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Risk assessment in safety of machinery: Impact of construction flaws in risk estimation parameters

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ABSTRACT

In the risk assessment approach as defined in the International Standard ISO 12100: 2010, risk estimation is an essential step that allows machinery designers and users to determine the level of risk, and to identify the most critical hazardous situations. Previous studies demonstrated that the numerous qualitative tools proposed to estimate risks in safety of machinery take several forms, and that many of their features can significantly influence the level of risk obtained.

In this study, the impact of some of these features was assessed, and construction rules regarding the parameters used in risk estimation tools were validated through an experimental study involving several users mainly from the industry. Five potential construction flaws of the risk estimation parameters were analyzed. The experimental results show that when the users perceive a certain challenge in the utilization of a risk estimation parameter, they are usually able to associate it with the presence of the flaw affecting the parameter. The results also demonstrate quite clearly that the impact of the construction flaws in the parameters is not uniform. In addition to the presence of the flaws within these parameters, the results obtained suggest that the assessment of the probability of harm is a problematic aspect of the risk estimation process in safety of machinery that requires further research. These results could contribute to the improvement of the robustness and the reliability of the existing tools, and help to support the training actually given by the partners in the risk assessment field.

1. Introduction

1.1. Context of the research

Machine-related hazardous situations have resulted in serious accidents in industries (Etherton et al., 1990; Backström and Döös, 2000; Lind, 2008). In order to reduce these hazardous situations, machines must be designed or modified by integrating risk reduction measures. Without making a specific risk assessment, it is difficult to choose optimized means of risk reduction (Lyon and Hollcroft, 2012; Hughes and Ferrett, 2005; Main, 2012; Pickering and Cowley, 2010). Risk assessment is a series of steps used for examining the hazards associated with machinery. It can be divided into two phases, namely (i) risk analysis, and (ii) risk evaluation as explained in international standard ISO 12100 (2010) *Safety of machinery – General principles for design – Risk assessment and risk reduction* (ISO, 2010). Risk analysis usually consists of three stages, namely (i) determining the limits of the machinery, (ii) hazard identification, and (iii) risk estimation. The risk assessment process is followed by the risk reduction process with an iterative approach and it comes to an end when the risk has been adequately reduced.

This article puts emphasis on the risk estimation stage, which consists in estimating the inherent level of risk for each hazardous situation linked to the use of a machine. Risk estimation is the last step in the risk analysis process, then followed by the evaluation and the reduction of the risk. It is hence a critical stage for the prioritization of risk reduction activities. An incorrect estimation of the risk can lead to the implementation of insufficient or inadequate reduction measures on a machine.

1.2. Literature review

According to Standard ISO 12100: 2010 (ISO, 2010), the risk related to a hazardous situation depends on a combination of the two following

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Probability of harm	Severity of harm		
	Slightly harmful	Harmful	Extremely harmful
Highly unlikely	Trivial	Tolerable	Moderate
Unlikely	Tolerable	Moderate	Intolerable
Likely	Moderate	Substantial	Intolerable

Fig. 1. Example of a two parameters estimation tool.

parameters: (1) the severity of harm, and (2) the probability of occurrence of that harm (in further text: probability of harm). The probability of harm can be established from (a) the exposure of the person or persons to the hazardous phenomenon, (b) the occurrence of a hazardous event, and (c) the technical and human possibilities to avoid or limit the harm. Many risk estimation tools using different combinations of these parameters are proposed by organizations involved in the safety of industrial machines, and some companies have established their own methods and tools (Paques and Gauthier, 2007). The primary objective of a risk estimation tool is to rank the different hazardous situations (scenarios) as per the risk indexes they represent in order to identify intolerable (unacceptable) risks and to prioritize interventions. Fig. 1 presents an example of such a tool, a two parameters risk matrix. In this example, both parameters use a three levels scale.

Some experts in machinery risk estimation observed that "*the tools used in different European countries to assess the risks related to a machine, when such methods exist, can give different results, even contradictory. In some situations, they can lead to different levels of safety for a given machine…*" (Charpentier, 2003). A certain difference in risk estimation results can be considered as "normal," hence tolerable, but a gap that is too important can eventually lead to the implementation of inappropriate risk reduction measures (insufficient or excessive) (Parry, 1999). Abrahamsson (Abrahamsson, 2000) emphasized that some potential users of risk estimation tools give them little credibility and regard them as unusable. He also concluded that the uncertainty is inherent to risk estimation, but that the guidelines specific to various industrial sectors could help improve this process (Abrahamsson, 2002).

Uncertainty in risk assessment has been a preoccupation for a number of years. While it is now considered more as an engineering method rather than a scientific method, the quality control and the validity of quantitative risk assessment has been studied by many authors (Goerlandt et al., 2017). Rae and al. questioned the usefulness of such methods and proposed a maturity model to cover their potential flaws (Rae et al., 2014). Efforts have also been made to overcome the reliability issues related to specific risk assessment methods (Khastgir et al., 2017).

However, the utilization of common risk estimation tools in the field of safety of machinery requires the interpretation of information that is often of a qualitative nature, usually using an ordinal scale as defined by Stevens (Stevens, 1946) . Yet, many risk estimation tools are not precise or detailed enough (Chinniah et al., 2011). For instance, a verbal qualitative scale of the type *Highly unlikely, Unlikely* and *Likely* is used in certain tools to determine the probability of harm. Without any other explanation, what is the exact meaning of *Unlikely*? This type of construction can lead to bias within the estimation process, and can significantly affect the final result (Duijm, 2015; Carey and Burgman, 2008; Christensen et al., 2003; Cox, 2008; Patt and Schrag, 2003; Beyth-Marom, 1982).

Nevertheless, and despite questions regarding the validity of risk assessment methods (Goerlandt et al., 2017; Rae et al., 2014; Khastgir et al., 2017) and the issues inherent to ordinal qualitative scales described in the literature (Hubbard and Evans, 2010; Franceschini et al., 2004; Smith et al., 2009; Woodruff, 2005), it is worth considering the intensive use of these scales to assess risks where quantitative data is not readily available, as it is the case in the field of safety of machinery. Moreover, it is important to point out that for safety of machinery, tools that include such scales are intended to be used in the risk estimation step, as defined in Standard ISO 12100: 2010 (ISO, 2010). This last step of the risk analysis must be followed by a risk evaluation step, where the risk index or level is one of the criteria that must be taken for account to decide if further risk reduction is required. Therefore, risk estimation is not an end in itself: it provides information for risk evaluation, where the final decision is taken (Paques and Gauthier, 2007).

There are also numerous benefits linked to the utilization of ordinal qualitative scales in risk estimation tools, such as providing a simple approach and a systematic framework for the assessment of hazardous situations (Ni et al., 2010). Consequently, research needs to be carried out in order to better characterize the conditions in which they are more likely to be useful or detrimental for the decision-making process in risk management (Cox, 2008; Lamy and Charpentier, 2009; Aven, 2012).

Considering (i) the increasing use of qualitative risk estimation tools in the field of safety of machinery, (ii) the great diversity of these tools, and (iii) the significant gap between the results they generate, Paques and Gauthier launched in 2004 a research program aiming to deeply analyze the features of the tools suggested in the literature or used in the industry (Paques and Gauthier, 2006). Two prior studies conducted in this research program showed that the numerous tools allowing to conduct risk estimation are of very diverse types, and that many of their characteristics can considerably influence the level of risk obtained (Chinniah et al., 2011; Paques and Gauthier, 2006; Paques et al., 2005). These studies also demonstrated that the tools showed significant differences regarding the risk estimation for the same hazardous situation. During these researches, flaws in the construction of those tools, likely to influence the result in certain circumstances, have been identified (Paques et al., 2005). A series of construction rules (Table 1) for the risk estimation parameters aiming at eliminating some of these flaws has also been suggested (Chinniah et al., 2011; Gauthier et al., 2012).

These rules potentially reduce the variability observed in risk estimation. They also guide the users to make a choice or help in the improvement of the existing risk estimation tools. However, additional research, through an experimental study involving users from the industry, was necessary to confirm the impact of the flaws of the risk estimation tools, and to validate the construction rules suggested.

1.3. Goals of the research

In essence, risk estimation tools aim at distinguishing in a qualitative manner the most critical risks from the less critical ones. These tools need to be designed in a way that the level of risk obtained by different users when applying a tool to a given scenario is more or less

Table 1
Flaws and construction rules of the risk estimation parameters (Gauthier et al., 2012).

Label of the flaw	Construction rules suggested
No definition of the range of exposure (probability parameter only)	Defining the probability parameters related to the range of exposure
Poor definition of the levels	Avoiding the use of unique or vague terms to define the levels of the parameters
Inconsistent definitions of the different levels	Avoiding the use of the same term or expression in the description of two levels of a parameter
Inadequate number of levels	Using between three and five levels for the severity of harm parameter Using between three and five levels for the probability of harm parameter
Gap between the levels	No discontinuity or gap between the levels of the parameter