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HELPING ENGINEERS TO ANALYSE AND INFLUENCE THE HUMAN FACTORS IN ACCIDENTS AT WORK

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This paper describes a series of projects in four organizations, each of whom wished to deepen their understanding of the human factors that influence accidents and incidents at work. A set of human factors analysis tools were developed which encompassed violations, errors and aspects of safety culture. Following a trial period and a peer review, the methods have been implemented, and used by investigators who were typically from an engineering background, and did not possess human factors expertise. The process and outcomes of these projects is described, with examples of how a human factors approach can add value to existing analytical methods. Some of the difficulties encountered are described, together with areas for future development.

Keywords: human factors; accidents; safety; error; violation; safety culture; accident investigation; incident investigation.

INTRODUCTION

In the UK process industries, there are strong societal, industry and regulatory expectations that every effort will be made to ensure the safety of process plant, minimize injury, and protect the environment. As part of their efforts to meet such expectations and minimize 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.

Investigations of many high-profile events across different industry sectors have concluded that a variety of types of human failures have been prominent amongst the contributory causes, including a poor safety culture (Piper Alpha), human error (Texaco Milford Haven) and violations (Herald of Free Enterprise). Such human influences on performance are often collectively termed ‘human factors’. The UK Health and Safety Executive has issued specialist human factors guidance (Health and Safety Executive, 1999), and employs many specialists to influence the process industries to develop their competence in managing human factors.

This paper describes a series of projects that developed, trialled and implemented a set of analytical tools to aid investigators, typically from an engineering or technical background, 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.

The project began with a request from a major process industry client who wished to improve the effectiveness of their existing incident investigation process. The existing process involved structured evidence gathering, interviewing by trained staff, development of an incident time-line, identification of critical factors, and the application of a root cause analysis model to guide recommendations.

Despite this structured process, which was recognized as being very effective at identifying *what* happened and addressing technical failures, a gap existed in consistently identifying *why* people behaved as they did, and developing recommendations which maximized their influence on future behaviour. The typical set of recommendations to address behaviour involved briefing personnel, rewriting a procedure, and providing further training.

The authors were asked to review the current incident investigation process, and make recommendations for improvement.

METHODS AND MATERIALS

The first author completed the organization’s incident investigation training course, to become familiar with the existing methods and process.

When analysing unsafe behaviour, an important distinction is made in the human factors literature between behaviours which are intentional (often termed a violation) and unintentional (often termed an error) (Health and Safety Executive, 1999). It was noted that the existing root

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cause analysis method in use included consideration of violations, but did not directly address human error. A sample of completed incident investigations were analysed using a human error analysis technique, the results of which suggested that explicit inclusion of human error in the root cause model would allow this aspect of human performance to be systematically considered.

In this organization, a very large number of people had already been trained in the use of the existing incident investigation process, and were familiar with its use. It was therefore deemed most practical to introduce structured methods to help investigators, who did not possess specialist human factors expertise, to 'step-out' of the existing process, where they wished to analyse why people behaved as they did, and formulate appropriate recommendations to influence future behaviour.

The following principles were applied to the design of the analysis toolkit:

- tools to be based on sound analytical methods, supported by existing research;
- methods designed to help the investigator reach their conclusions on the basis of evidence gathered;
- methods to be suitable for use by trained investigators, who are not human factors specialists;
- toolkit capable of being imparted via a 2-day training course, delivered by internal company personnel;
- toolkit to permits analysis of intentional and unintentional unsafe behaviour and identification of trends suggestive of a problem with certain aspects of safety culture;
- provide written support, guidance and examples for investigators.

A four-step process was developed, supported by structured worksheets, which allowed investigators to

(1) Accurately define and describe the behaviour(s) they wished to analyse.
(2) Determine, on the basis of the evidence available, whether it appeared the behaviour(s) were intentional or unintentional.
(3) For intentional behaviour, apply ABC analysis.
(4) For unintentional behaviour, apply human error analysis.

ABC Analysis

The method chosen to analyse intentional behaviour was ABC analysis. ABC analysis (Komaki *et al.*, 2000; Health and Safety Executive, 2002) is a well-researched and validated technique for understanding why people intentionally behaved as they did (in this case violate a working practice or procedure). It is applicable to any intentional behaviour, not just safety behaviours.

The ABC model is so called because of the three elements involved in understanding why people intentionally behaved as they did:

A refers to **A**ntecedents, which come before the behaviour and prompt or trigger behaviour.
B refers to the specific **B**ehaviour we are interested in.
C refers to the **C**onsequences of that behaviour for the person involved.

The ABC model assumes the following three propositions are true:

- Behaviour is largely a function of its consequences.
- People do what they do because of what happens to them when they do it.
- What people do (or do not do) during the working day is what is being reinforced.

Most unsafe behaviours do not involve people deliberately intending to harm themselves or others. From their point of view, their behaviour usually makes perfect sense. ABC analysis helps the investigator understand, from the other person's point of view, the antecedents (which triggered the unsafe behaviour), and consequences (which reinforced the unsafe behaviour). Once this is understood, antecedents and consequences can be rearranged (and written into recommendations) in such a way that will make it more likely that the person involved, and others in a similar situation, will behave safely in the future.

Antecedents trigger the behaviour or enable the behaviour to occur at least once. Consequences encourage the behaviour to occur regularly. Arguably much traditional health and safety management activity is devoted to providing antecedents for desired behaviours (e.g., training, suitable equipment, signs, procedures), and less attention is given to how consequences reinforce safe and unsafe behaviour, For this reason, ABC helps the safety professional gain additional insight into what influences safe and unsafe behaviour.

An ABC analysis begins by defining the antecedents of the behaviour. Antecedents can be the presence or absence of factors such as suitable tools and equipment, other peoples' example and procedures.

After the antecedents have been defined, the consequences of the behaviour are described from the perspective of the person who was involved. Examples of consequences include getting injured or harmed, saving time and getting approval from a supervisor or manager.

Each consequence is then assessed for the following, from the perspective of the person who performed the behaviour:

Positive/Negative—from their perspective, if this consequence occurred, would it be positive or negative? Note that getting injured or harmed will usually be assessed as negative.
Immediate/Future—from their perspective, does this consequence occur immediately after the behaviour (now or soon) or in the future?
Certain/Uncertain—from their perspective, is it relatively certain that this consequence will occur, or somewhat uncertain? Note that getting injured or harmed will usually be assessed as something which is uncertain (i.e., it has not happened to me yet, so it won't happen today).

Positive, Immediate and Certain consequences influence behaviour much more strongly than Negative, Future and Uncertain consequences do.

Having fully described the problematic behaviour, the next steps in the process are to define:

- a safe alternative to this behaviour;
- which antecedents will help to ensure that this behaviour is triggered; and
- the type of consequences that will help to reinforce the behaviour.

The results of the analysis can then be turned into practical recommendations to reduce unsafe behaviours and introduce new, safe alternatives to replace them.

Human Error Analysis

Various forms of human error analysis (HEA) have been widely used in a number of industry sectors, although the specific tools used for the purpose vary. The tool that was developed here is loosely based on an approach originally developed for use in air traffic control, which was designed to integrate into an existing incident investigation process (Shorrock and Kirwan, 2002). Unlike many such tools, this form of HEA was designed to be used by incident investigators who were not human factors specialists, and so assumes little or no knowledge in the field of psychology and human behaviour. The existing air traffic control approach required extensive development so it would be suited to the differing demands of the process industries.

The human information-processing model proposed by Wickens (1992) describes four stages of human information-processing and performance, namely perception, memory, decision-making and action. When performing any task, people perceive information about the outside world using all of the senses, and may use this information along with information retrieved from memory to arrive at decisions that are used to determine and execute action.

A human error can occur as a result of a failure in any of these four stages, as the following process industry examples illustrate:

- Perception error—misperceive a reading on a display
- Memory error—forget to implement a step in a procedure
- Decision error—fail to integrate various pieces of data and information, resulting in misdiagnosis of a process upset
- Action error—inadvertently operate the wrong device (e.g., a valve).

To find out why these four types of error happen, it is necessary to establish what caused the failure in that part of the human information-processing system, i.e., what were the underlying psychological factors? As well as explaining why an error has occurred, the underlying psychological factors also give us strong indications as to what we can do to prevent such errors, or reduce their impact.

It is also necessary to be mindful of the fact that human performance in general is very heavily influenced by the conditions under which people perform. Such conditions are known as performance-shaping factors, and can help to further clarify why an error occurred, and also provide a great deal of extra information to help specify a practical solution. Examples of performance-shaping factors, which may increase the likelihood of error, include very high workload, poor ergonomic design of equipment and displays, and inadequate training.

The HEA technique described, supported by a worksheet, allows the investigator, on the basis on the evidence gathered, to

- classify which type of error was involved (Perception, Memory Decision, Action);
- identify any performance-shaping factors;
- understand the underlying psychological error cause, each of which is linked to a set of example solutions, which can be further developed for specific circumstances.

To help the investigator, each error type is accompanied by industry and everyday examples, and a comprehensive checklist of performance-shaping factors.

Trialling of Methods

A draft tool-set comprising worksheets and associated guidance and examples was prepared. An experienced chemical engineer and incident analyst was trained in their use, and used them to independently analyse and reanalyse a range of safety, environmental and commercial incidents involving intentional and unintentional unsafe behaviours.

Initial results were encouraging, as the human factors analysis tools led to

- recognition of the contribution of human error, and appropriate corrective actions;
- more effective recommendations to address intentional violations;
- praise from the regulator for the added value the tools delivered to the reinvestigation of an environmental release;
- requests from operational managers for human factors analysis for all high-potential incidents.

Peer Review

Prior to finalization of the tool-set, and widespread implementation of training in their use, a peer review was held. This involved scrutiny by internal company HSE professionals, and a range of external human factors experts from the process industry, regulatory, academic and aviation domains. The proposals, methods and draft tool-set were supported, and some minor suggestions for improvement implemented.

Use to Date

Implementation in the first client organization involved a train-the-trainer model. The authors ran a 2-day pilot course for 20 delegates, which included four internal company staff who subsequently trained approximately 100 of their most-experienced incident investigators worldwide. The next stage of implementation involves training a larger number of less experienced incident investigators. The 2-day course involved minimal theoretical input, with the majority of time being spent working in small groups to apply the methods to a range of real incidents, identify and analyse errors and violations, and formulate recommendations which were compared to a set of model answers.

Subsequently a similar approach has been taken with three other organizations in rail maintenance and contracting and offshore engineering. With these organizations, it was necessary to develop some industry-specific case studies and examples for the course delegates to work upon.

Safety Culture Analysis

For one organization, their existing root cause analysis model was cross-referenced to a proprietary safety culture model, the Safety Culture Maturity®[1] model (Lardner *et al.*, 2001). This allowed trending of root causes from a series of incidents to determine whether they indicates common failings in the ten elements of the safety culture model, namely

- Visible management commitment
- Safety communication
- Productivity versus safety
- Learning organization
- Health and safety resources
- Participation in safety
- Risk-taking behaviour
- Trust between management and front-line staff
- Contractor management
- Competence.

The results can then be used to determine the need to analyse safety culture using all 10 elements or a sub-set of these elements.

RESULTS

By now approximately 200 incident investigators will have been trained from many nationalities, with varying levels of experience, drawn from across four different organizations and three industry sectors.

Results to date indicate that it is possible to train incident investigators, typically from an engineering background, to successfully use human factors techniques to analyse errors and violations, thus adding insight into why incidents occurred, and how they can be prevented in the future. One of the most significant learnings for many delegates concerned making the distinction between intentional and unintentional behaviour. Many commented that prior to being trained in these methods, all unsafe behaviour was treated as if it was intentional. The result was that discipline may have been inappropriately applied, and the root causes of human error were not established, resulting in repeat incidents.

In the first organization, the internal trainers were able to deliver the course materials to their colleagues, but found this quite challenging as they did not have a deep knowledge of the underlying theory. In the other three organizations, the authors delivered the course.

The following examples illustrate how the methods have added value to existing methods.

Analysing a Violation: an Example

Process control operators applied a series of safety overrides to maintain production, without first conducting a risk assessment and involving their supervisor, as specified in plant procedures. As a result, product vented from a knock-out drum, resulting in an environmental release. The initial investigation focused on the violation by the operator, and recommended discipline, briefings, rewriting the procedure and retraining.

Further analysis by an investigator trained in the human factors methods revealed that plant management had tacitly encouraged the application of over-rides to maintain production, and had inadvertently reinforced this practice. Also, it was established that the over-ride key was kept in a readily-accessible location, which allowed over-rides to be used without supervisory involvement. Additional recommendations, which flowed from the human factors analysis, ensured management's role in ensuring production versus safety conflicts was strengthened, and required removal of the key to the supervisor's custody. Without these additional recommendations, the initial recommendations would have limited effect.

Analysing an Error: an Example

An incident occurred where the lid of a rail-tanker filled with hazardous liquids was not closed prior to the train's departure, resulting in a potential for spillage. Initial investigations had focused on the 'carelessness' of the loading operator. A human factors analysis was requested.

It was established that this type of incident had occurred on a number of occasions, and had involved several different operators, all of whom had hitherto been considered careful and competent employees. It was established that the rail-car filling operation was a complex task, with many procedural steps. The radio communications system was not working, and the back-up communication system required the operator to interrupt the loading task to access a phone. The human factors analysis categorized the problem as a memory error, influenced by the performance-shaping factor of interruptions from the phone. A simple solution was proposed, which involved issuing a plastic seal for each rail tanker lid, to be fitted after loading of each tanker was complete. If the loading operator was left with any plastic seals, this indicated a lid remained open. The radio communication system was also fixed. Interestingly, management's reaction to these findings and recommendations were that they had expected something more complex and expensive to implement.

Despite these encouraging results, reaction to the tool-set has not been entirely positive. A few course delegates have had an unrealistic expectation that human factors will deliver a 'magic bullet', which will quickly and easily turn unsafe behaviour into safe behaviour. Also, some incident investigators hard-pressed for time have been disappointed to find that human factors analysis involves additional effort to that already devoted to incident investigation. Inevitably a deeper level of analysis will take more time.

Some have commented that they would also like to see human factors methods used in a more proactive fashion, rather than be used only in a retrospective fashion to analyse incidents which have occurred. This is a fair comment, and we would certainly not advocate only applying human factors tools and techniques for incident analysis. However, the specific objectives of these projects were to deepen understanding of human factors in incidents. We have found that where it is possible by this route to demonstrate added value, it opens up an opportunity to discuss the benefits of a more proactive approach.

[1]Safety Culture Maturity is a Registered Trade Mark of The Keil Centre Ltd.

Another observation concerns delegate's interest and willingness to analyse human behaviour using methods which are initially unfamiliar. Our experience has been that not all delegates are equally willing to embrace the new approach, preferring to stick with their existing understanding of human behaviour. Whilst it is difficult to generalize, our impression is that less-experienced investigators tend to be more open to experimenting with and using the human factors analysis tools.

DISCUSSION AND CONCLUSIONS

It is considered unlikely that the results obtained in this series of projects are untypical of other UK process industries. Current analysis of human behaviour in incident investigation is often relatively superficial, thus missing opportunities to improve human performance and prevent incidents recurring. A specific weakness is understanding of human error, which is much better understood and managed in other domains, for example aviation.

In these projects it has proved possible to improve the human factors competence of internal company incident investigators, who are not human factors specialists, and thus have a lasting influence on safe behaviour.

Whilst the results of this series of projects have been largely positive, two challenges remain. The first is to streamline the methods to be more readily used by busy incident investigators operating under considerable time pressure. In doing so, a balance has to be struck between simplicity and ease-of-use, and maintaining sufficient rigour. The second challenge is to be more selective in the choice of delegates for this type of training. It is not necessarily the most experienced investigator who will most readily grasp and use the methods, or act as an advocate for their use. Future selection criteria should include a keen interest in understanding human behaviour; an open, enquiring mind, and a willingness to suspend judgement until the analysis is complete.

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