Reliability Engineering and System Safety 150 (2016) 22–34

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

journal homepage: www.elsevier.com/locate/ress

Application of activity theory to analysis of human-related accidents: Method and case studies

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ARTICLE INFO

Article history:
Received 24 September 2015
Received in revised form
11 January 2016
Accepted 24 January 2016
Available online 2 February 2016

Keywords:
Accident analysis
Accident model
Human error
Causal factors
Activity theory
Activity system model

ABSTRACT

This study proposes a new approach to human-related accident analysis based on activity theory. Most of the existing methods seem to be insufficient for comprehensive analysis of human activity-related contextual aspects of accidents when investigating the causes of human errors. Additionally, they identify causal factors and their interrelationships with a weak theoretical basis. We argue that activity theory offers useful concepts and insights to supplement existing methods. The proposed approach gives holistic contextual backgrounds for understanding and diagnosing human-related accidents. It also helps identify and organise causal factors in a consistent, systematic way. Two case studies in Korean nuclear power plants are presented to demonstrate the applicability of the proposed method. Human Factors Analysis and Classification System (HFACS) was also applied to the case studies. The results of using HFACS were then compared with those of using the proposed method. These case studies showed that the proposed approach could produce a meaningful set of human activity-related contextual factors, which cannot easily be obtained by using existing methods. It can be especially effective when analysts think it is important to diagnose accident situations with human activity-related contextual factors derived from a theoretically sound model and to identify accident-related contextual factors systematically.

1. Introduction

It has been reported that 70–80% of significant accidents in high-risk industries, such as nuclear power plants (NPPs), are human-related accidents that can be attributed to human errors [1–3]. Thus, a human error has been emphasised as an important issue to achieve system safety. In high-risk industries, the operational experience feedback (OEF) system has been adopted to address the issues of human errors as well as technical failures [4]. The OEF system aims to take lessons from operational experience such as minor incidents or accidents and thus to prevent the occurrence of similar events in the future [5]. To extract useful lessons from the events, the OEF system has paid much attention to the accident analysis and the effective use of analysis results for developing corrective actions to improve system safety. Such an attempt has contributed toward reducing human-related accidents. However, it has been pointed out that accident analysis methods used in the current OEF system are still insufficient in prevention and reduction of human-related accidents [4]. It is thus necessary to develop a new approach to understanding and analysing human-related accidents, which can supplement drawbacks of the current OEF system. A new approach should make the process of analysing accidents more systematic and comprehensive, and produce valid results to be used effectively when designing and improving work systems.

The importance of thorough and valid accident analysis cannot be overemphasised. When the results of accident analysis are not good enough, the corrective actions cannot effectively contribute to the prevention or reduction of human errors [6]. More seriously, it leads to another side effect that analysts may believe that the causal problems of an accident had been resolved [7], and lose out on a chance to identify the latent vulnerability of work systems and take suitable actions.

Particularly, the analysis of an accident needs analysts' deep understanding of work situations surrounding the accident and logical reasoning to identify the probable causes of the accident [8,9]. For this reason, several analysis methods have been developed to support such a cognitive process of analysts [10]. Representative analysis methods are: Human Performance Enhancement System (HPES) [11], Korean-version HPES (K-HPES) [12], Human Performance

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http://dx.doi.org/10.1016/j.ress.2016.01.013

Table 1
Types of human-related accident analysis methods.

	No provision of a set of causal factors	Provision of a set of causal factors
Micro	Type I (e.g., root cause analysis techniques such as change analysis, barrier analysis, event and causal factor charting)	–
(Partly) Meso & Micro		Type II (e.g., HPES, K-HPES, HPIP, CREAM, SOL, TRACEr, HFIT)
Meso & Micro	–	Type IV (e.g., HFACS)
Macro & Meso & Micro	Type III (e.g., Accimap, STAMP)	–

Investigation Process (HPIP) [13], Cognitive Reliability and Error Analysis Method (CREAM) [14], Safety through Organizational Learning (SOL) [15], The Technique for the Retrospective and Predictive Analysis of Cognitive Errors (TRACEr) [16], Human Factors Investigation Tool (HFIT) [17], Accimap [18], Systems Theoretic Accident Modelling and Processes (STAMP) [19], and Human Factors Analysis and Classification System (HFACS) [20–22]. They specify a prescriptive process for collecting, analysing, and integrating data related to human-related accidents. Through the process, they enable analysts to associate an erroneous action with its probable causal factors. The methods described above can be classified into four types as shown in Table 1 by the two criteria: (1) the coverage of causal factors considered during accident analysis, which can be categorized into three levels: macro-level (e.g., government authorities), meso-level (e.g., companies and organisation, human activities), and micro-level (e.g., cognitive information processing of an individual worker), and (2) whether or not they provide a predetermined set of causal factors.

The Type I method is a generalised accident analysis method using root cause analysis techniques such as change analysis, barrier analysis, event and causal factor (E&CF) charting. Although this method is sometimes used by safety practitioners working in the industry, more elaborated types of methods have been developed to support the identification of the comprehensive causal factors related to human errors in a systematic way. As shown in Table 1, most of the methods belong to the Type II method. A causal factor list is provided to help analysts search and identify the probable causes of human errors. A causal factor list is usually developed based on both empirical data and accident models. These methods provide several taxonomies that describe error modes, error mechanisms, and causal factors related to human errors. Type III and IV methods were developed in order to deal with the organisational aspects of human-related accidents more comprehensively, particularly in the analysis of a complex and large-scale accidents [23–25]. These methods make a balance among macro-level, meso-level and micro-level when identifying causal factors, and thus they help analysts to identify various contextual factors.

There is no doubt that the methods shown in Table 1 are useful for understanding human-related accidents and identifying their causal factors. However, it has been pointed out that they still have two areas for improvement [26,27]. First, they derive causal factors based on a careful analysis of contextual factors related to human errors. However, there is a need to improve the way of using contextual factors and their interrelationships consistently in the following accident investigation process: characterizing the context of human erroneous activities, differentiating the important aspects of a human error to be further analysed from those that can be neglected, identifying the initial set of probable causal factors, and determining the most plausible causes from the set. Although this process is conducted based on the actual data on human errors and accidents, the data are usually interpreted based on a personal judgement of analysts. Thus, it is necessary to characterize the situation around human errors and accidents and relate the situation information to causal factors by using the same basis that offers broad, holistic contextual backgrounds of human activities. Second, most of the existing methods that offer a predetermined set of causal factors fail to give a theoretically sound background on the derivation of a set of causal factors and their interrelationships. They are mainly identified on an empirical data without considering a theory on human behaviours; therefore it is difficult to find coherent perspectives on a set of derived causal factors. In order to alleviate this limitation, it is necessary to employ a good conceptual model about human behaviours in a work system when identifying and organising a set of causal factors.

With these issues in mind, we propose a new approach for analysing human-related accidents based on activity theory, particularly to address the two drawbacks described above. This paper is organised as follows. Section 2 describes research backgrounds on human-related accident analysis and activity theory. Section 3 explains the proposed approach comprising four stages. Section 4 presents two case studies where the proposed approach is used for analysing human-related accidents in Korean NPPs, and discusses the characteristics of the proposed method in comparison with other methods. Section 5 gives a summary and describes the limitations of this study that should be further studied.

2. Research background

2.1. Human-related accident analysis

Fig. 1 illustrates the general concept of accident analysis and explains that various factors can influence the process and the outcomes of accident analysis [28]. Those factors include: accident models [29–31], analysis methods [32], analysts' expertise and bias [33,34], and analysts' work environment such as time pressure, available resource, and work practice [7]. Accident models provide a frame of reference to understand and explain how an accident occurs [29]. They can affect the whole process of human-related accident analysis, such as what to look for, which aspects to focus on, and which countermeasures to determine. For this reason, it can be said that the most important factor would be an accident model among those factors.

One of the main purposes of accident analysis is to identify a meaningful relationship between the concerned events (i.e., human errors) and their causal factors in the accident sequence. In the case of human-related accidents, causal factors are identified from various contextual factors, which are often called as performance shaping factors (PSFs) [35]. The PSFs influence human behaviours or cognitive process, and as a result, enhance or deteriorate human performance [33]. Several methods for human-related accident analysis provide their own pre-defined PSFs that analysts can selectively use during the whole process of analysing accidents. The existing sets of PSFs have different numbers of elements, varying degrees of depth and inter-dependency, and there is not a standard set of PSFs commonly used [36,37]. Organisational influences on human performance and safety have been in the spotlight in the past decades [38–40]. As a lesson learned from serious accidents such as Chernobyl accident, Challenger disaster, and Fukushima accident, organisational factors have emerged as one of the essential elements to prevent and mitigate accident situations [41–43]. Reflecting such an importance of organisational factors of human-related accidents, it has been emphasised that PSF models should address organisational perspectives.