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STATEMENT OF THE PROBLEM

OBJECTIVES

HYPOTHESES

RESEARCH METHODOLOGY

RESULTS & DISCUSSION

FINDINGS

RECOMMENDATIONS/SUGGESTIONS

CONCLUSIONS

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- Bowersox, Donald J., Closs, David J., (1996), "Logistical Management." Tata McGraw, Hill, New Delhi.
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CONTRIBUTIONS TO BOOKS

- Sharma T., Kwatra, G. (2008) Effectiveness of Social Advertising: A Study of Selected Campaigns, Corporate Social Responsibility, Edited by David Crowther & Nicholas Capaldi, Ashgate Research Companion to Corporate Social Responsibility, Chapter 15, pp 287-303.

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- Schemenner, R.W., Huber, J.C. and Cook, R.L. (1987), "Geographic Differences and the Location of New Manufacturing Facilities," Journal of Urban Economics, Vol. 21, No. 1, pp. 83-104.

CONFERENCE PAPERS

- Garg, Sambhav (2011): "Business Ethics" Paper presented at the Annual International Conference for the All India Management Association, New Delhi, India, 19–22 June.

UNPUBLISHED DISSERTATIONS AND THESES

- Kumar S. (2011): "Customer Value: A Comparative Study of Rural and Urban Customers," Thesis, Kurukshetra University, Kurukshetra.

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WEBSITE

- Garg, Bhavet (2011): Towards a New Natural Gas Policy, Political Weekly, Viewed on January 01, 2012 http://epw.in/user/viewabstract.jsp

IMPACT OF HUMAN ERROR IN MAINTENANCE MANAGEMENT AND MINIMIZING METHODOLOGY

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ABSTRACT

Numerous research studies have shown that over fifty percent of equipment fails prematurely after maintenance work has been performed on it. Poor maintenance performance can affect both the safety and commercial performance of an organization. . As maintenance is heavily reliant on human activity, maintenance quality is largely dependent on the performance of maintenance staff. Although it is never possible to eliminate human error totally, it is possible through good maintenance management to move towards this goal. This paper overviews the work done in a petrochemical plant to reduce human errors in maintenance and discusses methodologies which were used to reduce errors and thereby improve safety, reliability and availability of the plant.

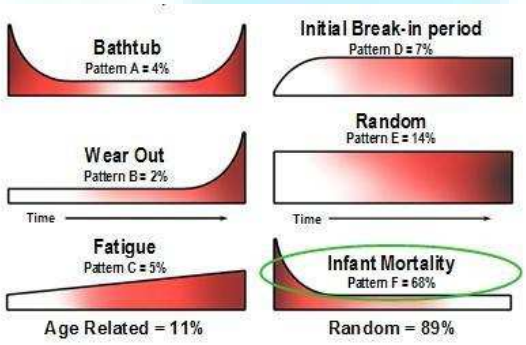
KEYWORDS

Reliability Centered Maintenance, Poka-Yoke, Failure Mode Effect Analysis, Preventive Maintenance, Performance Influencing Factors.

INTRODUCTION

In their ground-breaking work that led to the establishment of the technique that we now know as Reliability Centered Maintenance, Nowlan and Heap found, while analyzing the failures of hundreds of mechanical, structural and electrical components in aircraft, that these failures exhibited six distinct patterns which have been depicted in figure 1.

FIGURE 1: FAILURES EXHIBITING SIX DISTINCT PATTERNS



The interesting finding was that more than two-thirds of all components exhibited early-life failure. It was estimated that, between 1982 and 1991, maintenance errors ranked second only to 'controlled flight into terrain' accidents in causing onboard aircraft fatalities (despite the application of RCM techniques in the airline industry during that period)[2]. Furthermore, a study of coal-fired power stations indicated that 56% of forced outages occurred less than a week after a planned or maintenance shutdown.

MAINTENANCE RISKS & HUMAN PERFORMANCE IN MAINTENANCE

The publication is focused 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 & ORGANIZING
Policy
Resource Allocation
Roles, Responsibilities & Accountabilities
Formal Communications
Management of Change
Organizational 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

The HSE publication "Reducing error and influencing behavior" suggests that three overall factors affect the performance of any work activity including maintenance. These human factor issues are described below.

- Individual factors: The attributes and capabilities of the person, this includes their personal attitudes, habits and personalities as well as their skills and competence.
- Job factors: How the requirements of the task match the capabilities of the person undertaking the task. This includes consideration of workplace and environmental factors.
- Organizational factors: The organization has a great impact on the performance of individuals, yet the importance of the health and safety culture of the organization is often overlooked.

To achieve error free performance from maintenance staff, all three factors were focused upon. Under these factors, following sub-factors were analyzed as follows:

INDIVIDUAL FACTORS

FORMAL COMMUNICATIONS: Maintenance involves activities that need coordination, formal communications. When maintenance errors are analyzed, poor communication, e.g. during shift changeover, is often identified as a contributory cause. Existence of formal communication system, such as permit-to-work, does not inevitably ensure that the right information is communicated to the right people at the right time or ensures that information is communicated unambiguously and that the recipient properly understands it.

To achieve reliable communication following issues were recognized:

- Staff need to hand over work or plant systems to other staff during maintenance
- Staff may forget the maintenance status of plant and equipment so information on this must be provided in a practical and appropriate manner
- Staff may not have a single place of work to which information can be directed, so it is important to check that messages have been received
- Staff must have information about the maintenance requirements and priorities in terms of general requirements and task-specific requirements
- Communication systems should be in place to allow staff to pass information and concerns back to management
- These systems must be structured to ensure that the message is not distorted

PROCEDURES (PRESENTATION, UNDERSTANDING AND USABILITY): Procedures and other documentation only assist in ensuring high standards of safety and maintenance performance if they are used and followed correctly. The level of detail provided must suit the needs of the user and can vary from full procedures to checklists or job aids.

- Use simple language and clearly highlight hazards, critical tasks and checks, eg with suitable warnings
- Clearly indicate part numbers and other reference information, particularly where part numbers are very similar
- Any special tools required should be stated at the start of the procedure.
- Highlight any changes in the procedure and use tick boxes to show stages in a sequence.
- Procedures should be located as close as practicable to the workplace. Ensure checklist/task-list and Standard Maintenance procedures (SMP) are not only loaded in portal, but also they are kept in hard copy in bound form in workshop.

WORK DESIGN: When scheduling maintenance tasks, the workload of individuals needs to be controlled to avoid excessive stress or tiredness which can lead to poor maintenance performance. Additional problems arise because maintenance tasks are often carried out during unsocial hours (eg nights and weekends). Equally, there is a need to avoid under-utilizing staff as this induces boredom and a loss of skills, again leading to poor maintenance performance. High-hazard industries often make use of back-up systems to ensure safety systems are always available in the event of breakdowns. There is a need to stagger the maintenance of these systems. This will reduce the potential of individuals to repeat errors when maintaining a series of similar equipment.

Poor work design can have an adverse effect on job performance and occupational health, from factors such as excessive mental or physical stress (e.g. unrealistic timescales), excessive boredom (e.g. poor job variety) and lack of motivation (e.g. poor job satisfaction).

INDIVIDUAL CAPABILITIES: Maintenance tasks are often carried out by individuals working with little supervision. They comprise two main activities: manual manipulation of components; and decisions required during fault-finding or following maintenance inspections. People vary greatly in these two aspects, and hence, these factors should be taken into account when devising and implementing maintenance programs.

- ***Slips and memory lapses*** Slips and memory lapses (e.g. accidentally pressing the wrong button or missing out a step or steps in a task) usually occur in tasks which are so frequently carried out that they become 'automatic'. *In general, it is not possible to eliminate these errors through instruction or training*. The best approach to controlling these errors is through design, by eliminating the opportunity for making them, e.g. through interlock guards, and ensuring that components can only be fitted in the correct manner.
- ***Mistakes*** **:** Mistakes are situations where, despite a genuine attempt to comply with procedures, an error of judgment leads to an inappropriate *rule* being applied or a step in a procedure being done out of sequence. It is possible to reduce such errors by *improving the training and the quality of procedural documentation*.
- ***Violation (non-compliance)*****:** Violation is a separate form of human failure that occurs when an individual or individuals deliberately contravene established and known rules. Retraining staff in the correct practices cannot be the answer, as they already know what they should do. Violations are addressed by ensuring that staff does not perceive the benefits of non-compliance to be greater than any adverse consequences.

TEAMWORK: Maintenance staff may need to work in teams, particularly when maintaining larger items of plant and equipment. Therefore, it is important that maintenance staff have the ability to work well with a range of other people, providing mutual support and advice, particularly for new staff.

Shutdown teams – one engineer from a plant where annual turnaround is planned and other Engineer from second plant to work in a team to lead a particular work package is the style in a petrochemical unit considered for study while compiling this paper. More importantly, multi-disciplinary teams are formed for root cause analysis, improvement studies in addition to Quality Circle, Small Group Activity teams. Today's trend is to follow the winning team concept rather than dependency on champions.

COMPETENCE (TECHNICAL AND INTERPERSONAL SKILLS): As maintenance tasks are often very varied, the experience and skills of maintenance staff are important factors in ensuring high standards of performance. Competency assessment is one of the tools used to implement "Quality Assured Maintenance Management". The Standard Maintenance Practice includes required competency to carryout the job as detailed in the procedure.

SUPERVISOR EFFECTIVENESS: Supervisors have an important role in correcting poor working practices while encouraging good ones. *The skills and abilities needed by supervisors are often underestimated by organizations, and supervisors may not be provided with the support and training necessary. For most maintenance staff, the supervisor is their immediate 'management' representative and as such maintenance standards are often governed by the lowest standards tolerated by the supervisor. In cost-conscious environments, there is strong pressure on supervisors to improve productivity. In such circumstances, supervisors may focus on meeting production targets on some cost of safety and maintenance standards. Where this occurs over a long period, staff and supervisors come to regard these lower standards acceptable.*

JOB FACTORS

RESOURCE ALLOCATION: Failure to provide sufficient resources is a contributory cause in many maintenance incidents. For maintenance, the resources required will include people, time, tools and equipment, and procedures.

PROCEDURES AND PERMITS (CONTENTS): Maintenance procedures provide important controls for ensuring high standards of performance and safety. The role of maintenance procedures is to provide sufficient information to allow the user to carry out tasks correctly. The reasons often quoted for staff not following maintenance procedures and permits are that they are perceived to be inaccurate, out-of-date, impractical, too time consuming, or that they do not describe the 'best' way of carrying out the work. *To* address the accuracy and practicality of procedures and permits, they are periodically reviewed to ensure their relevance, accuracy and practicality through job cycle check.

ORGANIZATIONAL FACTORS

ROLES, RESPONSIBILITIES AND ACCOUNTABILITIES: In many organizations, maintenance can become undervalued by being primarily considered as an overhead with no contribution to profit. This tendency must be vigorously opposed if maintenance activities are to be successfully implemented. In particular, it is important that the maintenance program has clearly specified roles, responsibilities and accountabilities.

CREW/SHIFT HANDOVER AND SHIFT WORK: Failures in communication at crew or shift handovers are a common contributory factor to accidents associated with maintenance tasks carried out by multiple teams. Indeed, many of the UK's major accidents involve failures in the communication of key aspects of ongoing planned maintenance during shift handover.

Although there is an increasing move away from shift-based maintenance in many industries, some will always remain, either because of the nature of the particular industry or because of the need to support 24-hour operations with breakdown maintenance.

To minimize the potential problems of shift/crew handovers, it is important to ensure that handovers receive a high priority with the necessary resources provided (e.g. Sufficient time) and handovers of higher-risk maintenance activities are identified in advance and are subject to greater control. More than one form of communication (face-to-face, written log sheets, electronic records, etc.) would be effective in this regard.

OTHER CONTRIBUTING FACTORS

PLANT AND EQUIPMENT DESIGN: It is important that plant and equipment are designed so that the required maintenance can be carried out reliably and safely. Many of the situations that can cause poor maintenance performance can be eliminated or alleviated by improved design. Common problems include components that are poorly labeled, not easily accessible and which can be fitted incorrectly (eg the wrong way round).

Designers should take account of ergonomic and human factors and design for maintainability, e.g. frequently visited areas will need safe, suitable and permanent access provided. In majority of process industries maintenance crew gets involved from the beginning of the project and review drawings, model and site conditions so that most of the design related issues are taken care of. Plants are commissioned after thorough pre-startup safety review correcting many such points discussed above.

ROUTINE CHECKING OF MAINTENANCE PERFORMANCE: By its nature, maintenance is made up of activities which are a mixture of routine and non-routine tasks. As such, maintenance errors can originate from various sources. Some errors can be identified and corrected during maintenance, while others may be identified subsequently during post-maintenance testing. However, some errors will remain undetected when the item returns to service. The performance of the maintenance department needs to be routinely checked to identify and correct poor maintenance practices and to identify areas for improvement

REVIEW MAINTENANCE PERFORMANCE

The overall performance of the maintenance function needs to be periodically reviewed to ensure that it is meeting the requirements of your organization and to identify opportunities for improvement in performance.

There are various approaches which can be used to review the performance of maintenance functions:

- Incident reviews to analyze the underlying causes of previous events
- Workplace audits using experienced personnel to look for error-causing factors
- Task analysis to provide a detailed understanding of tasks that appear to be error prone, thereby assisting the identification of preventive measures
- Hazard identification techniques such as failure modes and effect analysis (FMEA) to identify the effectiveness of controls over critical maintenance activities

If poor quality maintenance causes so many incidents in highly regulated and hazardous industries such as nuclear power generation and civil aviation, what proportion of failures is being caused by maintenance within your organization?

What are the outcomes of maintenance-induced failures? Clearly, depending on the industry in which you operate, there are potentially significant safety and environmental risks. There is a long list of catastrophic failures in which, the inadequate performance of a maintenance task played a significant role. But besides the obvious safety risks, perhaps the bigger consequences are economic. General Electric has estimated that each in-flight engine shutdown costs airlines in the region of US$500,000. What could maintenance-induced failures be costing your organization?

Clearly, we need to do something to reduce the number of equipment failures that are being caused, not prevented, by maintenance. This paper suggests that the most appropriate approach is to:

- *admit that human error is inevitable (even in maintenance!) and design our systems and processes around this inevitability*
- *use appropriate tools to ensure that we are not unnecessarily over-maintaining plant and equipment (and therefore increasing the risk associated with the fact that this work may not be performed correctly)*
- *work to improve the quality with which maintenance activities are performed – including error-proofing where possible.*

The quality of maintenance is a major contributory factor affecting safety and operational costs. It affects the operating life of plant and also the risk of accidents during or following maintenance. For example, the tragic accident on the Piper Alpha oil platform involved a series of errors during maintenance. It resulted in the loss of 167 lives and is estimated to have cost over £2 billion, including £76 million in direct insurance payments. The extent and nature of the impact will, of course, depend upon the type of industry and the activities carried out. The focus on human error comes from the recognition that maintenance is largely a human activity. 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.

MINIMIZE HUMAN ERRORS IN MAINTENANCE

The methodology for minimizing human errors in maintenance focuses on the following aspects:

1. Safety Commitment of Team Leaders and Managers
2. Perceived Impracticality of Safety Rules, Communications and Job Design
3. Plant & Equipment Ergonomics
4. Knowledge and Skills
5. Rules: Application: Relevance and Accuracy
6. Organizational Support and Working Conditions
7. Safety Commitment of Workforce
8. Complacency
9. Supervision: Setting Standards, Monitoring & Detection

10. Organizational Learning and Committed Resources
11. Participation and Quality Training
12. Balance of Productivity and Safety
13. Management Style

SURVEY ON HUMAN FACTORS IN MAINTENANCE (HFIM)

Survey Feedback

1. The main issue in my opinion is "complacency". A lot is due to repeated jobs over and over again, and not paying attention to little details.
2. Managers and Supervisors need to be more patient when shops get a lot of work. Most mistakes are made when technicians get interrupted during their tasks to do other jobs and feel pressure to always get done quickly.
3. To improve or reduce HFIM management/errors you need:

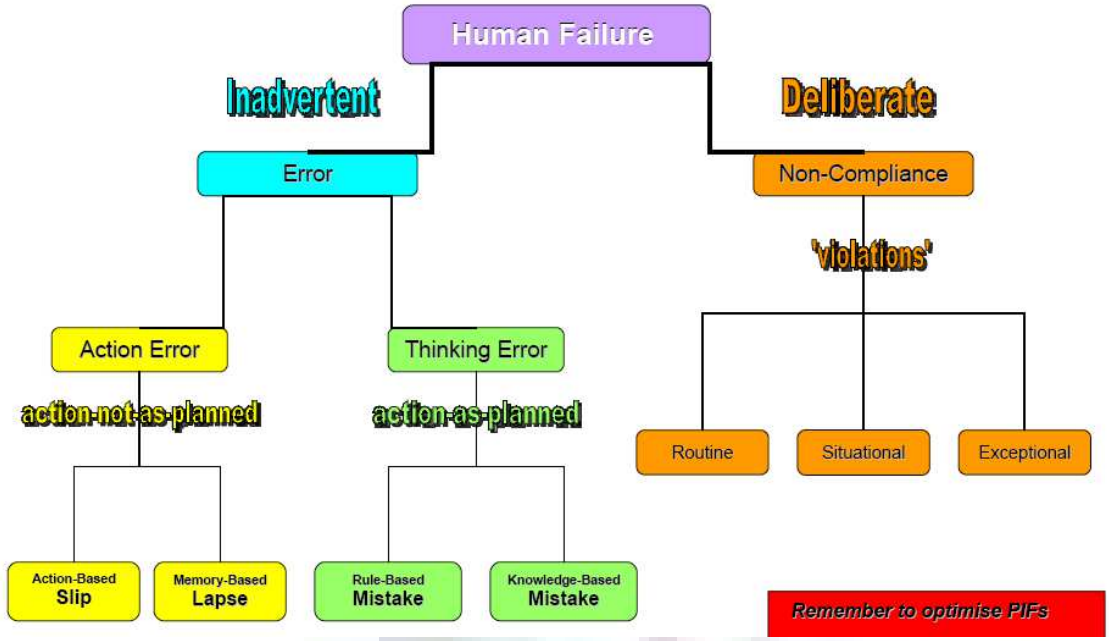
a. Effective implementation of supervisory training
b. Timely sharing of information (incidents/ accidents)
c. Motivation at all levels
d. Involvement of leaders and supervisors with the subordinates

4. Personnel should be trained and watched by supervisors to make sure they are gaining an understanding of correct processes and sticking to the procedures.
5. I think that work-pressure and fatigue are special human error producers. I think generally, the air forces have to consider a rest time for technicians just like the rest time valid for crew members.
6. Most common outcome is repeat/recur of present malfunction due to lack of efficient maintenance procedures related to HFIM.
7. The most important is psychological factors (i.e. wants, expectations, attitudes and motivation) then next comes human sensory factors and physiological factors.

AVOID UNNECESSARY MAINTENANCE: Using techniques such as Reliability Centered Maintenance and Preventive Maintenance optimization fully justify maintenance activities and accept the fact that human error is inevitable.

TYPES OF ERRORS AND SOLUTIONS: Performance Influencing Factors (PIFs) are characteristics of the job, the individual and the organization that influence human performance. Optimizing PIFs will reduce the likelihood of all types of human failures. Figure 2 exhibits types of errors.

FIGURE 2: TYPES OF ERRORS



JOB FACTORS

- Clarity of signs, signals, instructions and other information
- System/equipment interface (labelling, alarms, error avoidance/ tolerance)
- Difficulty/complexity of task
- Routine or unusual
- Divided attention
- Procedures inadequate or inappropriate
- Preparation for task (e.g. permits, risk assessments, checking)
- Time available/required
- Tools appropriate for task
- Communication, with colleagues, supervision, contractor, other
- Working environment (noise, heat, space, lighting, ventilation)

PERSONAL FACTORS

- Physical capability and condition
- Fatigue (acute from temporary situation, or chronic)
- Stress/morale
- Work overload/under load
- Competence to deal with circumstances
- Motivation versus other priorities

ORGANIZATIONAL FACTORS

- Work pressures e.g. production vs. safety
- Level and nature of supervision / leadership
- Communication
- Manning levels
- Peer pressure
- Clarity of roles and responsibilities
- Consequences of failure to follow rules/procedures
- Effectiveness of organizational learning (learning from experiences)
- Organizational or safety culture, e.g. everyone breaks the rules

SOLUTIONS

1) Writing effective work instructions

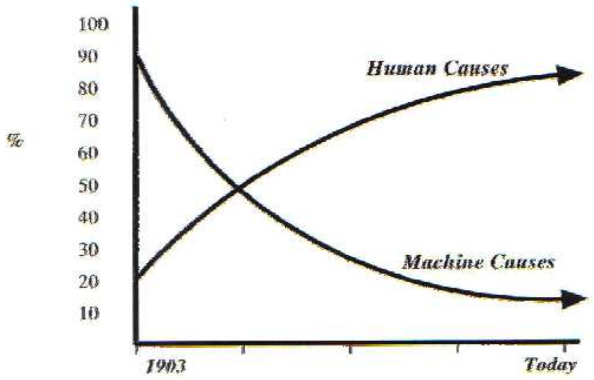
Omissions account for more than 50% of all maintenance errors, good work instructions can reduce it. Characteristics of good maintenance work instruction

- Written with the person who is going to read and use
- Avoid complex work instructions
- Simple consistent language
- Use figures and pictures wherever possible
- Use active not passive voice
- Incorporate adequate inspections at key points
- Highlight critical steps (Process Safety Management critical)

2) Training helps to avoid human error

- Qualified and skilled personnel
- Assign tasks appropriately
- Ensure good housekeeping standards
- Good spare part management

FIGURE 3: ROLE PLAYED BY HUMAN PERFORMANCE IN CIVIL AIRCRAFT ACCIDENTS



IATA, 1975

3) Poka-Yoke

Poka-Yoke is fool-proofing, which is the basis of the Zero Quality Control (ZQC) approach, which is a technique for avoiding and eliminating mistakes. Generally this technique is used in manufacturing processes, but has much wider uses, such as; offices - order and invoice processing, hospitals - drug dispensing, aircraft maintenance - particularly with processes having the potential of inducing catastrophic in-service failures.

The term Poka-Yoke is Japanese and can roughly be translated as mistake or fool-proofing. This is especially important when considering the technique and approach requires the workers active participation in the error cause removal programme. Use of dowel pins in assembly to match two mating parts is one of the simple examples of mistake proofing in maintenance. Notably, error cause removal and zero defects are phases first used by Philip Crosby but the approach is very different and should not be confused.

CONCLUSION

Poor maintenance performance can affect both the safety and commercial performance of an organization. No organization can afford to accept loss of image, property or human lives because of human errors. In today's world of competitiveness, lot is expected from maintenance, and this service is considered as profit centre, and it is understood that maintenance drives manufacturing. The availability, reliability and integrity are assured by maintenance. Even though human errors are inevitable, error minimizing or eliminating techniques through procedures, checklist and training is part of maintenance organization in petrochemical plants. As a proactive move, lot of techniques, such as Positive Metal Identification, Last Chance Inspection, Quality Assurance Sheets, Welding Procedure System, Task List, Job Package Files, Things-to-Do List, Micro Planning, to name a few, are in place in most of the organizations.

ABBREVIATIONS

RCM	Reliability Centered Maintenance
PM	Preventive Maintenance
FEMA	Failure Mode and Effect Analysis
PIF	Performance Influencing Factors
HSE	Health Safety and Environment
HFIM	Human Factors In Maintenance
ZQC	Zero Quality Control
UK	United Kingdom

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