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Can belief structures improve our understanding of safety climate survey data?

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ABSTRACT

Questionnaire-based surveys are a standard method used for assessing the safety climate within an organization. However, their analysis – in particular data aggregation – poses several challenges, among which are subjective judgment, incompleteness and uncertainty. This paper explores the use of approaches based on belief structures for aggregating data from safety climate questionnaires. Data relevant to this study were collected through a questionnaire administered to the employees of a nuclear research centre. The results show that, while belief structures may offer a promising way to represent data collected from questionnaires, the existing aggregation methods are not always adequate. Averaging schemes applied to belief structures seem the most suited – among the methods investigated – in the specific problem context analyzed. The analysis of the survey data shows the limitations of quantitative approaches for safety culture assessment and the need to always complement these with in-depth qualitative analysis.

1. Introduction

The investigation of major accidents in the last decades showed that the root causes for many events leading to accidental situations can be traced back to organizational and managerial factors [1,2]. Accordingly, the main focus in safety management started to change in the '90s, from the identification and assessment of "proximal" causes of accidents to more "distal" contributors [3], such as safety culture. This concept was introduced after the Chernobyl nuclear accident of 1986, in the post-accident analysis of the International Atomic Energy Agency [4]. During the '90s, safety culture became a focus point in several other domains [5], such as railways, healthcare, offshore, and aviation.

In the nuclear domain, a well-known conceptualization of safety culture [6] defines it as: *"that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, [nuclear plant] safety issues receive the attention warranted by their significance"* (p. 1).

It can be noticed that most aspects described in the definition above are of intangible nature and can be evaluated only indirectly, by looking at the tangible manifestations they generate [6]. Given its complexity, safety culture assessment requires multiple data collection methods, among which document reviews, observations, focus groups, interviews, audits, expert evaluations and questionnaires [7].

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Linked to the concept of safety culture is that of safety climate, which is defined as capturing the surface features of the safety culture discerned from the workforce's attitudes and perceptions at a given point in time [8]. Safety culture is commonly regarded as a stable characteristic of an organization reflecting its policy towards safety issues and is more difficult to assess than safety climate. In turn, safety climate is considered a temporary state of an organization that is subject to change due to specific circumstances [9] and is typically assessed through questionnaires. As pointed out by [8] and [10], safety climate can be considered as a manifestation or 'snapshot' of safety culture.

A common aim of questionnaires is to provide valid and reliable instruments to measure the most important safety climate factors and to determine their predictive power over measurable safety outcomes such as the number of incidents or the self-reported (or observed) compliance with procedures (see [11]; or, [12] for a review). For the latter purpose, statistical analysis is the standard methodology employed (e.g. [13]; and reviews in [10,12,14]). Alternatives to these "traditional techniques" have also been proposed. For instance, [15] used Bayesian Belief Networks to determine the relationship between organizational culture and safety culture. The study in [10] points out, however, that the answering scales used in questionnaires (most of the time qualitative Likert scales) are most likely not (quasi-)interval scales, which prohibits the calculation of means, variances, correlations and other transformations.

In this paper we investigate the use of belief structures, a concept rooted in the Dempster–Shafer theory of evidence [16], as a framework to model subjective judgment in the presence of uncertain or incomplete information, inherent to safety climate assessment. Belief structures have been used in several domains, including system safety analysis, risk assessment, environmental impact assessment, expert systems, or different applications of multi-criteria decision making [17–21]. In particular, belief-degree distributed fuzzy cognitive maps have been proposed for safety culture assessment [22]. However, the potential role of belief structures for safety climate data representation and aggregation has not been studied yet, to the best of the authors' knowledge.

First, this study proposes a method to map the data collected with a safety climate questionnaire into belief structures. The questionnaire was designed using the safety culture framework of the International Atomic Energy Agency (IAEA) as a starting point, specifically the characteristics and attributes defined within this framework [6]. Next, several aggregation rules are investigated among which a number of averaging schemes and the cautious conjunctive rule [23]. Finally, a prioritization procedure is suggested to infer which safety climate aspects seem the most problematic.

The remainder of the paper is organized as follows. Section 2 summarizes relevant concepts and literature, while Section 3 introduces algorithms for data aggregation. These algorithms are tested on a case study with realistic safety climate data in Section 4. Section 5 discusses the insights gained from this study and Section 6 gives some concluding remarks.

2. Background

2.1. Basic concepts in Dempster–Shafer theory of evidence

The Dempster–Shafer theory of evidence [16] is one of the most influential theoretical paradigms for reasoning with uncertainty. In particular, Dempster's rule of combination [16,24] provides a basic framework for combining independent and reliable pieces of evidence. In this section we briefly summarize the terminology and the mathematical notations that will be needed for later use in Section 3.

Let Ω be a finite set called the set of discernment.

A basic belief assignment (BBA) is defined as a mapping m from the power set 2^{Ω} to $[0,1]$ satisfying the property $\sum_{A\subseteq\Omega} m(A) = 1$. The subsets A for which $m(A) > 0$ are called focal sets. A BBA can be equivalently represented by its associated commonality, belief and plausibility functions [23]:

$$q(A) = \sum_{B\supseteq A} m(B),\ A \subseteq \Omega \tag{1}$$

$$bel(A) = \sum_{\varnothing = B\subseteq A} m(B),\ A \subseteq \Omega \tag{2}$$

$$pl(A) = \sum_{B\cap A\neq\varnothing} m(B),\ A \subseteq \Omega \tag{3}$$

It can be noted that the belief $bel(A)$ expresses the degree to which the evidence supports A, whereas the plausibility $pl(A)$ gives an upper limit of the latter.

A BBA is called *simple* if it has at most two focal sets; if it has two focal sets, then Ω is one of these. Taking up the notation proposed by [23] a simple BBA (noted SBBA) m can be noted A^w, where A is the focal set of m with $A \neq \Omega$, $m(A) = 1 - w$ and $m(\Omega) = w$.

A BBA is called *dogmatic* if $m(\Omega) = 0$, i.e. Ω is not a focal element.

Finally, a BBA will be called a belief structure (term used by [25]) if its focal sets are either singletons or Ω, i.e. they belong to $\{\{a\}\,|a \in \Omega\} \cup \{\Omega\}$.

Let two pieces of evidence on the same set of discernment be represented by two BBAs m_1 and m_2. These can be combined using Dempster's rule of combination which produces a new BBA denoted as $m_1 \oplus m_2$ (also called the orthogonal sum), defined as follows: