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AHP-based methodology for selecting safety devices of industrial machinery

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ABSTRACT

Safe machines make a major contribution to personnel safety on the workplace. Safety of machines is often guaranteed or enhanced by safety devices. The choice of a safety device involves multiple criteria decision making and a ranking of alternatives according to often contrasting performance measures. In this paper, a systematic methodology for selecting safety measures aimed at reducing mechanical hazards of industrial machinery is presented. The method at first includes a classification of mechanical hazards and applicable safety devices, then introduces an exhaustive list of 15 factors useful to judge the suitability of safety devices for comparison purposes. A comparison of relative importance between the rating criteria is then carried out in the framework of the Analytic Hierarchy Process decision making approach, based on expert opinion, allowing unambiguous prioritization of the above decision making factors. This allows a rapid ranking of alternatives and the selection of the most suitable device for a given machine that suits the mission requirements and the preferences of the decision maker. An application example is included to demonstrate the utilization of the method.

1. Introduction

Workers are killed or injured as a result of hazardous contact with machinery and equipment. According to NIOSH data, from 1980 to 1998 in the USA occupational injury from machinery was ranked third after motor vehicle and homicide as cause of death, accounting fatalities for approximately 13% of the total. The industry sectors that ranked the highest in injury due to machinery were: agriculture, mining, manufacturing and construction. Similar data are reported even for the other industrialized countries.

Some of the leading injuries experienced in these industries were: struck by or against an object, caught in or compressed by equipment, and caught in or crushed in collapsing materials.

Safe machines are, therefore, a prerequisite to ensure personnel safety on the workplace. Safety of machines is often guaranteed or enhanced by safety devices. Strict regulations have been enforced in most Countries dictating specific safety requirements to be satisfied by newly built machines or older ones which are to be maintained in service.

According to European Union Directives 2006/42/EC and 98/37/EC (superseding previous Directive 89/392/EC) machinery needs to satisfy a number of so called Essential Health and Safety Requirements (EHSRs) contained in Annex I of the Directive. To certify satisfaction of EHSRs, a conformity assessment must be carried out, a "Declaration of Conformity" must be given and the CE marking must be affixed. It is an offence to supply and use machinery not complying with the Directives. This applies to the supply and utilization of new and used machinery and other equipment including safety components.

Compliance to Directive can be accomplished by utilizing a hierarchy of methods, namely inherently safe design (to prevent any hazards if possible), adoption of proper safety devices (i.e. Additional Protection Devices, APD), or resorting to Personal Protective Equipment and/or training to contain any residual risk which cannot be dealt with by the above methods. In most cases APDs are adopted given that most operations performed by industrial machinery to process materials are hazardous, unavoidable, and can harm the operator in case he enters in contact with moving parts and working tools.

Then the problem of selecting the right safety device arises and involves a number of parties, namely designers and manufacturers of new machines, sellers, renters, buyers and users of new as well as old machines, those modifying a machine to adapt it to new purposes and those upgrading, refurbishing and reconditioning used machines. The EU certification process involves specific penal responsibilities in charge of those issuing the certification. So that the selection of safety device has relevant effects either on workers safety, and on all peoples involved in the machinery acquisition, installation and certification process.

Provided that the selection of proper safety devices for industrial machinery is often left to designers of new machines or users

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of the older ones, the choice is hard given that a vast array of alternative safety devices is available on the market, that many machines are one-of-a-kind and custom-built so that standard choices are often not allowable, and that the installation of an unsuitable device increases risk to workers. This also means that the designer or user can be held liable of any damage caused by an improper selection of safety devices (Baram, 2007).

The choice of a safety device, on the other hand, is influenced by many factors, such as cost, reliability, effectiveness, risk of neutralization or new hazards creation, work interference potential and so on. As a consequence, the selection of a safety device involves a multiple criteria decision making and a ranking of competing devices according to often contrasting performance measures.

As a contribution to solving this problem in this paper an AHP based approach is thus developed to allow ranking of alternative safety devices, to be used as a decision making tool when selecting the most suitable device for a given machine.

The paper is organized as follows. At first the relevance of machine-related injuries is highlighted by presenting statistical data. Then the critical role of design in providing safe machines is outlined. Subsequently a classification of mechanical hazards and risk factors from machinery is provided. Available approaches to risk assessment are then reviewed. A classification of available safety devices is thus carried out to help in screening the set of safety devices in order to define a subset of alternatives to be ranked. Afterwards, the parameters able to characterize any safety devices are also discussed and a set of decision making criteria is defined. Subsequently the AHP methodology for safety devices selection is described. Finally, a numerical example is presented to practically show the capabilities of the method, and a discussion of results concludes the paper.

2. Relevance of machine-related injuries

According to the European Commission (2009) from 1995 to 2005 the fatal accident rate per 100,000 workers year fell from 4 to about 2.5 in the manufacturing sector while a reduction of about 20% was observed in the non fatal accident rate respect 1995 values. Of fatal accidents at work from 2003 to 2005, 399 involved loss of control of machine, means of transport or handling equipment, 260 being caught or carried away by something or by momentum, and 249 were caused by loss of control of machine (including unwanted start-up) or the material being worked by the machine.

In the UK, according to the Health and Safety Executive statistics (HSE, 2011), 171 workers were killed at work in 2010/11 with a rate of 0.6 fatalities per 100,000 workers, and 115,379 injuries were reported leading to a rate of 462.1 per 100,000 employees; 4.4 million work days were lost due to workplace injury (and 22.1 million due to work-related ill health), while workplace illness and injuries costed society £ 14 billion in 2009/10.

According to Bailer et al. (2003) approximately 6000 US workers died each year between 1980 and 1995 due to occupational fatal injuries, while non-fatal injuries are order of magnitudes larger than fatal occupational injury counts. In manufacturing industry they report a rate of 3.8 fatal injuries per 100,000 workers years in the 1983–1994 period. Machinery accidents were found to be the top external cause with a rate of 0.647 per 100,000 workers year. However, machinery-related industry-specific rates were 6.3 for agriculture, forestry and fishing, 6 in the mining industry, 1.9 in construction, 0.7 in manufacturing, 0.6 in transportation, 0.4 in wholesale trade, and 0.1 in retail trade.

Machinery related fatalities in the USA were analyzed by Pratt et al. (1996). They found that between 1980 and 1989 these incidents resulted in 8505 civilian worker deaths and an average annual fatality rate of 0.8 per 100,000 workers. The highest industry-specific rate was noted in agriculture, forestry, and fishing (7.47). Hakkinen and Silvennoinen (1998) carried out similar analyses in the European scenario. Etherton et al. (2001), while citing US Bureau of Labor Statistics data, report that 464 occupational fatalities occurred in the US between 1966 and 1998 resulting from being caught-in-running-machinery (costing $122 million). In the 1995–1997 period instead 92,932 nonfatal injures of this type occurred of which 65% were in manufacturing industries. In 1996 the total nonfatal injures incidence rate for the manufacturing industry was 238.3 per 100,000 workers and the rate for machinery injury in manufacturing was 27.7 (11% of the manufacturing rate). Of the approximately 5700 workers fatally injured in the US in 2005 about 18% were injured by contact with objects and equipment, the second leading cause of occupational fatalities after transportation incidents, while contact with equipment caused 38% of deaths among workers in production occupations (Bulzacchelli et al., 2008).

The case of mechanical equipment injuries in small manufacturing and metal working businesses was instead examined by Gardner et al. (1999) and Munshi et al. (2005), while specific data on accidents in automated production systems are also given by Mattila et al. (1995).

Bellamy et al. (2007) report that out of 9500 analyzed investigation reports from the Dutch Labor Inspectorate in the 1998–2004 period, contact with moving parts of machine accounted for 20.96% of total accidents per year, meaning about 400 accidents per year including 5 deaths.

In two Swedish automotive industries between 12% and 17% of all occupational injuries were caused by an automatically controlled machine, while according to another survey 3% of operators annually incur injuries from such accidents (Backstrom and Doos, 1995, 1997a).

Bull et al. (2001) surveyed injury rates per year per 100,000 employees in Norway during the 1991–1996 period. They found rates of 1.0 and 3.7 respectively of accidents occurring during adjusting, cleaning, lubricating tools or machines, or during ordinary operation of tools and machines. In general, with a rate of 6.7, tools and machines were the objects involved in occupational injuries.

Pratt et al. (1997) examined fatal accidents in the US construction industry. They found that between 1980 and 1992, 1901 civilian workers died in machinery-related incidents, with an average annual fatality rate of 2.13 deaths per 100,000 workers. Major contributors were "struck, pinned, crushed, or run over" by mobile machine (29.9% of cases), by boom, bucket or arm (7.5%), "overturn" (17%), "compressed between equipment or between equipment and object" (6.8%).

Goodwin Gerberich et al. (1998) compiled statistics of machinery-related injuries of farm workers reporting that among the total of 764 farming-related injury events examined 151 (20%) were related to large machinery use, 72 (9.4%) to hand/power tools and 68 (8.9%) to tractors. The majority of injury events occurred while persons were lifting, pushing, or pulling (21%), adjusting a machine (20%), or repairing a machine (17%) and 19.8% were related to large machinery. The overall injury rate from machinery was 2214 per 100,000 workers per year, while the injury rate was 1127 from large machinery, 541 from power tools and 517 from tractors. Machine-related injuries in farming were also analyzed by Layde et al. (1995), by Lim et al. (2004) who, in particular, focused on accidents involving children up to 17 years old, by McCurdy and Carroll (2000) who reviewed studies on occupational injury among agricultural populations, and by Mohan et al. (2004) who analyzed the Indian situation. Narasimhan et al. (2010) instead correlated machine-related injury data of Saskatchewan farmers to presence of safety devices and low level of routine maintenance. Baker