TO ERR IS HUMAN – A CASE STUDY OF ERROR PREVENTION IN PROCESS ISOLATIONS

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This case study describes how practical human error analysis and prevention methods were applied to a series of errors which occurred during process isolations and de-isolations on an offshore oil and gas platform. The errors were uncovered during routine isolation audits. One of the errors involved a supervisor who was regarded as a most trustworthy, competent and reliable team member.

By undertaking a careful and detailed analysis of the incident, and the surrounding circumstances, it was possible to identify several factors which shaped this person's performance on that day, and explain how and why the error occurred.

It is sometimes said that to influence human error "*you can't change the human condition, but you can change the conditions under which humans work*".

In this case, quantitative human reliability analysis confirmed that changing conditions and systems of work would reduce the probability of error. Such changes were made, and this resulted in a 66% reduction in the number of isolation errors, and also a reduction in the potential severity of the remaining errors.

INTRODUCTION

Since its publication in 1999, UK regulatory guidance has emphasised the importance of reducing error and influencing behaviour, as part of effective health and safety management (Health and Safety Executive, 1999). More recently, the UK regulator has provided further emphasis and focus via a list of their top human factors concerns, published on their COMAH web-site (HSE, 2009). This includes "managing human failure" and "integrating human factors into incident investigations and risk assessments".

As part of their efforts to meet such expectations and minimise commercial loss, many companies in the process industries have implemented an incident analysis process, which includes some form of root cause analysis to determine the immediate and system causes for accidents, incidents and near-misses. However, many organisations still struggle to understand why the people involved in incidents behaved as they did, and to implement strong behavioural recommendations to prevent a recurrence. Whilst technical and engineering analysis and recommendations are typically strong, behavioural analysis is often weak, with standard, unfocused recommendations such as "warn people to be more careful", "provide coaching", "re-write the procedure" and "provide training".

ABOUT HFAT

In response to such concerns, the first author conducted a series of projects that developed, piloted and implemented a set of "Human Factors Analysis Tools" to aid investigators to better understand the human factors that influenced people's performance during incidents, and implement corrective actions designed to influence safe behaviour in the future. (Lardner, 2006) These tools, known as HFAT, have now been in use for five years in a wide variety of process industries, including oil and gas, petrochemicals, fine chemicals, and pharmaceuticals. The methods have been used in many countries, and translated into German and Norwegian.

Figure 1 below outlines the HFAT process. Above the dotted line is a typical conventional incident investigation process. Below the line is the HFAT process, which makes the important distinction between intentional unsafe behaviours (known as violations) and unintentional unsafe behaviours (known as errors). Depending on the type of behaviour, two analysis methods are available – ABC analysis (Keil Centre, 2002) and human error analysis (Lardner, 2006), each leading to recommendations appropriate for that type of behaviour.

In 2008 The Energy Institute published an independent review (Energy Institute, 2008) of methods for investigating and analyzing human and organizational factors aspects of incidents and accidents. Twenty-eight methods were reviewed against a set of nine features deemed most useful to the user. Only three methods, including HFAT, met all nine criteria. HFAT was the only method specifically-designed to supplement and enhance existing investigation methods, this minimising the need to retrain those already familiar with existing investigation methods.

HUMAN ERROR IN MAINTENANCE AND ISOLATIONS

Error during maintenance is arguably inevitable, as 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 which affect error, to move towards this goal and to control the likelihood of error.

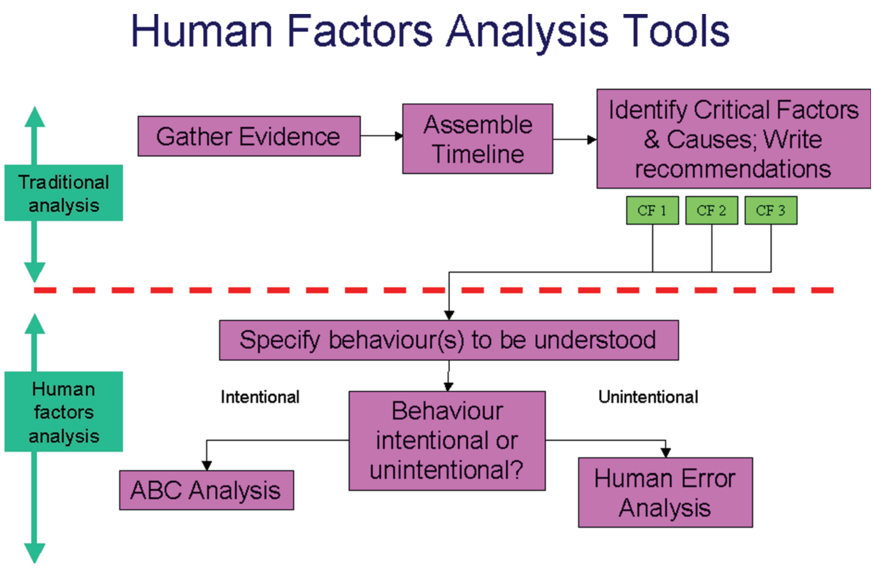

Figure 1. Human factors analysis tools

The publication "Improving Maintenance: a guide to reducing human error" (Health and Safety Executive, 2000) includes a relevant example involving an isolation

> *An electrician suffered severe burns while repairing a faulty 415-volt motor, which was live. Staff believed it had been isolated because the motor had been mechanically-positioned for repair during the previous shift. However, there was poor communication across shifts and staff were unclear about who was responsible for isolating equipment.*

This publication advises that "in general, it is not possible to eliminate these (maintenance) 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. Where this is not practicable, the plant or equipment should be designed, or arrangements put in place, to allow errors to be detected and corrected before any adverse consequences occur, e.g. by giving feedback of the results of an action or through post-maintenance testing".

Revised HSE guidance on the safe isolation of plant and equipment (Health and Safety Executive, 2006) included an "increased appreciation of the importance of human factors in safe isolations". HSE analysis confirmed that where incidents occur, the root causes often include human failures. The error/violation distinction is made (page 5) and a range of suggestions made on how to minimise error.

ABOUT BP MILLER

The Miller oil and gas field is located 270 km NE of Aberdeen in UKCS Blocks 16/7b and 16/8b and was discovered in 1982 by BP. Oil was found 4,000 metres beneath the seabed in a water depth of 100 metres.

Production from Miller field started in June 1992 and plateau production was from late 1992 to 1997 at rates of up to 150,000 barrels of oil and 255 million standard cubic feet of gas per day. Miller produced some 345 million barrels of oil during its lifetime.

The Miller field reached the end of its economic oil & gas-producing life in 2007 when Cessation of Production approval was received from the UK government. Preparations are currently underway to decommission the Miller platform but the oil and gas pipelines will be preserved for future opportunities.

THE SERIES OF INCIDENTS

The BP Miller platform, like many others, conducts regular audits to ensure isolations have been designed, applied or removed correctly. The Miller management team noticed a trend indicating that occasionally isolations had not been correctly implemented or removed.

These incidents had been investigated and reviewed by the platform management team, who felt that a more in-depth human factors analysis was required. The first author who co-designed HFAT, and the second author who had recently completed an HFAT training course jointly conducted the analysis.

Five incidents were analysed. The following initial observations were made:

- Three of the five incidents involved human error, and two involved violations of permit-to-work and isolation procedures.
- One isolation incident involved a very experienced electrical supervisor, and was a classic maintenance error, identical to another which occurred elsewhere in BP.

This incident is the subject of this case study. The basic facts were that the supervisor was performing a complex, multi-point electrical isolation on a gas turbine, and applied part of the isolation to the correct isolation point on the wrong, identical, adjacent turbine. When this person became aware of the error, he immediately offered to resign, so horrified was he about this significant error.
- Three of the incidents were detected during isolation audits, a technician spotted one, and the fifth was detected when a platform shutdown was triggered as a result of the incorrect isolation.

An initial human factors review identified a number of performance-shaping factors, which can increase the likelihood of errors, including being distracted during isolations, high workload, and lack of an independent check.

Interviews were conducted with a range of platform personnel involved in isolations. It became apparent that it was rare for an independent second person to check that an isolation made by an Isolating Authority had been correctly applied. Two exceptions were described:

- Mechanical isolations, where it was described as "standard practice", and often specified on the work permit, to have the Area Technician present, which could serve as a check on the correct application of the isolation. A pre-job site visit can also help to ensure mechanical isolations are applied to the correct equipment. Perhaps significantly, none of the five incidents reviewed involved mechanical isolations. It was unclear whether it was an explicit task of the Area Technician to check the correct application of the isolation, and whether they would possess the necessary competence to do so.
- High-voltage electrical isolations, where a second experienced technician is usually present to check the isolation is correctly applied.

In practice, for valve isolations and other electrical isolations, the main form of verification built into permit-to-work and isolation procedures occurs after the Isolating Authority enters into the permit-to-work IT system that they have isolated each of the isolation points. The Area Authority then "verifies" the isolation, but in fact this procedural step is not a verification, but simply confirmation that the Isolating Authority has indicated on the permit-to-work IT system that they believe they have correctly performed the isolation.

It was agreed by all interviewed that the permit-to-work and isolation process, when strictly adhered to, did not provide an independent check on whether all types of isolation or de-isolation have been correctly implemented. The existing process relied heavily on the flawed assumption that competent people will not make mistakes. It is possible that a pre-job isolation audit could detect an isolation error, but such audits are infrequent.

It was explained that, with some types of isolation, an independent check on whether an isolation has been correctly implemented does occur before work starts – for example checking whether electrical equipment is "dead", or the presence of an Operations Technician during a break of containment. It was unclear whether this type of check on isolation integrity was feasible for all types of isolations.

Those involved in implementing isolations were asked what, according to their opinion or experience, increased the likelihood of isolation errors occurring. Their replies included:

- Interruptions during isolations or de-isolations, caused by periods of high activity, responding to urgent loudspeaker announcements, and being called away to deal with breakdowns
- Pressure to get the job done quickly, for example to restart the plant
- During a complex de-isolation, lack of an experienced colleague to double-check
- Insufficient knowledge amongst recently recruited process technicians
- Being preoccupied by welfare and morale issues
- Having to supervise inexperienced staff whilst simultaneously performing isolations
- Unclear or missing equipment labels, leading to isolations being applied to wrong equipment
- Not assessing competence of Isolating Authorities under field conditions, which therefore does not assess people's ability to isolate with the actual pressures of the job in place
- Fatigue after mid-trip changeover

All of the above are recognized performance-shaping factors, which can increase the likelihood of human error.

ERROR TYPE, AND PERFORMANCE-SHAPING FACTORS

As previously explained, the isolation incident featured in this case study involved a very experienced electrical supervisor, and was a classic maintenance error. This incident is the subject of this case study. The basic facts are that the supervisor was performing a complex, multi-point electrical isolation on a gas turbine, and applied part of the isolation to the correct isolation point on the wrong, identical, adjacent turbine.

HFAT classifies errors as being one of four types of human failure:

- Failure of **Perception** – e.g. sight, hearing, – leading to an inaccurate understanding of events
- Failure of **Memory** – no recall, or inaccurate recall of knowledge
- Failure of **Decision-Making** – where perception and memory are accurate, but a wrong judgement, decision or plan is nevertheless made
- **Action** error – where a person does or says something unintended or incorrect, which is not due to a failure of perception, memory or decision-making

Using HFAT, this error was classified as an **Action** error caused by confusing similar items of equipment. In other words, the right action (an isolation step) was applied to the wrong object (the wrong turbine). The underlying cause of the action error was distraction, and this person's performance was also adversely shaped by high workload. Skilled and experienced people are particularly prone to action errors when doing familiar tasks, especially when interrupted mid-task. This can lead to resuming the task on the wrong piece of equipment.

When an incident occurs, it is common industry practice to ask those involved to write their own statement of events, in their own words. This can lead to an sketchy or incomplete understanding of events, as the person writing the statement has little or no guidance on what to include or exclude, and what aspects of events are likely to be relevant. Research indicates that a cognitive interview is likely to aid maximum recall of events by witnesses. (Kohnken, 1995)

During a cognitive re-interview with the experienced Electrical Supervisor, who was personally involved in an isolation error, some additional facts emerged which were not contained in his initial written statement. During that week he was covering the work of two people, as his usual experienced colleague was on sick leave. He was also supervising and coaching a less-experienced colleague. So, at the time of the isolation error, he was lacking the independent check he would normally have had via his experienced colleague, and was arguably distracted from his main isolation task by the secondary coaching/supervision task. He was then interrupted and distracted by being called away to deal with an "urgent" matter mid-task, and lacked his normal colleague who would have continued and finished the task despite the interruption.

In hindsight, the task he was called away to attend to was not so urgent that it would not have waited until the isolation was completed, but he did not know this at the time. At the first loudspeaker announcement, which he wisely ignored, he was part-way through the high voltage part of the isolation. This loudspeaker message said simply to contact control room. A short time later, as he finished the high voltage part of the isolation, he heard a second loudspeaker announcement to "urgently" contact the control room, without any explanation why. He then broke off from the incomplete isolation, and went to find out what was so urgent. He found catering staff standing by the open door of the freezer, saying the temperature was rising and food might spoil. He was frustrated that he'd been called away to deal with a task that would have waited a while longer, especially as door was lying open allowing the temperature to rise. He fixed the freezer problem, then went back to complete the isolation. No doubt his frustration did not put him in a great frame of mind for error-free performance[1], (Keil Centre, 2006).

Given this additional evidence, it is understandable why the error occurred in these circumstances.

[1]Recently published BP/HSE research identified feeling frustrated as amongst several "states of mind" which can be precursors to errors and/or violations. See Executive Summary in http://www.hse.gov.uk/research/rrpdf/rr488.pdf

HUMAN RELIABILITY ANALYSIS

Engineers are familiar with the calculation of reliability data for plant and equipment. Such calculations can be used to inform reliable plant design, and introduce redundancy when critical components are likely to fail. Similar human reliability assessment techniques have been developed by human factors professionals, and are based on the following assumptions:

- Human performance is fallible: even competent and experienced people make errors
- The more complex the task, the higher the probability of failure
- Human performance is shaped by surrounding events and known "performance-shaping factors", which increase the likelihood of error

Given that human error will happen, safety-critical systems must be designed to minimize error, and help detect and recover from remaining errors that occur.

Using data from studies of actual work performance, simulations and controlled experiments, the probability of error during different generic types of tasks can be estimated, and the effect of common performance-shaping factors calculated. (Williams, 1988)

The isolation task and key performance-shaping factors were subjected to human reliability analysis to help (a) develop evidence-based recommendations and (b) support the business case for their implementation.

Tables 1 to 3 below illustrates the probability of human failure when (1) performing a task of a similar

Table 1. Probability of human failure during isolation task

Task	Probability of failure
Task of similar nature to process isolation, with some self-checking	3 in 1000

Table 2. Probability of human failure during isolation task, without independent checking of output

Task	Probability of failure
Above, plus little or no independent checking of output[a]	9 in 1000

[a] This tripling of error rate is consistent with other UK research which has shown that hospital pharmacies without an independent check on pharmacist dispensing have an error rate three times higher than those departments with a second independent check on all work.

Table 3. Probability of human failure during isolation task, without independent checking of output, under time pressure

Task	Probability of failure
Above, plus time shortage for error detection and correction	81 in 1000

nature to a multi-point electrical or process isolation, (2) how that probability changes when no independent checking exists, and (3) how the probability further increases when time pressure exists.

The probabilities above can be compared to Miller data that indicated that approximately 138 process isolations were conducted between 15 July 2006 and 25 August 2006, and 3 process isolation incidents involving human error were detected. This yields a conservative actual error rate of 22 in 1000. This rate is considered conservative, as it does not account for errors that occurred and were not detected at all, and errors that occurred but were detected and corrected at the time by the person performing the isolation.

IMPLEMENTATION OF RECOMMENDATIONS

Using the guidance contained in the HFAT worksheets, a series of recommendations were made to (a) prevent & reduce such errors occurring (b) detect them at an early stage and (c) educate platform management and others on the nature of error, and how conditions at work can influence human reliability. The types of recommendation are shown below.

REDUCING ISOLATION ERROR RATE

Eliminate the performance-shaping factors that influence the isolation task, particularly those isolations considered safety-critical. This includes:

- Removing distractions that affect those conducting isolations, particularly those that involve interrupting isolations mid-task. This was achieved by ensuring that requests for unplanned work went via their supervisor, who is in a position to prioritise, and minimise interruptions and distractions during safety-critical work
- Removing time pressure to complete isolations
- Ensuring items of equipment are clearly-labelled
- Ensuring the availability of people to conduct isolations who have had their competence assessed on-the-job
- Providing more than one competent person to execute and check complex, multi-point isolations.

EARLY DETECTION OF ISOLATION ERRORS

Despite taking action to reduce the error rate, some residual errors will nevertheless occur. It is important to ensure that reliable means are in place to detect these errors at an early stage, and recover from the error.

There appeared to be two opportunities to do so (1) during or immediately after an isolation or de-isolation has been applied and before the isolation has been approved by the Area Authority, using self-checking ***and*** an independent check by a second person, or (2) before the work starts, by independent checking of the isolation's integrity by the work party.

It was recommended that such a system of checks be developed, with a focus on isolations with high consequences of failure.

Self-checking routines[2] involve going back through the isolation once complete, and physically checking each step in the isolation has been correctly applied to the right equipment. If interrupted during an isolation, the isolation should be checked from the beginning, to ensure a step is not missed out or incorrectly applied.

EDUCATING PERSONNEL ON HUMAN ERROR, AND PERFORMANCE-SHAPING FACTORS

Educate the workforce, starting with managers and supervisors, paying particular attention to the inevitability of human error, and identifying performance-shaping factors. Encourage the reporting of human error "near-misses", and potential sources of error. Encourage personnel to stop work when performance-shaping factors are adversely affecting personnel performing safety-critical tasks.

EFFECTS OF IMPLEMENTING RECOMMENDATIONS

After these recommendations had been implemented, the rate of error detected during isolation audits was monitored. Platform management were able to determine that the isolation error rate had ***reduced by 66%***, and that the remaining errors were of lower potential severity.

During a visit to the Miller platform, Health and Safety Executive inspectors stated they were impressed with the human factors effort to reduce to isolation incidents, and BP's efforts to promote this within their own organisation. They were keen for BP to also promote this work outside their own organisation. The work was seen as consistent with the Health and Safety Executive's guidance on the safe isolation of plant and equipment (Health and Safety Executive, 2006).

DISCUSSION

There is a perception amongst some managers and engineers that with good training and processes, errors are unlikely to occur – which is not the case. This paper has demonstrated why human error occurs, often involving the most competent and experienced personnel, how to analyse this, and put in place measures to prevent, detect and aid recovery from error.

Despite this, it is puzzling why some organisations are reluctant to tackle human error, thus hindering the development of a learning culture, and missing important implications for personal and process safety.

The first author has proposed a model that may help to illustrate some of the reasons why this happens.

In a basic safety culture, it is likely that many people, including management, are breaking the rules and health

[2]Despite being intuitively worthwhile, evidence on the actual effectiveness of self-checking is limited. Self-checking appears to be less effective for routine tasks, and more effective for high-risk non-routine tasks, where people are not operating in "automatic" thought mode. Providing external prompts for checking (e.g. via pre-job briefings, stop points in procedures) is also likely to be helpful.

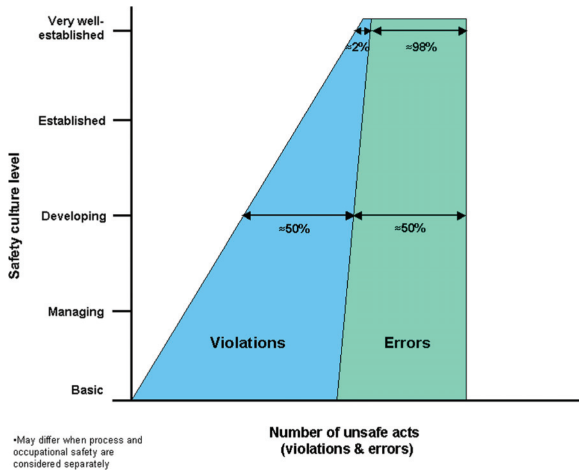

Figure 2. Safety culture level* vs. unsafe behaviour

and safety law. In other words, violations are frequent. As initial efforts are made to address rule violation, the absolute numbers reduce as safety culture improves.

Due to the focus on rule violation, three unintended consequences occur

1. It is not noticed that many of the unsafe behaviours contributing to incidents are actually unintentional errors, which often require different solutions to violations
2. As a result of not implementing appropriate error solutions, similar incidents recur
3. Blame and discipline become associated with all types of unsafe behaviour, and are therefore applied inappropriately to unintentional errors.

As levels of safety culture continue to improve, the proportion of unsafe acts which are violations reduces, Awareness of underlying errors increases, as they form a larger proportion of unsafe acts. Recognition of the need for appropriate error analysis techniques and solutions also increases. What would previously have been regarded as violations are reclassified as errors, and recurring incidents are tackled more effectively.

When a safety culture is well-established, violations are uncommon, and most unsafe acts are the result of unintentional errors.

Although this model is intuitively appealing, what data is available to support it? The first author has trained many people in use of HFAT, which helps the investigator to accurately distinguish between errors and violations. In three such process industry organisations, whose safety culture level is known to vary between levels 3 and 4, an approximate 50%/50% violations/error ratio was found. (Lardner, 2009).

In contrast, data from UK air traffic control (Scaife, 2008) indicates that 98% of unsafe behaviours in their domain are errors, with the remaining 2% being situational or exceptional violations. UK air traffic control is regarded as having a very well-established safety culture (NATS, 2009).

To further complicate matters, the situation may differ when process and occupational safety are considered. It may be the case that the relative proportions of error and violations differ when the causation of process safety and occupational safety incidents are separately established.

CONCLUSIONS

This case study has demonstrated that, when the wrong combination of circumstances coincides, error can occur even when the most competent and experienced personnel are involved. Nevertheless, practical steps can be taken to understand, anticipate, prevent and reduce error, and mitigate its effects.

To do this successfully it is important to distinguish between unsafe acts that are intentional (violations) and unintentional (errors), and also address any other factors that are influencing human performance.

The proposed model in Figure 2 suggests that this is much more difficult to achieve in an immature safety culture. An appropriate place to start is by educating managers and health and safety professionals of the likely benefits of a deeper understanding of how to reduce error and influence behaviour.

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