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Categorization and standardization of accidental risk-criticality levels of human error to develop risk and safety management policy

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ABSTRACT

In addition to increasing mechanization, technology upgradation and process automation, safety enhancement in systems operation is one of the key parameters of productivity improvement. Now, it is an established fact that human error plays a crucial role in accidents and needs to be addressed adequately in risk and safety management. This paper aims at assessing, categorizing and setting standards for human error risk and criticality of system activities. Based on the classification and standardizations of human error rate, consequences of human error and criticality index of errors, different policy decisions for risk and safety management are suggested. The proposed methodology has been demonstrated with reference to the system activities of an underground coal mining system. However developed method can be equally adapted to other systems.

1. Introduction

Continuous pressure for safely increasing productivity coupled with growing awareness about the safety standards has boosted industries to highlight the safety and risk issues. Various industries have agreed that human errors play the crucial role in accidental property damage, personal injury, and sometimes even death (Bennet and Passmore, 1985; Trager, 1985; Rimmington, 1989; Chadwell et al., 1999; Hobbs and Williamson, 2003; Ung et al., 2006; Chen et al., 2012). Injury and fatality rates in industries which have harsh and hazardous workplace environment, as in mining, are unacceptably high compared to their counterpart industries. Paul et al. (2005), Paul and Maiti (2007) and Ghosh and Bhattacherjee (2007) have studied the effect of demographic, behavioral, and environmental factors on personal injuries of mine workers in India. Landre and Gibb (2002) have reported that mining has only 1% of global work force, but it is responsible for 5% work related fatal accidents. A study by the US Bureau of Mines found that almost 85% of all mining accidents can be attributed to at least one human error (Rushworth and Tallbot, 1999). In Australia, two out of every three occupational accidents can be attributed to human errors (Hobbs and Williamson, 2003). These studies show that analysis and management of the human error aspect need to be integrated into the design criteria to reduce inherent designed error opportunities and enhance error recovery chances for improving the safety status of the systems.

Major policy decisions in risk and safety management are based on the analysis of past incidences. Accident data do not tell the type of error(s) behind the accident, and it may be inferred from the retrospective analysis of information related to the nature of the activity, crew members and the manifestation of error. Rivera et al. (2011) have rightly said that there is no clearly defined boundary for the membership of a particular type of error as the cause of an accident. Elimination or reduction of human error from various stages of a system to augment its safety and productivity necessitates a detailed analysis of human error (Swain and Guttmann, 1983). Several industry specific techniques have been developed for human reliability analysis (HRA) and error modeling. This restricts the sharing of knowledge, information and data in intra-domain analysis and management of human error. One of the most popular Generic Error Modeling (GEMS) approach has been proposed by Reason (1987). He has classified human error integrating behavioral, contextual and conceptual levels. Second generation HRA techniques such as Cognitive Reliability and Error Analysis Method (CREAM) (Hollnagel, 1998) assume that human error occurs due to the error in cognition process, influenced by a set of common performance factors, (CPFs), while A Technique for Human Error Analysis (ATHEANA) (Cooper et al., 1996) assumes

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human error rate (HER) is a function of performance shaping factors (PSFs) and plant reliability. The outcome of the HRA is used to identify weak links in the system and to guide to preparing intervention strategies for safety improvement. In these widely used HRA methods, human error risk analysis depends heavily on the experts' judgements and the consensus of the judges. Therefore, uncertainty is inherently imbedded into the analysis. The proposed model relies much on the statistical analysis of past performance and hence, takes due care of judgemental uncertainty in the analysis.

Risk control and safety enhancement process concentrates on the priority issues. Risk potential based ranking of actions for offshore operation has been proposed by Khan et al. (2006). Maiti et al. (2009) have presented an elaborate retrospective study of Indian coal mine accidents and identified the risk factors and estimated the risk. Khanzode et al. (2010) have ranked the risk potential of mining activities through incident attributes such as 'person', 'system', 'interaction-person' and 'interaction-system'. Maiti (2010) has considered the time between occurrences of injuries and the number of injuries per month to estimate safety performance of an underground coal mining system. These studies fail to address human error aspects adequately in risk estimation. However, assessment of criticality of human errors and devising their management strategies are key to HRA based safety and risk management.

Setting standards for risk criticality is an integral part of system approach to risk and safety management. Risk standardizations provide guidance on how to identify unacceptable risks and their impacts. These are further directed toward the design of enablers for system's risk aversion and safety enhancement. They are devised to avoid, mitigate, and manage risks and impacts of human error as a way of developing safety functions. This study intends to answer the following questions. How are the:

Risk potential of human error assessed?
Benchmark values of different risk levels decided?
Target areas identified for safety improvement?
Risk and safety management policy of human error developed?
Suitable interventions for human errors and their consequences selected?

The proposed methodology is based on retroactive analysis of past incidents/accidents and has been explained in reference to the collected data from the safety division of three Indian underground coal mines. Probable human errors behind every incidence have been accounted and analyzed for error rate, consequences of error and criticality. Risk levels and criticality values have been categorized using k-means clustering technique and cluster boundaries have been drawn by using support vector machine (SVM) as a linear classifier. Developed risk-criticality diagram guided risk and safety management policy has been framed. A graphical representation of the methodology is given in Fig. 1.

2. Human error and its consequences

Human error infests almost every aspect of human life (Peters and Peters, 2006) but often shows no concern at all or little concern. Knowledge and error flow from the same mental sources, and only success can discriminate one from the other (Mach, 1976). One may define errors as the human actions that fail to produce the desired result. Sanders and McCormick (1997) have defined human error as 'an inappropriate or undesirable human decision or behavior that reduces, or has the potential of reducing effectiveness, safety or system performance'. Swain (1989) has described human error as 'any member of a set of human actions or activities that exceeds some limits of acceptability, means out of tolerance performances' and this limit has to be decided by the system. Any wrong action can be justifiable in some system until it does not lead to the occurrence of any incident and later it is categorized as human error. Therefore, human error is a subset of human actions, i.e., responses initiated by the sensory triggers that do not produce the desired result. Sensory organs of humans continuously scan the environment, be it physical or subjective. A change in the environment acts as a sensory trigger. Human response is the sum of four functions, namely perception, attention, memory and action and is activated through sensory triggers. Under or over performance of these four functions change human responses into human errors.

In the literature, many researchers have proposed different (case specific) classification models for human error, but the pioneer works of Rasmussen (1983) and Reason (1984, 1990) are more generic in nature. Common human errors are of five types, i.e., slip, lapses, rule base mistake (RBM), knowledge based mistake (KBM), violation and are adapted in this study for further analysis. A summary of these five types of errors is presented in Table 1.

2.1. Consequences of human error

To identify the risk, associated with human error, it is essential to assess its consequences. Sometimes a little mistake can play a major role in the occurrence of a catastrophe. Therefore, due attention is required for all sorts of error even for a common slip/lapses. Most common errors could have serious consequences for people, industry and environment. But most of the time employees suffer (physically, financially and emotionally) more than the employers. Many researchers Mottiar (2004), HMSO (1993), Mossink and Greef (2002) have discussed the impact of accident. As human errors are one of the major causal factors of accident/incident, these can be indirectly accounted as the impact of human errors also. Following section describes the extent and degree of impact of accident/incident on employee, employer and on environment.

2.1.1. Employee costs

In the aftermath of an accident, the victim, i.e., the employees of an industry is affected both financially and emotionally. The financial and psychological impacts on employees are as follows:

I. *Financial losses:* The amount of financial losses for employees varied greatly on the mode of payment. The largest amount of loss is due to a reduction in salary. The other modes of payment are medical and travel expenses due to injury, loss of savings because of injury. Sometimes, the new salary package of the injured employee may be reduced because of permanent disability, loss of limbs, etc.
II. *Psycho-socially effects:* The pains and suffering of an employee from an accident are hard to measure objectively. Any accident can affect the human being socially and emotionally both, e.g., family members and close friends are depressed and disturbed, and many other social issues may be created which affect the victim negatively. It is not possible to count all.

2.1.2. Employer costs

Although an accident costs highly to the employees, it has substantial impact on the employer too. Firstly, organization incurs huge amount of financial loss due to disturbance in production schedule. Other issues, e.g., employee compensation, medical reimbursement, salary for an absence period of employees, repairing and replacement of tools, public relation and corporate images are also affected negatively by the accident.