MANAGING THE HUMAN CONTRIBUTION TO RISK AT MAJOR HAZARD INSTALLATIONS

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INTRODUCTION

Human Factors is a relatively new area for many organisations and the aim of this paper is to provide an introduction to the discipline and also outline key guidance material that the Health & Safety Executive (HSE) has developed in relation to managing human factors. In particular the paper will describe a good practice approach that major accident hazard installations can follow to make the demonstration that the human contribution to risk is being properly controlled.

REGULATORY BACKGROUND

The Control of Major Accident Hazard Regulations 1999 (COMAH) apply to any establishment in the United Kingdom that stores or handles certain quantities of dangerous substances[1]. It requires that the Operator of the establishment take 'all measures necessary to prevent a major accident and limit their impact on people and the environment'. The COMAH regulations are enforced by a competent authority (CA) consisting of the Health and Safety Executive and the Environment Agency or in Scotland, the Scottish Environment Protection Agency. The Regulations place duties on the CA to inspect activities subject to COMAH and prohibit operation of an establishment if there is evidence that measures taken for prevention and mitigation of major accidents are seriously deficient. The CA charges for work it undertakes on COMAH. Charges are made on an actual basis, i.e. the recovery of the full costs of the time spent carrying out COMAH-related activities for a particular establishment.

Operators of establishments holding larger quantities of dangerous substances (i.e. top-tier sites) are required to prepare a document setting out their policy for preventing major accidents (or MAPP) and a safety report describing measures to prevent and mitigate major accidents[2]

HUMAN RISK AND ALARP

COMAH places a general duty on all operators of hazardous installations to take all measures to prevent major accidents and limit their consequences to people and the environment. By requiring measures both for prevention and mitigation there is recognition that all risks cannot

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[1] 'The dangerous substances' which cause the duties to apply are detailed in schedule 1 of the Regulations as are the quantities which set two thresholds for applications, e.g. any establishment storing/handling >200 tonnes of Natural Gas is a top-tier site (>50 tonnes for Lower Tier). For Chlorine, the threshold for lower and top tier is 10 and 25 tonne respectively.

[2] Other duties of COMAH top-tier sites include: updating safety report after significant changes or new facts/information become available; a requirement to review the safety report every five years to ensure content remains accurate; prepare and test an on-site emergency plan to deal with consequences of a major accident; supply information to local authorities for preparing and testing off-site emergency plans; and provide information to the public who could be affected by an accident, e.g. details of dangerous substances, possible major accidents and their consequences and what to do in the event of an accident etc.

be completely eliminated. Prevention is based on the principle of reducing risk to as low as is reasonably practicable (ALARP)[3]. In essence, making sure a risk has been reduced ALARP is about weighing the risk against the sacrifice needed to further reduce it. In most cases, decisions about risk and the measures that achieve ALARP involve a comparison between the control measures a duty holder has in place, or is proposing, and the measures the Competent Authority (HSE) would normally expect to see in such circumstances, i.e. relevant good practice. Good practice can be defined as "those standards for controlling risk that HSE has judged and recognised as satisfying the law, when applied to a particular relevant case, in an appropriate manner".

RELEVANT GOOD PRACTICE AND HUMAN FACTORS

HSE guidance document L111 *A guide to the Control of Major Accident Hazard Regulations 1999 (as amended)* sets out relevant good practice in relation to the consideration of Human Factors. It states that where reliance is placed on people as part of the necessary measures to prevent major accident hazards, then Human Factors (including human reliability), should be addressed with the same rigour as technical and engineering measures. To understand better what is meant by this statement it is necessary to define "Human Factors".

What are "Human Factors"?

Human Factors is a hybrid discipline that uses theories and constructs from other subjects to help understand and improve human performance - its principles, standards and techniques are not simply 'common sense', although most of its subject matter is not complex. In a nutshell, Human factors refer to all those things that need to be controlled to obtain reliable human performance in a task. In the UK, the term '*ergonomics*' is often used to describe the same subject area. HSE guidance on human factors '*Reducing error and influencing behaviour'* (HSG 48) defines Human Factors as environmental, organisational and job factors, and human and individual characteristics which influence behaviour at work in a way which can affect health and safety. This definition includes three interrelated aspects that must be considered: the job, the individual and the organisation:

- The Job: including areas such as the nature of the task, workload, the working environment, the design of displays and controls, and the role of procedures. Tasks should be designed in accordance with ergonomic principles to take account of both human limitations and strengths. This includes matching the job to the physical and mental strengths and limitations of people. Mental aspects would include perceptual, attentional and decision making requirements.
- The individual: including his/her competence, skills, personality, attitude and perception of risk. Individual characteristics influence behaviour in complex ways. Some characteristics such as personality are fixed; others such as skills and attitudes may be changed or enhanced.
- The organisation: including work patters, the culture of the workplace, resources, communications, leadership and so on. Such factors are often overlooked during the design of jobs but have significant influence on individual and group behaviour.

In other words, human factors is concerned with what people are being asked to do (the task and its characteristics), who is doing it (the individual and their competence) and where they are working (the organisation and its attributes), all of which are influenced by the wider societal concern, both local and national.

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[3] For environmental risks, prevention is based on the principle of using the best available technology not entailing excessive cost (BATNEEC).

Why are Human Factors important?

Research indicates that Human Factors contribute to up to 80% of workplace accidents and incidents. There are numerous examples of where failure of people at many levels within an organisation has contributed to a major disaster:

- Piper Alpha (UK), July 1988: 167 workers died in the North Sea after a major explosion and fire occurred on an offshore platform. A breakdown in communication at shift handover and a failure of the permit-to-work system were identified as contributory factors. The Cullen report was also highly critical of the Safety Management System of the owners of the platform, Occidental Petroleum.

- Esso Longford Gas Explosion (Australia), September 1999: 2 workers died and 8 others were injured when hydrocarbon vapour from a ruptured heat exchanger ignited causing a burning vapour cloud. The Royal Commission formed to investigate the cause of accident found poorly designed plant, inadequately trained personnel, excessive alarm and warning systems (workers had become desensitised to possible hazardous occurrences), degraded levels of supervision and poor communication of safety critical information at shift handover. The commission concluded that the company's "safety culture" was more oriented towards preventing lost time due to personal injuries and ill health rather than protection of workers from major accident hazards.

- Ladbroke Grove (UK), October 1999: a 3-carriage commuter train went through a red signal and collided with an in-bound high-speed-train. The two trains smashed into one another at a combined speed of 130 mph killing 31 people. The signal in question, SN109, had been passed at danger no fewer than 8 times in the 6-year period, 1993-1999. During the Inquiry that followed Ladbroke Grove, Lord Cullen spoke of "lamentable failures in the system" and "institutional paralysis of the rail industry and the regulator".

- BP Texas City Disaster (USA), March 2005***:*** 15 workers were killed and 170 injured due to loss of primary containment by overfilling of a vessel resulting in the formation of a large flammable vapour cloud that subsequently ignited. The United States Chemical Board (CSB) and the James Baker Panel identified numerous 'human factors' failings including high turnover of refinery plant managers (change management), high workload of control room operators, inadequate training, fatigue from shiftwork and overtime, poorly designed distributed control system, outdated and ineffective safety critical procedures. The CSB report also noted how, similar to Longford, a reliance on the low personal injury rate at Texas City as a safety indicator failed to provide a true picture of process safety performance and the health of the safety culture.

- Buncefield (UK), December 2005: Vapour from thousands of gallons of petrol ignited causing an explosion measuring 2.4 on the Richter scale. It was Britain's most costly industrial disaster, destroying nearby businesses and leaving 43 people injured. The safety system in place to shut off the supply of petrol to the tank to prevent overfilling failed to operate. Petrol spilled out of vents in the tank roof and cascaded down the side of the tank. As overfilling continued, a vapour cloud formed (the mixture of petrol with cold air) and drifted towards a nearby industrial estate where it found an ignition source. The main explosion at Buncefield was unusual because it generated much higher overpressures than would have been expected from a vapour cloud explosion. Research is still being carried out to understand the mechanism of the violent explosion. However, the investigation into the immediate and underlying causes of the incident has focused on the switch used in the ultimate high-level alarm system. To test correct operation, a lever or plate fitted to the head of the switch is moved to simulate a high level of liquid in the tank. It is postulated that failure to put the test lever/plate back to its correct position lead to the switch being inoperative and therefore, the ultimate high-level detection system not working. The Buncefield investigation board have recommended overfill prevention systems be installed that automatically stop the supply to a dangerously full tank by means which are fully independent of the tank gauging system and the operator.

MANAGING THE HUMAN CONTRIBUTION TO RISK - COMMON PITFALLS

The lack of effective management of human factors was identified as a contributory factor in the causation of the above incidents. In particular, the analysis revealed several 'human factors' concerns (or common pitfalls) that HSE regularly encounter when inspecting high hazard sites. These can be summarised as follows:

Operator error versus system and management failures

In general, most safety activities in complex systems are focused on the actions and behaviours of individual operators - those at the sharp end. There is a tendency for organisations to blame accidents on the acts or omissions of an individual without considering the more fundamental failures which led to the accident, failures which are more deeply rooted in the organisation's design, management and decision-making functions. However, operators are sometimes set up to fail when they inherit system defects created by poor design, incorrect installation, faulty maintenance and bad management decisions (Reason, 1990). The argument can be made that front-line operators were set up to fail in several of the examples given above and so it is increasingly important that the role of management and organisational factors be considered when addressing the human contribution to risk.

Process Safety versus personal safety:

Investigations of the Esso Longford and BP Texas incidents found there to be a focus on personal and occupational safety rather than on process safety and major hazard issues. According to Gall (2008), the debate over process versus personal safety has gone on for some time but recently, there seems to be some concern among human factors specialists that organisations fail to understand the issue. It would appear that central to this concern is the 'accident triangle' or 'accident pyramid' approach to safety improvement. Heinrich's research published in 1931 is often quoted as the starting point, but his findings have been supported by later studies. The numbers may differ slightly but Heinrich's examination of a large amount of incident and accident data suggest that, for every 300 'unsafe acts' encountered in an industrial plant, there will be 29 minor injuries and one major injury. The theory is that by reducing the 300 unsafe acts, there will be a corresponding reduction in major and minor injuries. The problem with this approach is that organisations often go for the 'easy wins' and will develop initiatives to reduce, for example slips, trips and falls. These are important and they are common, but this focus can lead to major hazard organisations taking their eye off process safety and the arrangements that need to be in place to reduce the incidence of low probability, high consequence events. In other words, the causes of personal injuries and ill-health are not the same as the precursors to major accidents and are not an accurate predictor of major accident hazards. This focus can result in sites being unduly complacent about process safety performance, which in turn can lead to an underestimation of risk.

Hardware versus human issues

The third concern relates to the imbalance between hardware and human issues. Despite the growing awareness of the significance of human factors in safety, particularly major accident safety, the focus of many sites is almost exclusively on engineering and hardware aspects, often at the expense of 'people' issues. For example, a site may have determined that an alarm system is safety critical and have examined the assurance of their electro-mechanical reliability, but they then fail to address the reliability of the operator in the control room who must respond to the alarm. If the operator does not respond in a timely and effective manner then this safety critical system will fail. Furthermore, it is not always possible to engineer-out human performance issues. All automated systems are still designed, built and maintained by human beings. For example, an increased reliance on automation may reduce day-to-day human involvement, but the knock-on-effect will be an increase in maintenance activity, where performance problems have been shown to be a significant contributor to major accidents. In addition, where the operator moves from direct involvement to a monitoring/supervisory role of a complex control system, they will be less prepared to take timely and correct action in the event of a process abnormality. In these infrequent events the operator, often under stress, may not have 'situational awareness' or an accurate mental model of the system state and the action required. Certainly this was the case in the Buncefield incident where despite the automatic tank gauging system failing to show an increase in levels, it did show a rising temperature in the tank which should have indicated to the control room operative that the tank was filling.

Identifying good practice in relation to managing the human contribution to risk.

Based on the discussion of key human factors issues, it is possible to identify 'good practice' in relation to managing the human contribution to risk as involving consideration of:

- the human acts and omissions that can that can initiate, mitigate and prevent major accident sequences (rather than a narrow focus on personal/occupational safety);
- the wider management and organisational factors that influence behaviour (rather than just focusing on individual front line operators);
- human performance capabilities and limitations when designing and implementing risk control systems, e.g. Human-machine interfaces, control room operations etc.

The remainder of this paper will describe a proactive process which incorporates the identified elements of good practice. The methodology can be used by Major Accident Hazard installations to assist with making the necessary demonstration that the human contribution to risk is being properly controlled.

PROCESS FOR MANGING THE HUMAN CONTRIBUTION TO RISK IN SAFETY CRITICAL TASKS

The process is described in detail in HSE's Human Factors Toolkit (HSE, 2004) and involves six key steps as follows:

1. Identify activities with the potential to affect major site hazards;
2. Prioritise MAH tasks;
3. Break down of the task/activity into its constituent parts, e.g. Task Analysis
4. Identify potential human failures;
5. Identify factors that make failures more likely;
6. Implement appropriate risk management strategies

Step 1: Identify activities with the potential to affect major site hazards

The first step involves reviewing documentation such as site procedures, risk assessments, training plans (and if they exist, safety reports) in a bid to identify safety critical tasks[4]. It is important to focus on activities that relate to major accident hazards where human failures have the potential to lead to significant consequences[5]. Activities which will require further analysis include:

- tasks that have the potential to initiate a major accident sequence (e.g. inappropriate valve operation causing loss of containment);
- tasks designed to mitigate the consequences of failures (such as activation of ESD systems, control room activities etc);
- tasks designed to prevent an incident (e.g. maintenance of safety systems).

Step 2: Prioritise tasks

Resource should be targeted at the most critical tasks by using a systematic process to prioritise the identified tasks. A number of risk screening techniques exist for ranking tasks in terms of criticality (e.g. HSE 1999) and a multi-disciplinary team is recommended for screening tasks in terms of:

- The likelihood of errors being recovered at a later stage in the process i.e. what warnings, planned checks exist to capture error prior to its consequences being realised etc;
- The complexity of the task in terms of how many steps does it involve? Are they simple or complex etc?
- How familiar the operator is with the task? i.e. how often does the operator encounter the task as opposed to how many times the task takes place.
- If the task requires safeguards/controls to be defeated? i.e. as part of the procedure the task requires the operator to remove, inhibit or take off line some equipment that under normal operating conditions is designed to provide defence against release of a hazard (e.g. alarms defeated, trip systems over-ridden, safety valves isolated and/or changes to the configuration etc)?
- How much impact do human actions have upon the probability of hazard release i.e. what degree of human interaction is there between operators and control equipment?

Step 3: Break down of the task/activity into its constituent parts, e.g. Task Analysis

The next stage of the process involves developing a clear understanding of how the tasks are carried out. An incomplete understanding will significantly reduce the accuracy and validity of the analysis. Recognised Human Factors techniques, such as Task Analysis, can be used to decompose the task and existing procedures can also be used as input into the analysis. It is important that operator experience be harnessed as some aspects of the procedures may be incorrect, or not represent current best practice. One advantage of task analysis is the ability to break tasks into meaningful, bite-sized pieces. The analysis should seek to identify the purpose of a series of steps. Task experts often explain what they do but don't describe why they are doing it. These pieces, or chunks, are useful in terms of describing the task to an outsider, but are also useful later when carrying out the risk analysis. For example, certain pieces may be more important than others from a MAH perspective and can be subjected to greater scrutiny. By limiting each step for analysis to a single action, this process can also be used as an opportunity to review existing procedural support.

[4] Some critical tasks may be undocumented.
[5] A task may be a physical action, a check, a decision-making activity, a communications activity or an information gathering activity.

Step 4: identify potential human failures

As for previous analysis stages, the identification of possible human failures for each task step is best done as a team. A list of guide words[6] can be used to help structure the analysis and tease out potential human errors, including physical and mental, intentional and deliberate, e.g.

- Action Errors (e.g. task not completed);
- Checking errors (e.g. check omitted);
- Information retrieval errors (e.g. wrong information obtained);
- Information communication errors (e.g. information not communicated);
- Selection errors (selection omitted);
- Planning errors (plan omitted);
- Violations (deliberate deviation from rule/procedure).

Step 5: Analyse factors that make human failures more likely

Performance Influencing Factors (PIFs) are the characteristics of people, tasks and organisations that influence human performance and therefore the likelihood of human failure. PIFs include time pressure, fatigue, design of controls/displays and the quality of procedures. Evaluating and improving PIFs is the primary approach for maximising human reliability and minimising failures**.** PIFs will vary on a continuum from the best practicable to worst possible. When all the PIFs relevant to a particular situation are optimal, then error likelihood will be minimised. It is important to look for PIFs that are dominant in the task step being assessed (rather than all possible PIFs). To assist with this, HSE have developed a range of techniques and methodologies for exploring PIFs known to have a strong influence on human performance and which tend to be rooted in an organisation's design, management and decision-making functions. The following are examples of guidance/assessment material that has been developed in this area (the list is not exhaustive)[7]:

- *Fatigue Management*: HSE have developed a fatigue index tool to asses the level of fatigue experienced by shift-worker(s) based on a set of parameters that include: commuting time, workload, breaks and the shift rota. The tool allows different shift working arrangements and rotas to be easily compared in terms of risk (i.e. the average risk of an accident/incident occurring) and fatigue (i.e. the predicted values of sleepiness). In addition to this, HSE have released guidance that aims to improve understanding of shift work and its impact on health and safety (HSE, 2006).

- *Staffing arrangements:* practical methodology developed for assessing whether staffing arrangements are sufficiently robust, particularly in relation to controlling abnormal and emergency conditions. The assessment has two parts: The 'Physical' assessment looks at the ability of staff to detect, diagnose and recover hazardous scenarios whilst the 'Ladder' assessment benchmarks organisational factors in relation to industry best practice. The methodology has been developed so that it can be completed by non-experts.

- *Usability and reliability of procedures*: several sources of guidance are available to help organisations develop accurate, fit-for-purpose, and reliable operating procedures. A key part of the guidance relates to determining the level of procedural support needed for a task. For example, high criticality, complex and rarely performed tasks will require a full step-by-step procedure. For other 'simple' tasks,

[6] A form of human HAZOP using human factors guide words) adapted from the *Systematic Human Error Reduction and prediction Approach* or SHERPA (Embrey, 1986).
[7] HSE guidance/assessment material also exits for managing other PIFs such as safety critical communications, supervisor effectiveness, change management, control room design and human-computer interfaces (HCI)- see HSE's Human Factors website for further details: www.hse.gov.uk.humanfactors/

which are regularly performed and the consequence of error is low, a job aid, containing some key information, may be more appropriate etc. Guidance material also exists on writing procedures so that they promote human reliability e.g. HSG 48 (HSE, 1999).

- *Alarm Management*: simple and practical guidance has been developed on how to recognise and deal with typical human-factor problems involving alarm systems, e.g. alarm flooding, poorly prioritised alarms, sub-optimal control room ergonomics etc. In addition, The Engineering Equipment and Materials Users Association (EEMUA)[8] have produced guidance on the design and optimisation of alarm systems for industrial processes which HSE has adopted as 'authoritative good practice' (e.g. EMMUA 191). The EEMUA guidance includes recommendations for alarm system performance metrics, e.g. average alarm arrival rates (normal and upset), number of standing alarms etc.

- *Training & Competence*: this is a key strategic inspection topic for HSE[9] and guidance on how to assess competency management systems (CMS) is currently being piloted within the Hazardous Installations Directorate of HSE. In summary the methodology focuses on 4 areas: (i) how competence criteria are identified by breaking tasks/activities into their component skills and knowledge; (ii) how competence based selection & training are managed to ensure right people are recruited and provided with necessary knowledge and skills to do the job to an agreed standard and on a regular basis; (iii) how methods appropriate to competency criteria are used to assess levels of competence; (iv) how competencies are maintained/enhanced, including the provision of refresher training etc.

Step 6: Implement appropriate risk management strategies

The final stage in the analysis involves implementing control measures which are appropriate to the risk. As with all controls, the starting point should be to eliminate the hazard at source (design out) and then reduce by combating the risk (engineer in) and only rely on individual actions as a final resort. When reviewing how to address issues that are identified by the process, it is important to consider human error mechanisms that may underpin the identified failure modes. To assist with this, it is suggested that competent Human Factors support be provided (e.g. Registered Member of the Institute of Human Factors, MIEHF) although in many cases, appropriate risk control measures may already be in place (and if this is the situation it should be clearly documented as part of the demonstration that critical task steps have been systematically and competently analysed). However, control measures should be proportionate to the task risks and may include short term actions, such as corrective maintenance measures through to longer term engineering improvements and/or site wide campaigns such as better labelling of lines and vales etc.

The analysis and management of human factors issues is an ongoing process and should form part of an organisations' risk management activities. Managing the human contribution to risk should be seen as a leadership issue and therefore, somebody with the suitable level of authority should be appointed to ensure that identified improvements to human factors risk control are implemented, (e.g. a 'controlling mind' for Human Factors).

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[8] The Engineering Equipment and Material Users' Association (EEMUA) is a European based, non-profit distributing, industry Association run for the benefit of companies that own or operate industrial facilities. EEMUA aims to improve the safety, environmental and operating performance of industrial facilities in the most cost-effective way.

[9] In June 2009 HSE published "The health and safety of Great Britain – Be part of the solution". One of the goals of the strategy is to reduce the likelihood of low frequency, high impact catastrophic incidents. Competence to manage major hazards is a strategic inspection topic across HID in supporting this goal and is included in intervention plans for major hazard duty holders.

CONCLUSION

Human Factors is a relatively new area for many organisations and this paper has provided an introduction to the subject area and described the interface with key health and safety legislation in the UK. It outlined the requirement for high hazard organisations to address Human Factors with the same rigour as technical and engineering measures. A methodology for doing this was described, the first stage of which involves identifying human tasks/activities that have the potential to initiate, mitigate and prevent major accident sequences. Subsequent stages include developing a clear understanding of how the tasks are carried out (task analysis) and identifying the potential human error mechanisms that may underpin the identified failure modes. A key aspect of the process involves analysing the performance influencing factors (PIFs) that make these failures more likely. To assist with this, and reflecting the shift in theoretical perspective on human error from an individual to a 'systems failure' approach, HSE have developed guidance and assessment material on areas such as fatigue management, staffing arrangements, procedural compliance, alarm management , training and competence. It is recommended that once appropriate control measures have been implemented (with reference to the preferred hierarchy of controls), senior management should ensure that human factors remain an ongoing part of the organisations risk management activities. If an operator of a COMAH establishment cannot demonstrate that a process is being followed for managing the human contribution to risk, then HSE will consider formal enforcement action under the duty to take all measures necessary to prevent a major accident and limit their impact on people and the environment.

Finally, it is hoped that the paper has demonstrated the need to take a proactive approach to managing the human contribution to risk. As previous incidents such as Piper Alpha, Esso Longford and BP Texas have demonstrated, waiting for an incident to happen in order to reveal an opportunity to improve is a practice that can have catastrophic outcomes where human factors are concenred.

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