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How harsh work environments affect the occupational accident phenomenology? Risk assessment and decision making optimisation

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ABSTRACT

This paper describes a procedure to evaluate the risk of occupational accidents combining SKM (SOM & K-Means) and FAP (Fuzzy Logic approach) to explicitly take into account the impact that harsh productive environments can have on the occupational accident dynamics. The procedure proposed consists of an advanced approach based on two evaluation steps: (1) the investigation of occupational accidents dynamics in a productive sector through the SKM approach, based on neural networks; (2) the occupational accidents risk assessment for a specific plant through the Fuzzy Logic approach, exploiting the knowledge inherent in the accident analysis of an industrial sector to the benefit of the risk assessment in a specific work environment. The application of SKM and FAP approach respectively to the metallurgical sector and to an Italian industrial plant allowed the validation of the proposed procedures.

Taking into account the accidents occurred in the Piedmont metallurgical sector from 2006 to 2013, the risk assessment for an Italian steel-manufacturing company was carried on, highlighting how a critical work environment can affect the accident dynamics, and how to correctly take into account their impact during the risk assessment could bring to an effective operational safety improvement.

1. Introduction

The occupational accident investigation represents a focus step in safety management systems, with the aim of avoiding that the occurred accidents can happen again in the future. Considering that the procedures for the quantitative risk assessment of occupational accidents appeared to be still lacking, in 2009 the authors developed a decisional methodological instrument (FAP – Fuzzy Application Procedure) to assess the exposure of the workers to the risk of accidents in a specific plant and/or site activities. In particular, starting from a complete and homogeneous injuries data sample, the tool developed allowed to:

- Assess the level of risk related to a work phase and/or a work sector.
- Verify and quantify the risk reduction of the risk after the implementation of preventive and/or protective measures.
- Define a priority for the interventions on the basis of the assessed risk levels.

The authors chose to apply the tool to an Italian steel manufacturing plant.

The work in the steel industry is recognised to be one of the most critical because of the large number and the severity of the hazard factors the workers can be exposed to, as detailed in ILO (2005).

In fact, the metallurgical sector was characterized by a large number of occupational accidents and by the coexistence of work environments of different criticalities, from very critical, e.g. finishing operations, to harsh e.g. melting and casting operations. Nowadays the situation remains almost the same: on the basis of the indicators developed by INAIL (Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro) in 2013, the Italian metallurgical sector, which includes the manufacture, melting and laminating of iron, steel and other metals, seems to be the most dangerous sector for workers. Indeed, the frequency index, expressed by the ratio between the number of occupational accidents and the number of workers exposed to the risk, is equal to about 50 accidents per 1000 employees, a value that is higher (84.5% more) compared to the overall average of accidents, which is of 27.06 accidents per 1000 employees. Therefore, the metallurgical sector shows a risk of occupational accidents which almost doubles the average registered for other sectors; it is even worse than those sectors traditionally considered at high risk as

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agriculture, the processing of materials for building and glass, the wood and site activities.

In the literature, this situation has been traced back both to the nature of the job and to a general lack of safety culture in the whole sector. The dependency from the nature of the job is highlighted in Nordlof et al. (2015): the work tasks are usually heavy and demanding for the body, with a continuous latent risk for crushing injuries and burns. Therefore, it is essential to have a deep knowledge of the risks related to the work environment, taking into account the occurred events in order to identify adequate preventive and protective measures able to minimise and manage the risks for the benefit both of the operators and of the productivity. With reference to that, Nielsen et al. (2006) examined how the implementation of an incident reporting scheme in industrial plants could reduce the frequency of occupational accidents. But, in order to identify measures that could be effective over time, namely clear, simple and above all shared with the organization, it is necessary to understand the working climate.

In fact, some studies on the safety in the steel-manufacturing sector have focused on the influence of behaviour, attitudes, climate, indicating that a correct safety culture can form a first protection against unsafe attitudes and behaviour and thus occupational accidents. Brown et al. (2000) showed that in a positive safety climate, characterized by an open-door policy for hazard and accident reporting, a genuine concern for employee well-being, and fairness in accident investigations, the employees of the steel company under study were likely to work more safely. Watson et al. (2006) illustrated the importance of management policies and practices in emphasizing safety. Cavazza and Serpe (2009) found out that the unsafe behaviours are a symptom of something dysfunctional at an organizational level. They also showed that workers reveal less ambivalence toward using personal protective equipment when they perceive that there is an atmosphere in the organization that support safety. Nordlof et al. (2015) investigated and described safety culture and risk-taking inside a large steel-manufacturing company in Sweden by exploring workers' experiences and perceptions of safety and risks. An overall finding was that the workers perceive the risks related to their workplace, but the priority given to the productivity and an organizational lack of attention towards safety culture represent a constant obstacle for the adoption of safe behaviours.

Therefore, the aim of the present study was to develop an advanced tool for the risk assessment of occupational accident able to take into account the accidental phenomenology of the plant under study (related to the work environment climate), to exploit the knowledge that can be gained from the analysis of accidents database of the whole industrial sector, in order to highlight or bias accident dynamics and/or contributors that could have not still been revealed.

2. Description of the methodological approaches

The proposed procedure, aimed at building a decisional tool to assess the exposure of the workers to the risk of accidents in the industrial work environment, is constituted of two specific analyses:

(1) SKM: for the investigation of occupational accidents dynamics in a reference productive sector.
(2) FAP: for the occupational accidents risk assessment for a specific plant, starting from the knowledge arising from the first step.

The analysis of the accident dynamics already occurred in the larger industrial domain is used to disclose possible accident dynamics or critical factors that shall be considered in the risk assessment of specific work environment.

The two approaches are briefly described in the following paragraphs.

2.1. SKM (SOM K-means method)

The collection of occupational accidents historical data is a consolidated praxis, above all for statistical purposes (Murè and Demichela, 2009). An occupational accident data base is generally characterized by a high number of records and an elevated number of descriptive parameters that are used to characterize each accident. The management of this large amount of information with traditional statistics methods, like multivariate analysis or linear regression, requires plenty of a priori assumptions over the distribution of the variables involved and becomes heavy to apply (as discussed in Comberti et al., 2015 about the previous work of Palamara and Demichela, 2007 and Palamara et al., 2011). Therefore, the data mining approach represents a consolidated alternative to extract information from a complex data base (Edelstein, 1999; Zaiane, 2003). In 2011, Piccinini and Palamara, presented an interesting tool, originally designed in two level of clustering, aimed at classifying the occupational accidents data: the first level was represented by a SOM (Self Organising Map), an unsupervised learning algorithm for generating topology preserving transformation from a high-dimensional data vector space to a low-dimensional map space; the second level consisted of a classical numerical clustering algorithm (k-means), which was used to make a quantitative partition of the domain depending on the level of similarity of the data. A further development in this coupled method of clustering applied to risk assessment field was recently introduced by Alikhani et al. (2013): a hybrid clustering-classification method was developed by using k-means and SOM as clustering methods to improve accuracy of classification. Taking into account the results about the test on Palamara's method and the Alikhani's clustering method, Comberti et al. (2015) proposed an advanced promising method called SKM (SOM K-means method), which was applied to the occupational accident databases.

Therefore, in order to extract information from the Piedmont metallurgical occupational accidents database, SOM K-means method has been adopted, as preliminary discussed in Demichela et al. (2014). Then, the results of this analysis have been employed for the risk assessment of a specific plant through Fuzzy Application Procedure, in order to verify and prevent potential unforeseen accidents dynamics.

2.2. FAP – Fuzzy application procedure

Murè and Demichela (2007, 2009), and updated in Murè et al. (2015) showed the advantages of the Fuzzy Logic approach through the application to a vehicle tyre company and a steel manufacturing company. In particular, the method allowed to include in the risk assessment very different types of parameters (as the frequency of events, the time of exposure, ecc.), highlighting their interactions in originating the accident. The FAP methodology is thus based on the risk function below, where the output is the risk level, R

$$R = f(F, S, E, L) \tag{1}$$

where: F is the frequency of occurrence of an event; S is the probable damage derived from the event; E is the contact factor and L is the judgment of the analyst on the degree of adequacy of the existing protection measures.

The FAP methodology uses Fuzzy Toolbox of Matlab® as a solver. FAP was then developed as a support tool for the fuzzy methodology in order to obtain a greater effectiveness in the analysis and a more user friendly approach. Given a spreadsheet file, where the analyst has to introduce the normalized input parameters, FAP: