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Bayesian network analysis of safety culture and organizational culture in a nuclear power plant

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ABSTRACT

Many high-hazard industries around the world have explicitly recognized the critical role that human, management and organizational risk factors play in major accidents. The findings of accident investigations and risk assessments demonstrate a growing recognition that the cultural context of work practices may influence safety just as much as technology.

The objective of this paper is to establish a relationship between the concepts of safety culture and organizational culture in a Nuclear Power Plant (NPP). This study permits the identification and quantification of the possible mechanisms for improving the safety culture in the NPP acting on organizational culture. It therefore provides a methodology to identify potential strategies for safety improvement.

Probabilistic (Bayesian) Networks (BNs) have been used to determine the relationships between the organizational culture and safety culture in a quantitative form. To this aim, we considered data from a survey conducted of every employee at a Spanish NPP. The resulting data-driven models allow us to establish the probabilistic relationship among organizational culture factors, including the 12 OCI (Organizational Culture Inventory) scales, that have an influence on safety culture. The study yielded a ranking of organizational cultures that can be used to improve safety culture in a NPP.

1. Introduction

Many high-hazard industries around the world have explicitly recognized the critical role that human, management and organizational risk factors play in major accidents (Booth and Lee, 1995; Oien, 2001). An analysis of the main accidents that have taken place throughout history shows that these events cannot be explained by random equipment failures alone, but also by a combination of human and organizational factors. Some of these accidents from the late 1970s and the 1980s include: Three Mile Island accident in 1979 (Kondo, 1996; Le Bot, 2004; Maddox and Muto, 1999); Bhopal gas tragedy on 3 December 1984 (Shrivastava, 1994); Space Shuttle Challenger disaster on 28 January 1986 (Winsor, 1988, 1989); the Chernobyl disaster on 26 April 1986 (Medvedev, 1991; Meshkati, 2007; Misumi et al., 1999; Stanton, 1996); and the explosion onboard the Piper Alpha oil platform in 1988 (Moore and Bea, 1993; Pate-Cornell, 1993).

That is why the incorporation of organizational factors into risk management, measurement and control models took on such importance in the 1990s. For example, PSA, Probabilistic Safety Assessment, is a methodology for quantifying risk in industrial domains. Traditional PSA (Rasmussen, 1997, 1975) does not explicitly account for the influence of organizational factors on accident risk. After conducting an analysis of the main accidents, however, the incorporation of organizational factors into PSA has been addressed by various researchers. Embrey (1992) developed a model based on Bayesian Network (BN) for the inclusion of organizational factors in PSA as applied to the rail transportation sector. (Davoudian et al., 1994a,b) developed an approach, applicable to Nuclear Power Plants (NPPs), called work processes analysis model (WPAM). The WPAM uses a set of twenty organizational factors developed for the Nuclear Regulatory Commission (Jacobs and Haber, 1994). The ASRM (Luxhoj, 2004) utilizes the Human Factors Analysis and Classification System (HFACS). The omega-factor approach is a method that models organizational failures and their influence on NPP safety (Mosleh et al., 1997; Mosleh and Goldfeiz, 1999). The Socio-Technical Risk Analysis (SoTeRiA) extends the PRA framework to include the effects of organizational factors as the fundamental causes of accidents and incidents. This framework

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integrates the technical system risk models with the social (safety culture and safety climate) and structural (safety practices) aspects of safety prediction models (Mohaghegh et al., 2009; Mohaghegh and Mosleh, 2009a,b). Finally, Léger and Weber (2009) developed a method for risk assessment considering three main aspects on the system resources: technical, human, and organizational; the integration is based on system knowledge structuring and its unified modeling by means of BN.

The findings of accident investigations and risk assessments evidence a growing recognition that the cultural context of work practices may influence safety just as much as technology (Antonsen, 2009; Goh et al., 2010). The assumed link between culture and safety, epitomized through the concept of safety culture, has been the subject of intense research in recent years (Antonsen, 2009; Guldenmund, 2007; Kettunen et al., 2007; Mengolini and Debarberis, 2007).

The term "safety culture" was introduced into the nuclear industry by the IAEA's International Nuclear Safety Advisory Group after the Chernobyl accident to denote the management and organizational factors that are important to safety (INSAG, 1986). But safety culture may not capture all of the management and organizational factors that are important to safe plant operation (Sorensen, 2002). The major problem with most existing safety culture models is that they are not integrated into general models of organization and of organizational culture (Grote and Kunzler, 2000).

Organizational culture is a concept often used to describe shared corporate values that affect and influence members' attitudes and behaviors. In the literature, no attempt is made to link or integrate safety culture with organizational culture. The goal of this paper, then, is to establish a relationship between these two concepts of safety culture and organizational culture, in order to determine how to improve safety culture by altering organizational aspects.

The methodology used to achieve this aim relies on Probabilistic (Bayesian) Networks (BNs). Currently, BNs are being applied in different research related to safety (Galan et al., 2007; García-Herrero et al., 2012; Li et al., 2012; Mariscal Saldaria et al., 2012; Zhao et al., 2012). For instance, Zhou et al. (2008) proposed a BN model to establish a probabilistic relational network among causal factors, including safety climate factors and personal experience factors, which exert influences on human safety behavior. McCabe et al. (2008) demonstrated using BNs that the higher the work pressure, the higher the interpersonal conflict. They also showed that low-quality leadership was most strongly associated with work-related health problems and accidents. Martín et al. (2009) used BNs to analyze the factors affecting the performance of tasks that involve a high risk of falls from ladders or from other auxiliary equipment. This enabled them to identify the circumstances that have the greatest bearing on workplace accidents during these activities, such as the adoption of incorrect work postures, the duration of tasks and a worker's inadequate knowledge of safety regulations.

Focusing on people and organizations, the paper by Ren et al. (2008) aims to contribute to offshore safety assessments by proposing a methodology to model causal relationships with a BN capable of providing graphical inter-relationships and of calculating numerical values for the likelihood of each failure event occurring. Bayesian inference mechanisms also make it possible to monitor how a safety situation changes when information flow travel forwards and backwards within the networks.

In this paper we analyze the relationships between organizational and safety cultures in a nuclear power plant (Santa María de Garoña-Nuclenor S.A., Spain) using Bayesian networks. Section 2 defines the concept of organizational culture and describes the organizational culture questionnaire used in the study, that is, the Organizational Culture Inventory (OCI). Section 3 defines the concept of safety culture and explains the questionnaire used to asses safety culture. The methodology is illustrated in section 4. In order to quantitatively establish the relationship of the model, a survey of every employee at the nuclear power plant was conducted in June of 2007; in section 4.1 data acquisition is explained. The survey consisted of two parts: the first part included 120 questions related to organizational culture, taken from the Organizational Culture Inventory (OCI) developed by Human Synergistics International (Cooke and Lafferty, 1987); and the second part, on safety culture, included 35 questions (written by the authors) based on the five components of safety culture defined by the International Atomic Energy Agency (IAEA). The study used probabilistic Bayesian network models to analyze the influence of organizational cultures on safety culture. In section 4.2 Bayesian network models are briefly described. Section 5 shows the results and establish the probabilistic relationship among organizational culture factors, including the 12 OCI scales that have an influence on safety culture. Finally conclusions are developed in the last section; in summary, this study allows us to identify those steps to take so as to improve the safety culture at a nuclear power plant.

2. Organizational culture

Before defining the concept of organizational culture, we must establish the concept of culture. Hofstede (1990) defines culture as "a collective mental approach that distinguishes the members of one group or category from those of another". Culture is acquired, not inherited, and stems from the social environment's effect on the individual, and not from his genes. Therefore, culture can be acted upon, evaluated and improved. Schein (1992) makes reference to the set of values, needs, expectations, beliefs and norms that are accepted and practiced by cultures, and distinguishes among several levels of culture: basic assumptions, values and ideologies, artifacts (slang, stories, rituals and decoration) and practices. Artifacts and practices express managerial values and ideologies.

The concept of organizational culture and/or climate gained much attention in the 1970s and 1980s. In the 1970s, much research was undertaken under the title of organizational climate, with the term "culture" replacing "climate" in the 1980s.

Uttal (1983) defines the concept of Organizational Culture as a system of shared values (what is important) and beliefs (how things work) that interact with a company's people, organizational structures, and control systems to produce behavioral norms (the way we do things around here).

2.1. Organizational culture questionnaires

The four major self-reporting measures for organizational culture are compared (by correlation and factor analysis) by Xenikou and Furnham (1996). These four questionnaires are: the Organizational Culture Inventory (OCI), developed by Cooke and Lafferty (1987); the Organizational Beliefs Questionnaire (OBQ), developed by Sashkin (1983); the Corporate Culture Survey (CCS) by (Glaser, 1983); and the Culture Gap Survey (CGS) by Kilmann and Saxton (1983). The study set out to compare and contrast these different, but supposedly equivalent, questionnaire measures of culture by correlation and factor analysis. The correlation analysis showed the convergent validity of the questionnaires, and the factor analysis yielded six factors (accounting for 70,6% of the total variance) providing a framework of the organizational culture dimensions.

In the model of Xenikou and Furnham the first factor is labeled "openness to change in a cooperative culture" and contained four subscales of the OCI, two subscales from the CGS, and one subscale of the OBQ, and accounted for 33.3% of the variance; the four subscales of the OCI are humanistic orientation, affiliation, achievement and self-actualization, these are the four constructive