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Whose fault is it anyway? A practical illustration of human factors in process safety

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Abstract

Major process accidents have typically occurred not through a single failure, but through a combination of events, some of which had contributors from past actions and failures (latent or unrevealed failures). People are integral and key features of business systems; therefore systems, tools, and equipment should be designed with the potential capabilities and limitations of people in mind. This paper demonstrates the benefits of using human factors approaches to improve system safety and reliability. Practical examples from past experience are quoted and a framework for human error prediction is described. Guidance is given on the practicalities of deriving recommendations from these types of studies.

Keywords: Human factors; Human error; Process safety management; Predictive human error analysis

1. Introduction

Despite numerous incidents attributed to human factors, the importance of the proper treatment of human factors within the process industry has not yet been comprehensively accepted. This paper presents a clear definition of human factors within the process safety environment, and demonstrates the value of predictive human error analysis (PHEA) as a tool to improve process safety. Examples are used to illustrate the key human factors issues arising and to demonstrate their relation to process safety management.

Consider your morning coffee shop stop! While you are attempting to fumble through your wallet before you have had your mandatory intake of fuel, the people behind the counter have upset conditions on their hands—too many grouchy patrons and too little time. In order to move the process along, shortcuts are taken. This occurs every morning, and nothing ever goes wrong ... right? It just so happens that this morning, a new blender has been installed. Joe Java, who is exhausted from a late night on the town, turns it on without closing the lid, and frozen coffee frappe billows over onto the floor. This has happened before too, but no one has fallen on it ... until now.

Human factors issues are at the core of this small-time process safety related incident. An individual knew the protocol, broke the rules, and caused an accident. In this case, one human factors incident relates to a number of typical PSM issues, such as management of change, pre-startup safety review, training and operating procedures. Additionally, as a result of the incident, emergency response was required, and an accident investigation was conducted.

Although a coffee shop is not what we typically think of when we think of process safety and human factors, if we can see the risk in our morning coffee, we can only imagine the implications human factors can have on our daily tasks at our facilities. Human factors relates to the interaction of people, systems, products and machines in their working environment. When we understand what individuals are capable of doing, what limitations they have, and what a person may do in a given situation, we can start to understand how to optimize their performance for our business.

This paper supports the philosophy that people are integral to business systems; therefore, systems, tools and equipment should be designed with the potential capabilities and limitations of people in mind. When we recognize these potential differences we can better appreciate the ways in

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which systems, procedures, working environments and people should interact with each other for optimum business performance.

2. Background

The importance of the human factors contribution to safety has been demonstrated over the past decades by the often-quoted examples of the contribution of human failure to major accidents within the process industry. Given this demonstration, it is surprising that the value of assessing human factors has not yet been comprehensively accepted throughout the industry. So what is *human factors*?

A recent definition of human factors as related to the process industry comes from the UK health and safety executive:

> "Human factors refer to environmental, organizational and job factors, and human and individual characteristics which influence behavior at work in a way which can affect health and safety" [1].

This definition is in line with that inferred by The International Association of Oil & Gas Producers (OGP) human factors framework and by a number of other common frameworks (see Fig. 1). Each of these frameworks represents a potentially wide scope of activities; the figure therefore provides only a high level description of areas of interest. This is almost inevitable as the nature of human interaction within business systems covers a diverse spectrum of issues. The benefit of utilizing frameworks like this is that they can be used to help highlight potential areas of interest and provide a starting point for our evaluation.

The areas of potential concern listed in Fig. 1 can be assessed using many different types of tools and techniques. Bearing in mind the interaction between all human factors activities, approaches can be selected that best suit the current organizational problems. It is also possible to use the frameworks as the basis for developing a "human factors" audit of the organization, which can then be used as a diagnostic tool to identify areas of potential improvement. Some examples of the types of questions that may be asked are listed below:

- Has the task been designed according to human capabilities and limitations?
- Is the environment suitable for carrying out the task?
- Has the organization made sufficient supervisory, training resources and procedures available?
- Have the operators been involved in writing procedures?
- Does the organization promote a positive safety culture?

2.1. Understanding the causes

The coffee shop incident described earlier is intended to be typical of the types of incidents that may occur in process plants, where the potential hazards are much greater. Major accidents that have happened in the past have typically occurred not through a single failure but through a combination of events, some of which had contributors from past actions and failures (latent or unrevealed failures). A cursory analysis of the coffee shop incident may have led to the following conclusions:

- The immediate cause of the problem was a human error in not following the procedures.
- The root cause of the problem was insufficient training.

Further investigation may have prompted a manager to recommend carrying out a hazard identification exercise on the process or at least on the new equipment. Given the

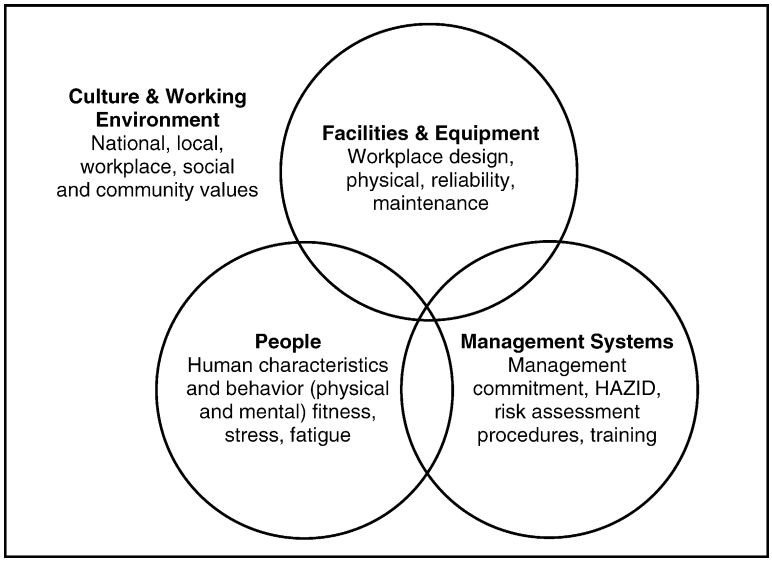

Fig. 1. OGP Human factors framework (International Association of Oil and Gas Producers, http//info.ogp.org.uk/HF/).

nature of the incident, an obvious recommendation from a technical perspective would be to provide an interlock between the lid and the blender.

There may then be a temptation to consider the problem solved and assume it cannot happen again. However does this type of analysis provide enough detail to take meaningful actions for preventing recurrence? In this simple incidence perhaps so, but in a real scenario it is unlikely. There must also be a mechanism for understanding the detailed reasons for the failure and for proactively investigating whether they may arise in other similar processes. The human factors framework that was illustrated in Fig. 1 provides a mechanism through which we can develop a more detailed understanding of the incident from a human factors perspective. Some sample questions that could be posed are further developed below.

2.2. Task design

Has the task been designed according to human capabilities and limitations? There are a number of human performance features that are well known, yet these factors are not always reflected in the design of equipment. One of these factors is that people are known to make errors; it is a natural part of our behavior and cannot be avoided. However, this is not to say that the undesired consequences of errors cannot be avoided. We must design systems that are *error tolerant* and that give the operator the best chance of recovery. In order to do this, a system can be analyzed in order to predict the types of errors that could be made. A number of popular models describe the types of errors that can be made. One of the most common models is Reason's (1990) distinction of slips, lapses, mistakes and violations [2].

- Slips are failures during the actual execution of actions, speech, etc. (i.e. 'actions-not-as-planned'). The plan itself may or may not be acceptable.
- Lapses are failures at the storage or recall stage (i.e. forgotten information, planned actions, etc.). Again, the plan may or may not be acceptable.
- Mistakes are errors in the selection of objectives (or faulty intentions) or the means to achieve them (the plan). So intended actions may proceed as planned, but fail to achieve their intended outcome. Mistakes are generally more difficult to detect, since the feedback may be that "all is going according to plan."
- Violations are situations where operators deliberately carry out actions that are contrary to organizational rules, operating procedures, etc. In some cases, it is possible for routine violations to become the normal way of working (e.g. to save time, because the rules are too restrictive, lack of enforcement, etc.). Situational violations occur due to such situations as time, pressure, staffing shortages, unavailable equipment, or poor weather. Exceptional violations are rare and occur when something has gone wrong.

The benefit of this error classification model is that it can be used to provide the basis for a *predictive human error analysis*. Predictive human error analysis is a term used to describe a number of techniques that allow an analyst or team of analysts to identify potential human errors that may occur within a process or procedure.

A number of methods can be used to carry out PHEA; an example of what a PHEA may look like is illustrated below.

The application of these types of tasks has proven effective, particularly when examining procedural tasks. The application is also possible, although more complex, for decision making tasks. Looking back at the coffee shop example, using this approach would not only have identified the potential for not replacing the lid but also for committing any other similar errors that may occur within the process.

When applying these techniques it is sensible to gain maximum benefit from the process by not only considering safety but also quality and production.

2.3. Environment

Is the environment suitable to carry out the task? From a human factors perspective, the assessment of the working environment is usually considered in safety terms to identify and assess performance shaping factors (PSFs). PSFs are factors that can influence the probability of the operator/controller or other personnel being able to perform the task reliably. These factors usually form a part of the overall PHEA approach (see Table 1). An illustration of typi-

Table 1
Example PHEA sheet format (Kirwan, 1990)

HTA task step	EEM	Recovery step	PEM	Causes, consequences and comments	Recommendations		
					Procedures	Training	Equipment
51.1	Action too late	No recovery	Place losing error	Overfill of tanker, resulting in dangerous circumstance	Operator estimates time/record s amount loaded	Explain hazards of overfilling	Fit alarm-timing/ volume/tanker level
51.2	Action omitted	52.4	Lapse of memory	Feedback when attempting to close closed valve. Alarm when liquid vented to vent line			Mimic to show valve positions

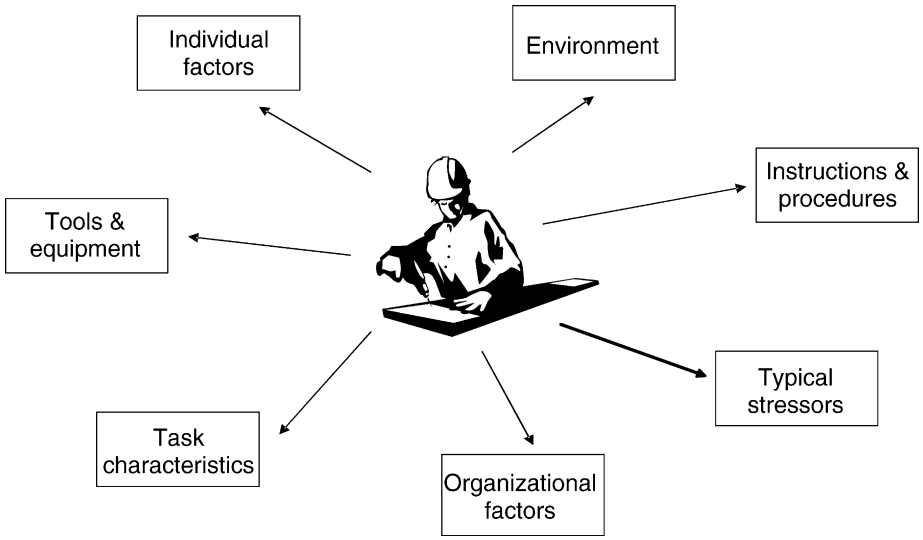

Fig. 2. Examples of performance shaping factors.

cal PSFs is shown in Fig. 2. In the coffee shop example, the most significant PSFs were likely to be around the typical stressors that may occur with any job and any new employee, for example time pressure and inexperience. Given an understanding of the potential effect of these PSFs on behavior, we can predict an increased potential for error. Armed with this knowledge the solution is to look for some way of minimizing the potential effect of the PSF. In this simple example, one way of doing this is to look at the arrangements for training and induction within the organization. While all employees eventually have to learn to cope with these types of situations, it is not likely to be the most conducive environment for a new employee or for any sort of training to occur. Perhaps the organization should put a process into place where initial training is only conducted during the quieter periods of the day, when there is less pressure and it is more likely to have time for better quality training.

2.4. Organizational provisions

Has the organization made sufficient supervisory, training resources and procedures available? At the coffee shop, training is carried out on the job by the senior person who is in the shop at the time. On-the-job training is a commonly used training mechanism, and it can be very effective for routine tasks; however, it also has its limitations particularly with respect to infrequent events or tasks. Aside from the timing issues described earlier, there are some key indicators for optimizing the effectiveness of this type of training.

- Trainers are able to set the right example, have a desire to act as a trainer and have received some instruction in 'how to train.'
- The trainee is introduced as an extra member of the team, not a replacement in the first instance.
- Some record is kept of what has been covered and what progress has been made.
- On job training is used as part of an overall training program.

The important human factors issue is that the trainee is developed at an appropriate pace and is not exposed to scenarios with which he is not able to cope. The idea of being thrown into the deep end seldom results in first class performance. While there may be a short-term cost to providing the appropriate training and ensuring appropriate supervision or staff rosters, in the long-term the benefits of improved performance and competence will be apparent.

2.5. Culture

What is the culture of the organization? In the coffee shop, there are indications that some problems exist within the organization's culture. Shortcuts are mentioned as occurring frequently, and unsafe conditions (spills) are also allowed to exist. There are tools and techniques available to analyze these situations.

Shortcuts are examples of violations, as described earlier. The importance of the classification of violations is that it gives valuable insight into how to address the potential problem. Punishment is seldom an effective deterrent, especially if it is a routine violation that everyone commits.

That a spill occurred, and spills had occurred previously, could indicate a number of potential issues in the organization, for example, allowing unsafe conditions to persist. Perhaps awareness of hazards and education is not high? Perhaps a behavioral safety program may be beneficial? Whatever the solution, one way of diagnosing the problem is to run a safety culture survey or safety climate survey. Many such surveys are available, and their application can generate a wealth of useful information about the organization.

However, be aware that having asked people to participate, it is essential that the results are disseminated and actions are taken. If employees do not see results and improvements, the exercise soon becomes just another fruitless initiative, and further exercises of this sort will be very difficult.

3. Explicit ties to process safety

A main issue at the heart of the coffee shop debacle is the person–process interface and the ways in which it influences the performance of Java Joe. Although it would be excessive to implement a full process safety management system at the corner coffee shop, classically applying PSM-related principles may improve efficiency and reduce the risk of accidents.

When analyzing human factors issues, it is essential to review the operator/process and operator/equipment interfaces, the number of tasks individuals must perform and the frequency, the potential for extended or unusual work schedules, the clarity and simplicity of control displays, and automatic versus manual procedures, etc.

3.1. Management of change

The new blender is not a replacement-in-kind. Although it performs the same functions as its predecessor, it is the newer, stronger, faster model. While the original blended at a high speed, it was possible to blend the frothy fuel sans lid without spurting from the spout. The new equipment works at industrial strength and blends at a faster rate of speed; therefore, blending without the important lid results in sending your morning drink billowing out the top and onto the counter and floor.

A simple management of change procedure would have brought to light the new design and higher speed. The procedure would also have a trickle-down effect requiring new procedures, and training to ensure all employees understood the differences between the two pieces of equipment prior to operating the new blender.

A method for managing change may have uncovered the need for a simple interlock preventing the blender from running until the lid was fastened securely.

Management of change is essential in our plants. The fact that an action seemingly as harmless as preparing a caffeine-deprived client's coffee requires such a procedure demonstrates how important it is to manage change.

3.2. Operating procedures and training

In this case, extensive procedures and associated classroom training are not necessary; however, an introduction to the new equipment and its features would have been appropriate. Effective procedures would ensure each employee was aware of the changes before beginning his or her shift.

In relating procedures and training to human factors, such issues as busy mornings, upset conditions, broken equipment and sleep-deprived employees, must be addressed. These conditions are similar to those addressed by the procedures and training provided at a chemical plant. In these, each operating phase is addressed, such as, initial startup, normal operations, temporary operations, and emergency operations. In addition, the procedures and training address operating limits and consequences that may result when deviating from these limits. In the coffee shop scenario, the limits and consequences will be less extensive than those found in a process plant; however, it is important to be prepared for scenarios that may prevent the process from running smoothly.

3.3. Incident investigation

If the coffee shop had taken a process safety approach to incident investigations, near misses would have been reported and assessed. The knowledge that spills had occurred in the past and the improvements implemented following the report may have reduced the likelihood of this incident occurring. Although the extent of the incident is not as catastrophic as a release of hazardous chemicals, reviewing incidents with employees, understanding the events that led to the incident, and taking steps to avoid recurrence is important in maintaining a safe work environment.

4. Conclusions

To demonstrate the interwoven elements of PSM and human factors, consider the following scenario which is taken from personal experience:

A number of years ago, a major petrochemical company contracted one of the authors to carry out a predictive human error analysis on a safety critical procedure. The purpose of the short assessment was to demonstrate the application of the technique with a view to assessing its potential value for a more widespread application.

The task selected involved manually draining water from a series of eight liquefied petroleum gas spheres. The procedure involved opening a series of valves and observing the effluent until the product was visually detected. A search of incident databases revealed that a serious accident had previously occurred in South America, where the operator had left the drain valve open while going off for a cigarette.

The first task was to walk and talk through the procedure with the operators. Two different versions of the procedure were identified, neither of which included correct reference to the current layout of the system. Investigation showed that the formal management of change procedure had been bypassed as the switch for implementation was, at that time, based on a financial limit. Consequently, eight small-scale changes had been made!.

The results of the analysis highlighted a number of potential errors in the system. The most obvious being the potential to leave the discharge open leading to a loss of product and potential vapor cloud. Interestingly, during the internal consultant review of the analysis, the engineer involved suggested that the immediate and total solution was to use a spring-loaded valve on the discharge. According to the engineer, using the suggested valve would mean the incident could never occur; however, from a human factors perspective this was actually not the total solution.

The design of the system was such that the operator had to walk past the discharge pipe outlet to leave the area; therefore, the likelihood of the operator leaving the valve open in "error" was considered very low. However, should a plant emergency occur, there would be a higher likelihood of this "error" occurring, because the operator would want to vacate the area quickly. The most realistic potential problem was that the operator may want to take a shortcut (a violation) in the overall process, and would find a way to keep the spring-loaded valve open if he so desired. This highlighted a *cultural*, *training* and general *risk awareness* issue. Therefore using this approach recommendations were made to address cultural, training, and awareness issues, but additional recommendations also addressed potential scenarios that had not yet occurred. The recommendations were guided by the fact that this was an existing facility with a limited remaining lifespan.

What this example illustrates is that the obvious technical solution does not always account for the range of potential human factors issues that need to be considered when trying to find the optimal solution. The issues surrounding this assessment ranged from cultural and training issues and implementation of management systems to the *actual behaviors* of people at the plant.

Returning to the coffee shop, the narrative demonstrates the many potential ways in which an incident can be analyzed. In this case, traditional analysis methods would have likely identified the same issues as have been described in this paper; however, in a more complex scenario it is important to obtain a level of understanding detailed enough to reveal real avenues for improvement. An understanding of human factors and application of appropriate human factors techniques facilitate this level of detailed understanding.

Additionally, it is much better to prevent an incident than to allow it to happen; therefore, human factors principles are most powerfully applied when used in a predictive mode. In particular, PHEA is a very powerful method of improving system reliability and safety. There is a degree of overlap between PHEA and other forms of hazard identification, such as HAZOP; as a result, organizations should look for the most appropriate method to fit with or compliment their existing approaches.

This paper has aimed at demonstrating the value of understanding human factors within the process industry. There are now a plethora of human factors techniques available to compliment existing approaches. In order to improve safety records, it is time for organizations to consider the use of these approaches and select those that will yield the most benefit. When analyzing human factors issues, it is important to remember:

> "If the technology is difficult to use, if working conditions are poor, if information is presented in a manner which is difficult to interpret, or if staff are inadequately trained performance will be adversely affected. This applies equally to technology which is required to help run the organization (e.g. information of technology to new products)" [3].

Whose fault is it anyway?

References

[1] Health & Safety Executive, HSG48, Reducing Error and Influencing Behaviour, HSE Books, 1999.
[2] Reason (1990) as quoted in B. Kirwan, A Guide to Practical Human Reliability Assessment, Taylor and Francis, 1994.
[3] Advisory Council on Science and Technology, People, technology, and organizations: the application of human factors and organization design, 1993.