Safety Science 50 (2012) 1569–1583

Contents lists available at SciVerse ScienceDirect

Safety Science

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

A fuzzy Bayesian network approach to improve the quantification of organizational influences in HRA frameworks

Li Peng-cheng [a,b,*], Chen Guo-hua [b], Dai Li-cao [a], Zhang Li [a]

[a] Human Factor Institute, University of South China, Hengyang, 421001 Hunan, People's Republic of China
[b] Institute of Safety Science and Engineering, South China University of Technology, Guangzhou, 510640 Guangdong, People's Republic of China

ARTICLE INFO

Article history:
Received 30 April 2010
Received in revised form 15 March 2012
Accepted 20 March 2012
Available online 20 April 2012

Keywords:
Human reliability analysis
Bayesian network
Human error
Organizational factors
Situational factors
Individual factors

ABSTRACT

Organizational factors are the major root causes of human errors, while there have been no formal causal model of human behavior to model the effects of organizational factors on human reliability. The purpose of this paper is to develop a fuzzy Bayesian network (BN) approach to improve the quantification of organizational influences in HRA (human reliability analysis) frameworks. Firstly, a conceptual causal framework is built to analyze the causal relationships between organizational factors and human reliability or human error. Then, the probability inference model for HRA is built by combining the conceptual causal framework with BN to implement causal and diagnostic inference. Finally, a case example is presented to demonstrate the specific application of the proposed methodology. The results show that the proposed methodology of combining the conceptual causal model with BN approach can not only qualitatively model the causal relationships between organizational factors and human reliability but also can quantitatively measure human operational reliability, and identify the most likely root causes or the prioritization of root causes causing human error.

1. Introduction

Statistic analysis shows 20–90% of system failures are related to human factor, of which 70–90% were directly and indirectly initiated (Hollnagel, 1993; Zhang et al., 2001). According to Jacobs and Haber (1994), organizational factors encourage unsafe acts and ultimately produce system failures. Reason (1997) writes: "Human error is a consequence, not a cause. Errors are shaped and provoked by the upstream workplace and organizational factors". To keep system safety he says that "we cannot change the human condition, but we can change the conditions under which people work". Industrial experience and research findings have shown that major concerns regarding the safety of nuclear power plants and other complex industrial systems are not so much about the breakdown of hardware components or isolated operator errors as about the insidious and accumulated failures occurring within the organization and management domains (Davoudian et al., 1994a). Catastrophic accidents (Flixborough (1974), Seveso (1976), Three Mile Island (1979), Bhopal (1984), Challenger (1986) and Chernobyl (1986)) in high-hazard industries have demonstrated that organizational factors are the root causes of human errors (Reason, 1997, 1990; ∅ien, 2001). Despite the important role of organizational factors has been recognized, and there are a number of quantitative methods and frameworks (e.g., MACHINE (Embrey, 1992), WPAM (Davoudian et al., 1994a,b), SAM (Pate-Cornell and Murphy, 1996), Omega Factor Model (Mosleh et al., 1997), I-RISK (Papazoglou et al., 2003), 'ASRM (Luxhøj et al., 2001), Causal Modeling of Air Safety (Ale et al., 2006), SoTeRiA (Mohaghegh and Mosleh, 2009)) that aim at quantifying the impact of organizational factors of safety risk, the current methods and models do not include an explicit representation of the possible impacts of organization and management factors on human reliability. Mohaghegh and Mosleh (2009) pointed out that common among many models and methods is to solve three major problems: (1) what are the organizational factors that affect risk, namely, building a set of organizational factors classification; (2) how do these factors influence risk, namely, building a causal model of human error; (3) how much do they contribute to risk? namely, building a quantitative method to quantify the contribution of the factors.

In the part of organizational factors classification, many authors study the classification of organizational factors, for example, a set of 20 organizational factors developed by Jacobs and Haber (1994), a set of 10 categories of organizational factors developed by Thaden et al. (2004), a set of organizational risk indicators developed by ∅ien (2001), a set of three categories of organizational factors developed by Vuuren (1999), they are focused on the classification of organizational factors to identify possible organiza-

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* Corresponding author at: Human Factor Institute, University of South China, Hengyang, 421001 Hunan, People's Republic of China. Tel.: +86 734 8282730.
E-mail address: lipengcheng0615@163.com (P.-c. Li).

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http://dx.doi.org/10.1016/j.ssci.2012.03.017

tional defects. In addition, the quantitative frameworks or methods such as MACHINE (Embrey, 1992), WPAM (Davoudian et al., 1994a,b), SAM (Pate-Cornell and Murphy, 1996), and Omega Factor Model (Mosleh et al., 1997) also have their own set of factors. As organizational complexity and the ambiguity of the complex interactive mechanism of an organization, the relationships between organizational factors is not clear, the term "organizational factors" do not reach a unified definition (for example, Reason (1990) regards organizational error mainly relates to the management decisions and organizational processes similar to resident pathogens that are parasitic in the system. Lee (1995) views organizational factors on safety as matters of management systems concerning NPPs, etc.). Therefore, the classification boundary of organizational factors is no clear. In addition, the classification of organizational factors is not comprehensive, non-specific, and there are duplication, cross, abstract, compound categories such as "stress" is a compound classification.

In the part of the construction of causal model of human error, the various kinds of organizational accident causal models are available that try to link safety or human error with organizational factors, a general – and by now famous – approach is Reason's model of organizational accidents, better known as the Swiss cheese model (Reason, 1990, 1997). The model describes the overall organizational framework for accident causation and the contributing factors including organizational influences, unsafe supervision, preconditions for unsafe acts and unsafe acts in an organizational accident. Embrey builds the generic model called MACHINE (Model of Accident causation using Hierarchical Influence Network), which describes the generic relationships of causal influences of accident causation (Embrey, 1992). Rasmussen and Svedung develop a hierarchical model of the socio-technical system involved in risk management (Rasmussen and Svedung, 2000). At the social and organizational levels of their model, Rasmussen and Svedung use a control-based model, and at all levels they focus on information flow. Leveson develops Systems-Theoretic Accident Model and Processes (STAMP) model to model the whole system from the control point of view (leveson, 2004). In addition, CREAM proposed by Hollnagel builds a set of cause-effect classification tables to capture the causality of human error (Hollnagel, 1998). IDAC proposed by Chang and Mosleh (2007a,bc,d) describes the hierarchical structure, influence paths of the IDAC performance influencing factors and assesses the effects of the performance-influencing factors (PIFs) affecting the operators' problem-solving responses including information preprocessing (I), diagnosis and decision making (D), and action execution (A). Mohaghegh and Mosleh (2009) develop socio-technical risk analysis (SoTeRiA) which describes the influencing paths from organizational factors to accident risk scenarios and formally integrates the technical system risk models with the social (safety culture and safety climate) and structural (safety practices) aspects of safety models. The models or methods related above try to capture the causal relationships between organizational factors and human errors or system safety. However, there exist certain limitations on some aspects of the detailed classification of organizational factors, the influence relationships between organizational factors and other contextual factors, and usability of models or methods, etc. For example, the classification of elements of Reason's Swiss cheese model is not specific, IDAC does not describe the causal relationships between organizational factors and other contextual factors, SoTeRiA is relatively complex due to lack of structured analytical framework, and thus it is not very convenient to use in practice, etc. In the part of the quantification of the contribution of the factors, the traditional HRA methods such as THERP (Swain and Guttmann, 1983), CREAM (Hollnagel, 1998) partly consider the impacts of organizational factors on human reliability, they are looked as influencing factors to revise basic human error probability (HEP). However, the classification of Performance Shaping Factors (PSFs) is not completely separate and orthogonal, and there exists certain mutual influencing relationships among PSFs, thus it leads to the possibility of double-counting of effects, which can have spurious effects on the HEP calculation and reduces the accuracy and quality of analysis results. In order to model the causal relationships between PSFs including organizational factors to improve the quantification level of HRA, several of the methods use variations of the Bayesian Belief Network (BBN) or the Influence Diagram, System Dynamics (SD) approach and hybrid model technique, for example, MACHINE (Embrey, 1992) uses Influence Diagrams to link human error to organizational factors, and it quantifies probability of human error or accident on the basis of data obtained by expert judgment. Yu et al. (2004) use a System Dynamics approach to assess the effects of organizational factors on nuclear power plant safety. System Dynamics modeling can capture the dynamic aspects of organizational influences and take into account nonlinear dynamics, feedback, time delays, and interdisciplinary aspects. Mohaghegh (2007) thinks that System Dynamics is a powerful tool to model the pattern of organizational behavior, but without a comprehensive knowledge about the organizational behavior, System Dynamics applications can be very misleading. Mohaghegh and Mosleh (2009) develop a hybrid technique to incorporate organizational factors into probabilistic risk assessment of complex socio-technical systems on the basis of the proposed set of principles. The hybrid technique integrates System Dynamics (SD), Bayesian Belief Network (BBN), Event Sequence Diagram (ESD) and Fault Tree (FT) into socio-technical risk analysis (SoTeRiA) framework to quantify the organizational safety risk. In the hybrid technique, BBN is used to model human reliability, but the data related to the parameters of human reliability model is obtained by experts, therefore, fuzzy BBN can reduce the subjectivity of expert judgment and the uncertainty of the results. In addition, Reer (1994) presents a new probabilistic method for analyzing human reliability under emergency conditions. It considers two essential factors ("time windows" and "organization of human operations") to quantify human reliability. Furuta and Kondo (1992) build a mathematical model of group process on the basis of the information processing network, analyzes the effects of group organization on human reliability from the aspects of leadership style, connection strengths among group members, emergency assistance styles, etc., and obtained the quantitative results.

In short, a variety of models and methods are developed in these three aspects, but the existing models and methods have some limitations in dealing with the effects of organizational factors on human reliability:

(1) No general and acceptable principles were established to define and classify organizational factors because of their complexity, fuzziness, varieties and less of clear boundaries.
(2) It is hard to establish a causal model to model the effects of organizational factors on human reliability due to the complexity of interactions within an organization.
(3) It is hard to consider and define the relationships and its correlation degree between human activities and internal or/and external performance influencing factors (PIFs) due to lack of data.
(4) It is very difficult to obtain abundant and precise data in regard to organizational factors from industry. Although several human error databases have been built up, the data are less relevant to the organizational factors.

Recently, Bayesian Networks (BN) has been proposed to model the complexity in the man–machine system. It can describe the