted to achieve, however, he makes a simple error in his actions. As he knew what should have been done, there is little advantage in further training. If the consequences of such an error are significant then the most effective action would be to eliminate the possibility of this happening by some form of design. Interlocks or fittings which can only fit one way can physically prevent this type of error.

Mistakes

If a rule or work procedure has been forgotten, or never fully understood, then a maintainer could make a wrong decision especially during a procedure with some novelty. In the above example, the maintainer knew what he wanted to achieve but failed to achieve it. With this general type of error the maintainer makes a mistake and chooses a wrong action. Training is obviously an important issue for reducing this type of error.

Violations

These are the most difficult area of human error to address. These are intentional deviations from maintenance procedures. Such decisions can involve a range of issues such as: the perceived advantages to the individual from a short cut; the risks of damage to plant and equipment if the work is not done or not done in the specified manner; the likelihood that the maintainer will be subsequently identified; and the time allocated to the job in relation to the time the job takes to fully adhere to the approved procedure.

There will therefore be a range of factors which influence the likelihood of maintenance rule violations. These can be divided into those which directly motivate the maintenance crew/individual to break agreed rules/procedures (termed direct motives) and supplementary factors which increase, or reduce, the probability of any individual deciding to commit a violation (termed behaviour modifiers). For example, avoiding heavy physical work may be a

direct motive for neglecting a maintenance task, however, a lack of effective supervision would be a behaviour modifier which increases the probability that the violation would occur as the chances of him being detected would be low.

These problems were being researched in some depth in a number of industries, and it became increasingly clear that the human factors of maintenance operations was a topic of growing interest in most industries and a topic whereby significant improvements could be achieved from even a limited consideration by engineers and management.

The author has been involved in the development of a number of human factor methodologies which have potential application in the field of maintenance. They are all solution driven, and were developed to be used by the non-human factors specialists. Many were developed to specifically address maintenance issues. These methodologies are summarised below:

Methodologies addressing design issues:

The ECSC Maintainability Design Guidelines

The Bretby Maintainability Index

Methodologies addressing the wider Human Factors issues:

The **HFRG** report on Improving Maintenance - A Guide to Reducing Human Error

The HFRG report on Improving Compliance with Safety Procedures

The **HSEC** Ltd Human Factors Solutions CD-ROM

1.4 ERGONOMIC PRINCIPLES IN DESIGNING FOR MAINTAINABILITY

The European Coal & Steel Community report

A set of design guidelines were developed following a research project co-funded by the ECSC and the NCB. It was apparent that machinery entering the mining industry had insufficient attention given to features which made them 'maintenance friendly'. A review of the literature reveals major flaws in both the contents and presentation of available ergonomic guidelines.

One critical aspect of the available guidelines were that information was presented in a 'Maximum - Minimum' or 'Optimum' format. It was readily apparent that designers would seldom be able to meet these 'ideal' human factors requirements having taken into consideration the range of other demands on the product. A major problem was therefore apparent in that the designers would then have no idea whether his/her compromise had minimal or severe impact on the performance of the maintainer. It was decided to develop a set of guidelines which provided, as far as possible, the performance information to enable the designer to identify the nature of the performance decrement which could be expected if, say, the ideal access to certain fasteners was not provided. Much better trade-off decisions could therefore be made.

As a result a number of basic pieces of research had to be undertaken. The resulting guidelines provided performance related information on the following design issues:

1. Access requirements for tool applications - spanners/wrenches
2. Access requirements for tool applications - screwdrivers
3. Access requirements for manual tasks
4. Locating components in cavities for optimum maintenance access
5. Fastener choice - taking into consideration the maximum force application to tools
6. Manual lifting - taking into consideration the postures adopted by the maintainer

7. Manual lifting - implications for hatch cover design
8. Facilities for the use of powered hand tools
9. Fault diagnosis job aids
10. Labelling - reducing the potential for error
11. Mechanical handling - choice and location of lifting points

Further details can be found in reference 4 and an updated and shortened version of the guidelines can be found in reference 5.

1.5 THE BRETBY MAINTAINABILITY INDEX

As equipment becomes more complex and expensive, the consequences of machine failure become more critical. Industry has generally recognised this for some time and is striving to increase machine availability through improvements in machine reliability, as well as through improved planning. Although recent improvements in reliability have had some effect, until machines need no routine maintenance, designing "maintenance friendly" machinery is important if industry is to reduce these costs.

As maintenance can significantly reduce a machine's availability, engineers and designers ideally need quantitative information on the quality of the maintainability of complete machines. Existing maintainability indices (eg Dept of Defence, MIL-HDBK-472, or Society of Automotive Engineers, SAE J817a) are either excessively time consuming to use or are incomplete. The Bretby Maintainability Index (BMI) was developed to specifically overcome the limitation of the current indices. It was based on the SAE index, but extensively modified to make it time based, and much more comprehensive.

Its basic elements are shown below:

SECTION A: ACCESS

- | | |
|---------|------------------|
| Part 1: | Hatches & Covers |
| Part 2: | Apertures |
| Part 3: | Location |

SECTION B: OPERATIONS

- | | |
|----------|--------------------------|
| Part 1: | Removal & Replacement |
| Part 2: | Slackening & Tightening |
| Part 3: | Carrying & Lifting |
| Part 4: | Preparation |
| Part 5: | Fluid Compartment Checks |
| Part 6: | Component Checking |
| Part 7: | Lubrication |
| Part 8: | Draining |
| Part 9: | Filling |
| Part 10: | Cleaning |
| Part 11: | Adjustment |
| Part 12: | Miscellaneous |

SECTION C: ADDITIONAL ALLOWANCES

Percentage modifiers to take account of energy expenditure, posture, head room, visual demand, task requiring more than one man

SECTION D: FREQUENCY MULTIPLIER

Used to weight scores depending on whether job is done, for example, shiftily or weekly. In order to use the BMI, each task on the maintenance schedule must first be identified in terms of the actions needing to be performed and the recommended maintenance intervals. Each task is then assessed independently against each section of the BMI. Points are allocated depending on the number of body motions, degree of difficulty etc. The total of the scores for each part of Sections 1 and 2 are then increased by the percentage modifier of Section 3. This allows for energy expenditure estimates, postural difficulty, etc. Finally this score is then modified to take into account the different maintenance intervals. For example a task which is performed on a daily basis is weighted more heavily than a similar task which is only performed monthly. The weighted scores for all tasks in the maintenance schedule and then totalled to give the final BMI result for the machine.

The BMI can be interpreted in a number of ways depending on whether it is part of a design process, whether it is used to help select a new machine, or whether it is used to determine if it would be cost effective to modify existing plant to improve their maintainability characteristics.

Reviewing Routine Maintenance Schedules

A vehicle was assessed using the BMI against the routine maintenance schedule recommended in the engine and vehicle manufacturer's maintenance manuals, and also against others specified by the colliery. The Index score showed that these routine tasks would require approximately 196 minutes each day, or around 786 man-hours per annum.

Compared with other vehicles, the routine maintenance demand for this machine appeared high. The Index was able to highlight that a small proportion of the tasks accounted for the majority of the total index score for the vehicle. As a result it enabled the manufacturer and company engineer to review and revise their schedules and reduce the total maintenance demand by 45%, or approximately 88 minutes per vehicle per day.

Revising the routine maintenance schedules to meet the real needs of machinery can be a very easy means of achieving immediate increases in availability and reducing the demands on the maintenance crew.

Selecting Machinery with the Lowest Maintenance Demand

Traditionally factors such as purchase price, performance, and reliability have been taken into consideration when selecting new machinery. The costs of maintaining machinery is however less often considered despite these cumulative costs frequently exceeding the initial purchasing costs.

Table 1, summarises the annual time required for the routine oiling and greasing tasks on six modern mining machines.

Machine	1	2	3	4	5	6	
Oiling		58	90	127	147	123	83
Greasing	102	26	140	20	174	255	
Total		160	116	267	167	297	338

NB. These time are determined both by design features and the maintenance schedules

It can be seen that the highest scoring machine requires nearly three times as long (an extra 222 hours each year) to conduct the routine oiling and greasing tasks than the lowest scoring machine. However a closer look at the results shows that if a "hybrid" machine were manufactured using the best features of the six machines, then its score would be only 78 hours a year, or a further saving of 33% over the current best design.

Such information, when used with initial purchasing costs, reliability data, and machine performance, allows the engineer to better estimate the long term cost of ownership and therefore enable him to make better purchasing decisions.

Improving Existing Equipment Design

Any analysis of the causes of machine stoppage for maintenance or repair are likely to show that a large proportion of the stoppages are caused by a relatively small number of failures. For example, data from one site revealed that 25% of all maintenance time was spent replacing hydraulic lines, water hoses and power cables. It was estimated that the average time to replace these items would be reduced from 2.2 hours to under 1 hour if a quarter of the hoses and cables were relocated to give improved access.

The BMI has been used to help engineers identify where they need to focus their attention to make improvements, and once they have identified potential design changes, the Index can then be used to predict the benefits which would be expected following any specific design alterations.

Further details of the Index can be found in reference 9 with an example of its application given in reference 10.

1.6 IMPROVING MAINTENANCE - A GUIDE TO REDUCING HUMAN ERROR, HUMAN FACTORS IN RELIABILITY GROUP (HFRG) REPORT

The Human Factors in Reliability Group (HFRG) is a forum for individuals from industry, regulatory and academic institutions who have an interest and expertise in human factors, associated with reliability. It was inaugurated in 1981 to:

- foster collaboration between organisations with a direct interest in optimising and assessing human reliability in human-machine systems, and
-
- to support research and dissemination of information in these areas.

The main output from the HFRG has been reports produced by specialist sub-groups. A subgroup was formed specifically to address human reliability in maintenance. The sub-group first met around 1997 and the work has recently been published in the HSE report "Improving maintenance - a guide to reducing human error", ISBN 0-7176-1818-8.

Although it is never possible to totally eliminate human error, it is possible through good maintenance management and an understanding of the issues that affect error, to move towards this goal and to control the likelihood of error.

Guidelines had been produced as early as 1986 for improving maintainability features of equipment, however, these were specifically aimed at the mining industry (eg reference 4). These focussed on aspects of the design of equipment which made it "maintenance friendly". These were later developed for general industry (reference 5) however, again these were restricted to design features and omitted the many 'organisational' and 'individual' features

which would also have a significant impact on human error in maintenance operations. During the mid-90's there were still only limited guidance available for managers and engineers to review the whole maintenance operations and identify the many issues which could detract from safe and reliable maintenance in their own organisation. There was also limited guidelines available to assist managers generate suitable practical actions to reduce these problems. Several maintenance indices had been developed, however, even the most well developed (eg reference 6) did not address the organisational or individual factors which were becoming increasingly recognised as critical to human reliability in most tasks. The HFRG therefore set out to produce a document which would have utility for most industries and provide a methodology which could be applied by the non-human factor specialist and which was solution orientated.

The underlying model was developed from the combined experience of the authors and aspects of the resulting methodology had been previously proven in a number of industrial applications. The finished methodology received a full peer review by the HFRG and was used in limited trials before publication.

The Guide seeks to provide practical advice and a methodology to help managers, engineers and others who are responsible for, or involved in, the management of maintenance within their organisation and who are concerned with the performance of people undertaking maintenance activities improve the quality of maintenance activities through the reduction of human error. The Guide has four sections. The first two provide an overview of the importance of human factors in maintenance and list the main issues under management control. The third section provides a method for identifying the key issues which will adversely affect maintenance in an organisation. This is based on the application of a questionnaire and/or an incident review procedure. The fourth section provides guidance, on addressing each of the identified issues. The sections are colour coded to help the user use this document.

Maintenance Risks & Human Performance in Maintenance

The publication is focussed on 18 human factors issues which can impact on safety and maintenance performance. These are based on the HSE HSG(65) (reference 7) model under 'policy', 'planning/implementing', and 'audit/review'. The issues are listed below:

Policy & Organising

- Policy
- Resource Allocation
- Roles, Responsibilities & Accountabilities
- Formal Communications
- Management of Change
- Organisational Learning

Planning & Implementing

- Procedures and Permits (Contents)
- Procedures (Presentation, Understanding, Usability)
- Work Design
- Crew/Shift Handover & Shift Work
- Individual Capabilities
- Competence (Technical and Interpersonal Skills)
- Teamwork
- Supervisory Effectiveness
- Environmental Factors
- Plant & Equipment Design

Measuring Performance

- Routine Checking of Maintenance Performance

Audit & Review

- Review of Maintenance Performance

Assessment Method

The description and instructions for using the methodology are provided in the Appendices of the report. They are in three stages.

1. The first stage is for the manager/engineer to identify the specific areas of concern. This could be in terms of the physical location of the maintenance work, the type of work (eg routine/breakdown, or electrical/mechanical), and the main consequences (eg plant reliability, safety to the public, safety to employees etc).
2. The second stage is the application of the questionnaire and/or incident review process. Instructions are provided on the scoring of each method. It is suggested that both processes are used, however, it is acknowledged that each have their strengths and weakness and that in some situations it may only be prudent to apply one process. For example, an incident review will not be successful if there have only been a small number of incidents and if the incidents have not been well documented. They will also have limited value if aspects of the general nature of the industry is changing, for example, if a significant part of the work is become automated or mechanised. In such circumstances the causes of past problems may have limited value to the causes of future problems.
3. The third stage involves a simple method for harnessing the output from the two processes to identify the priority areas for improvement. In this way, managers and engineers can develop a suitable action plan.

Maintenance Management Issues

The assessment method will usually identify 3 to 5 of the 18 issues which would benefit from review by management. The final section of the guide provides useful information and

suggestions on each of the 18 issues in a way that management can select those relevant and then identify a number of practical suggestions relating to making improvements in each area. Two worked examples are provided in Appendix 4 of the Guide.

Assessment Forms

A number of forms are used in the examples given in the Guide. Blank forms are provided at the end of the report and these can be freely copied.

Sub-Group Members

The main authors were:

Steve Mason,	Health Safety & Engineering Consultants Ltd (HSEC)
Jon Berman,	Greenstreet Berman
Greg Gibson,	Nuclear Industry

Other contributors were:

David Clarke,	Rolls Royce & Associates
Huw Gibson,	The University of Birmingham
Gareth Hughes,	Det Norske Veritas
Ronny Lardner,	The Keil Centre
Nigel Finch,	Civil Aviation Authority (CAA)

(Sadly, Nigel died before the report was published)

This report is available from HSE Books for £16. Full details are: Improving Maintenance - A Guide to Reducing Human Error, HSE Books, ISBN 0 7176 1818 8. HSE Books can be contacted by Fax on 01787 313995

1.7 IMPROVING COMPLIANCE WITH SAFETY PROCEDURES - REDUCING INDUSTRIAL VIOLATIONS

Human Factors in Reliability Group (HFRG) Report

The author chaired another sub-group of the HFRG which specifically addressed the organisational factors which increased the likelihood of safety rules and procedures being intentionally not followed. The methodology is based around a workforce questionnaire. It has equal applicability to maintenance operations as to other tasks. The report was published in 1995.

This report is available from HSE Books for £20. Full details are: Improving Compliance with Safety Procedures - Reducing Industrial Violations, HSE Books, ISBN 0 7176 0970 7. HSE Books can be contacted by Fax on 01787 313995

1.8 THE HSEC LTD HUMAN FACTORS SOLUTIONS CD-ROM

HSEC have recently developed a computer-based tool to allow managers and engineers to gain a deeper insight into the many human factor issues which can affect health and safety. It is equally applicable to maintenance and operating efficiency and reliability. It can be very quick to apply and produces a hard copy detailing all the potential latent failings in the system and

provides selected guidance and recommendations for managers/engineers to select their own action plan.

This new tool was originally visualised as having its main use as part of risk assessments for specific major operations, although there are clearly many other potential applications. It is sufficiently quick to use to encourage its routine application on selected major operations.

The methodology focusses on the following aspects of human factors:

1. Safety Commitment of Team Leaders and Managers
2. Perceived Impracticality of Safety Rules
3. Communications
4. Job Design
5. Plant & Equipment Ergonomics
6. Knowledge and Skills
7. Rules: Application: Relevance and Accuracy
8. Organisational Support
9. Working Conditions
10. Safety Commitment of Workforce
11. Complacency
12. Supervision: Setting Standards, Monitoring & Detection
13. Organisational Learning
14. Committed Resources
15. Participation
16. Quality Training
17. Balance of Productivity and Safety
18. Management Style

An assessor would first input details of the task and workgroup being assessed. The assessor then chooses whether to base the human factors assessment on his own views of this operator or to apply a short questionnaire to the workforce who will be involved in that operation. We recommend that the questionnaire should be applied, however, we recognise that this may not always be possible.

In its simplest form, the assessor rates his/her level of agreement with 44 issues using a Likert Scale. A 'hint' facility is provided for each issue to help the assessor fully appreciate the factors which should be considered for each issue.

The input information is used to produce an overview of the workgroup's positive and potentially negative features. The negative statements are then treated in greater detail. Individual statements are given for each potentially negative aspect. These are presented in a standardised format providing a summary of the problem along with supporting statements derived from the assessor ratings and questionnaires. This is intended to help the assessor fully appreciate the human factors issues associated with each negative aspect. These cover:

- Key factors which support the conclusion of the root problem
- Further supporting information
- Factors which could have caused or contributed to the problem
- Any factors which would lessen the impact of the root problem

An option is given for each negative aspects for the assessor to view our recommended management actions for that problem. These will be very dependant on the exact input material provided for each workgroup and task being assessed. These recommendations are then summarised in terms of: those which should be considered immediately; those which should be considered during the actual task; those which should be considered immediately following completion of the task; and further longer term considerations. We recommend that this list is reviewed by the manager/engineer responsible and recommendations selected for action. The resulting page then forms the agreed management action list to safely manage that job. This can then be signed and dated. The agreed action plan then forms the management controls to minimise human factors problems and effectively maintain or promote a positive safety culture for the work group. It may also provide useful information for any permit to work scheme. The document can then be audited as necessary.

The tool is available on a CD-ROM and the price includes 12 months telephone support to HSEC Ltd's Principal Human Factors Consultant and software engineers.

HSEC also have a wide range of specialist tools which are routinely used in addressing human factors problems in a number of industries. Those wishing to know more about these management tools should contact Steve Mason (HSEC's Principal Human Factors Consultant) at the address given below.

Contact details:

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1.9 REFERENCES

1. Ferguson CA, Mason S, Collier SG, Golding D, Graveling RA, Morris LA, Pethick AJ, Simpson GC 1985. The ergonomics of the maintenance of mining machinery. Institute of Occupational Medicine Rept. TM 85/12 (Final Report on CEC contract no. 7247/12/008).
2. Mason S, Rushworth AM 1992. Human aspects of maintenance, Maintenance, Volume 7, Number 3, September 1992.
3. Mason S, King C, Basford K, Fitzakerly H, Peach G, Simpson G 1994. Improving the human aspects of electrical isolation procedures on the surface and underground. British Coal Corporation, Report on CEC Contract 7250/13/036.
4. Mason S, Ferguson CA, Pethick AJ 1986. Ergonomic principles in designing for maintainability. Community Ergonomics Action Report no.8 Series 3. Luxembourg: European Coal and Steel Community.
5. Mason S 1995. The Ergonomics of Workplaces and Machines - a Design Manual, second edition. Chapter 'Maintainability', Ed TS Clark & EN Corlett, Taylor & Francis.
6. Mason S, Rushworth AM 1989. Improving machinery availability through the application of a new maintainability index. Mineral Resources Engineering, Vol 2, No. 3, 249-261.
7. HSE. Successful Health & Safety Management, HSG 65, HSE Books, ISBN 0-7176-1276-

8. HFRG/HSE 2000. Improving Maintenance - A Guide to Reducing Human Error, Co-Chairman of HFRG Sub-Group, HSE Books, ISBN 0 7176 1818 8.
9. Mason S 1990. Improving plant and machinery maintainability, Applied Ergonomics March, 1990 (NB the version described in this publication does not provide the final version with improved health and safety indicators).
10. Mason S 1991. Improving mining machinery maintainability, Mintech 91 - The Annual Review of International Mining Technology and Development, 1991.
11. HFRG/HSE, 1995. Improving Compliance with Safety Procedures - Reducing Industrial Violations, HSE Books, ISBN 0 7176 0970 7. HSE Books .