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Contribution of dynamic experience feedback to the quantitative estimation of risks for preventing accidents: A proposed methodology for machinery safety

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ABSTRACT

This paper proposes a methodological approach for designing a dynamic risk identification and estimation support tool for machinery safety. Based on a comprehensive literature review and by updating the risks through dynamic experience feedback integrated into quantitative risk estimation, the methodology makes it possible to better equip machinery safety practitioners to intervene effectively. The methodology combines dynamic risk identification and Logical Analysis of Data (LAD) as two potential methods applied in machinery safety. LAD is an artificial intelligence technique introduced to extract information from accident reports in order to analyze machinery-related accidents in the workplace, which has not been covered in previous studies of machinery safety. The practical relevance and feasibility of the proposed methodology are explained using an example involving two accidents that occurred on the same machine in the same sawmill.

1. Introduction

Machinery-related industrial accidents cause significant bodily injuries, in particular death, and reversible and permanently disabling injuries. In the United Kingdom in 2003 and 2004, half of the accidents related to operating machinery were attributable to printing presses and conveyors (Healey, 2006). In Australia between 2003 and 2013, 84 deaths involving moving machinery occurred (Safe Work Australia, 2014). In the United States between 1980 and 1995, machinery was the second main cause of death at work and, from 1992 to 2001, an annual average of 148 fatal and 318,488 non-fatal accidents occurred on operating machinery (Flaspöler et al., 2010). In Canada, 70% of the 1975 deaths occurring between 1990 and 2008 were attributable to machinery and farm equipment (McManus, 2014). In Quebec in 2013, machinery-related injuries totalled 3503, including seven deaths and 800 accidents involving access to moving parts (CSST, 2014).

Chinniah (2015) analyzed 106 serious and fatal accidents linked to the moving parts of fixed machinery that occurred in Quebec between 1990 and 2011. The study identifies the following main causes of accident: easy access to moving parts, lack of safeguarding, bypassing safeguards, absence of lockout procedures during maintenance, lack of training, unexperienced workers, modifications to the machinery and their safety control systems, and lack of risk assessment. Other studies that deal with analysis of machinery-related accidents (Lindquist, 2011; Caputo et al., 2013; Gardner et al., 1999) point to some or all of the same causes.

In the field of safety of machinery, there are hundreds of standards. One important standard is ISO 12100 which describes design principles, risk assessment and risk reduction for machinery. It is intended primarily for machine designers and manufacturers, but is widely used when existing machines are modified or residual risk need to be reduced by end users (e.g. in factories). Although ISO 12100:2010 stresses the importance of experience feedback about machinery-related accidents to be used as inputs for safer machine designs, the use of such feedback in reality is quite limited. One example is the lack of consideration for maintenance activities on machinery by machine builders. This translates in machines which are poorly designed and then exposing maintenance personnel to high risks, as supported by the large number of accidents during maintenance activities. Safety practitioners in the workplace learn from accident causes described in accident reports as well as from near misses (i.e. incidents). However, such learning is based on experience feedback described as static, as the knowledge available in the accident and incident reports is limited to

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case studies. To improve the feedback, a dynamic method which allows new knowledge to be inferred from the information contained in case studies and other circumstantial events seems more adequate. Dynamic experience feedback makes it possible to tap the full potential of accident and incident reports that, at present, are not being used to their fullest.

Moreover, safety practitioners want to choose and apply an optimal risk estimation method that provides useful results with minimal effort (Chinniah et al., 2011). The choice is even more difficult for small and medium-sized enterprises (SMEs) that have few or no risk analysis resources at their disposal. Unfortunately, occupational health and safety (OHS) is often a part time activity for a single resource and optimal usage of the time allocated to risk identification and reduction is crucial. SMEs are considered to be particularly vulnerable to the impact of occupational accidents morally and economically (Programme on Safety and Health, 2013). According to Chinniah (2015), enterprises with limited occupational health and safety resources need, among other things, to prioritize risk assessment or at least hazard identification.

In addition, to reduce the direct costs related to the victim's absence from work or to the production shutdown that occurs when the machine is sealed by a labor inspector for serious non-compliance, safety practitioners should identify and analyze the risk associated with their machines. To do so, they typically use a qualitative risk matrix tool for risk estimation due to its simplicity and the ease of integrating the results into risk management policies. However, risk matrices have limitations in the area of risk ranking (Cox, 2008). It should be noted that probability-based quantitative risk estimation tools are rarely used for machinery safety (Gadd et al., 2003), even if some studies (Cox, 2008; Duijm, 2015) find them more effective than qualitative tools. Quantitative risk estimation is mostly used for process safety involving complex systems and reliability considerations (e.g. nuclear or chemical process installations). Risk quantification for occupational injuries, including injuries caused by moving machine parts, has been studied (Papazoglou et al., 2015; Aneziris et al., 2013; Demichela and Pirani, 2013). However, in qualitative and quantitative methods, the risk estimation is frozen in time. The evolution of the machinery is not integrated in the process. New information about usage is neglected.

Hence, three questions arise from these considerations:

(1) How to help safety practitioners efficiently identify and estimate machinery-related risks?
(2) How to help safety practitioners prioritize risk reduction measures and, at the same time, keep their machines from being sealed by an OHS inspector who identifies a non-compliance with current OHS legislation following a routine inspection or an occupational accident?
(3) How to help safety practitioners monitor risk progression?

To answer these questions, it would be relevant for safety practitioners to have access to an efficient (i.e. that enables targeted prevention), easy-to-use tool that provides information about the risks present in a machine and would enable them both to prevent accidents in order of priority and to avoid having seals placed on their equipment. With that in mind, this paper proposes and describes a methodological approach for designing a dynamic tool to support machinery-safety decisions. This paper aims to introduce two potential methods in the field of machinery safety. These concepts concern dynamic experience feedback integrated into quantitative risk estimation and extraction of relevant information from accident reports using Logical Analysis of Data (LAD) as an artificial intelligence technique. Accordingly, the paper focuses especially on: the comprehensive literature review that leads to the proposed methodology, the description and justification of each step of the methodology as well as relationships between them, and the practical relevance and feasibility of the proposed methodology using an example of two accidents that occurred on the same sawmill machine.

The methodology involves updating the risks by integrating dynamic experience feedback into risk estimation, and integrating LAD into dynamic experience feedback. LAD is a data mining technique and optimization combinatorial algorithm based on Boolean logic. This algorithm is known for its robust performance (even when data is scarce) in medicine, for disease diagnosis and prognosis (e.g. Alexe et al., 2003), finance (Hammer et al., 2009). It is also known for its capacity to characterize and distinguish classes of events. Thus, it is useful for machinery risk identification respecting different contexts of use. Accordingly, it is useful for targeted prevention. LAD has been used neither to occupational safety nor to machinery safety. Thus, proposing LAD for machinery safety is one novelty that this paper brings. What is also original about this approach is that the updating of the probability of a hazardous scenario or event is based on accident reports as well as on new events detected over time through inspections. The combination of these techniques constitutes the added value of the tool over the static qualitative tools generally used in the machinery safety field.

The proposed combination aims first to improve the risk identification and estimation steps of the risk management process in machinery safety (Fig. 1). It then aims to perpetuate the risk estimation process (i.e. update the risk) even if the risk has been adequately reduced. Machine conditions of use can reduce the effectiveness of the risk reduction measures in place, which can in turn affect risk estimation. The risk reduction measures then become insufficient to tackle the new risks.

This technique thus facilitates risk identification since the tool itself will identify the main direct and indirect causes of accidents. Risk estimation will become robust and leave less room for interpretation. Dynamic risk estimation tools are more realistic and thus more effective than static tools, as they reflect the progression of the risk.

The remainder of this paper is divided into five sections. Section 2 presents a comprehensive review of the literature on risk identification and risk estimation tools in machinery safety and on risk management methods used in other engineering fields, as well as the medical and the financial fields. Section 3 introduces LAD technique and explains its main steps to extract information. Section 4 presents the possible contribution of risk management methods from other fields when applied to machinery safety. It also discusses the three questions asked above in light of these results. Section 5 describes in details the proposed methodology for the dynamic tool for supporting decision-making and explains its usefulness with an example. Section 6 presents the conclusion of the paper and further related research areas.

2. Risk analysis – available tools and techniques

In machinery safety, ISO 12100:2010 defines risk as the combination of the probability of occurrence of harm to humans and the severity of this harm (ISO, 2010). The probability of occurrence of harm is a function of: (1) exposure of the person or persons to a hazard; (2) the probability of occurrence of the hazard; and (3) the possibility of avoiding or limiting the harm. As is true for preventing the consequences related to any hazard, preventing machine-related accidents is achieved through an iterative risk management process (Fig. 1) that:

- determines the machine's conditions of use;
- identifies the associated risks that threaten the users' health and safety (hazardous phenomena, situations, and events);