



# A Bayesian network analysis of workplace accidents caused by falls from a height

J.E. Martín<sup>a</sup>, T. Rivas<sup>b,\*</sup>, J.M. Matías<sup>c</sup>, J. Taboada<sup>b</sup>, A. Argüelles<sup>b</sup>

<sup>a</sup> CIPP Internacional SL, Parque tecnológico de Asturias, Edf. CentroElena II. Of. 4A. 33428 Llanera Asturias, Spain

<sup>b</sup> Department of Natural Resources and Environmental Engineering, University of Vigo, Lagoas Marcosende, 36200 Vigo, Spain

<sup>c</sup> Department of Statistics, University of Vigo, Lagoas Marcosende, 36200 Vigo, Spain

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## ABSTRACT

This article analyses, using Bayesian networks, the circumstances surrounding workplace tasks performed using auxiliary equipment (ladders, scaffolding, etc.) that may result in falls. The information source was a survey of employees working at a height. We were able to determine the usefulness of this approach – innovative in the accident research field – in identifying the causes that have the greatest bearing on accidents involving auxiliary equipment: in these cases, the adoption of incorrect postures during work and a worker's inadequate knowledge of safety regulations. Likewise, the duration of tasks was also associated with both these variables, and therefore, with the accident rate. Bayesian networks also enable dependency relationships to be established between the different causes of accidents. This information – which is not usually furnished by conventional statistical methods applied in the field of labour risk prevention – allow a causality model to be defined for workplace accidents in a more realistic way. With this statistic tool, the expert is also provided with useful information that can be input to a management model for labour risk prevention.

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## 1. Introduction

Techniques used to manage accident prevention in companies include accident analyses, accident investigations, safety inspections and incident recall, etc. (Bird and Germain, 1990; Ley 31/1995), which provide management with information on the causes of accidents among particular groups of employees. Knowing the circumstances and causes of accidents enables corrective and preventative measures to be implemented that exercise greater control over factors that may cause accidents.

Different information sources are used in order to apply these analysis tools. *Fatality inspection records*, which are completed after the accident, have been used by some authors for their research (Janicak, 1998). These records reflect the circumstances of the accidents providing data, for example, on the job, type of activity, type of injury, direct cause of the injury, etc. In Spain, fatality records are the most widely used source of information for historical studies of workplace accidents (Orden TAS/2926/2002; Begueria, 1988). Other information sources – including risk reports (Bird and Germain, 1990) and worker surveys (Gillen et al., 2002; Kines, 2003; Paul and Maiti, 2007) – enrich the theories elaborated from the usual sources of information and provide additional, mostly sub-

jective, information (largely on the behaviour of the worker during the risk activity).

Irrespective of the information source, the data is usually analysed using conventional descriptive statistics (Kines, 2003), factorial analysis (Dedobbeleer and Beland, 1991), analysis of variance (Janicak, 1998), and multiple regression (Gillen et al., 2002). The conclusions obtained using these simple data processing techniques – which form the basis for many management models – enable the relationship between the accident and each causal variable to be analysed, but do not enable the interplay between causes to be determined. These techniques fail to reflect, therefore, the fact that an accident is usually the result of more than one factor – that is, the outcome may be greater than the sum of the parts (Bird and Germain, 1990).

More effective approaches to defining the interplay between variables have been developed by other authors, for example, using structural equation models (Paul and Maiti, 2007). In the present work we use an approach based on Bayesian networks (BNs) to describe the circumstances (and relationship between circumstances) associated with tasks performed at a height that might result in personal injury or damage to property. BNs have been applied in several knowledge areas, such as medicine (Antal et al., 2007), ecology (Adriaenssens et al., 2004), environmental assessment impact (Baran and Jantunen, 2004; Marcot et al., 2001; Matías et al., 2006), business risk and product life-cycle analysis (Zhu and Deshmukh, 2003), and more recently, to handling data obtained as a result of prospecting for minerals and

\* Corresponding author. Tel.: +34 986811922.

E-mail addresses: [jmmatias@uvigo.es](mailto:jmmatias@uvigo.es) (J.E. Martín), [trivas@uvigo.es](mailto:trivas@uvigo.es) (T. Rivas), [jtaboada@uvigo.es](mailto:jtaboada@uvigo.es) (J. Taboada), [aargu@uvigo.es](mailto:aargu@uvigo.es) (A. Argüelles).

rocks (Rivas et al., *in press*). In the workplace risk area, Galán et al. (2007) applied a canonical probabilistic test (based on Bayesian models) to the analysis of nuclear system safety and Papazoglou and Ale (*in press*) and Papazoglou et al. (2006) applied functional block diagrams and event trees to quantify the risk of falls. More specifically for construction and mining accidents, Matías et al. (2008) compared the predictive capacity of BNs with other expert systems, concluding that BNs, in addition to their good predictive capacity, possess a satisfactory interpretative capacity in regard to workplace accidents, given that: (1) they enable different circumstances to be simulated and their effects on each of the variables in play to be probabilistically analysed; (2) they enable the use of discrete qualitative variables (such as the many parameters that have a bearing on accidents); and (3) they enable the causal dependency relationship between variables to be mapped.

Using BNs, we analysed workplace accidents caused by falls from a height in order to identify the most important causes of this kind of accidents and, most of all, to determine the relationships existing between these causes, which will allow the real circumstances of the unsafe work tasks performed at different heights to be defined.

We focused on falls, from a height of more than 2 m above floor level, of employees working in a standing position. In Spain, workplace falls from a height are a major cause of workplace fatalities, third only to accidents involving vehicles and heart attacks (Ministerio de Trabajo y Asuntos Sociales, 2006). These accidents, which occur most frequently in the construction and mining sectors, have been studied by several authors (Gillen et al., 2002; Janicak, 1998; Kines, 2003; Hale et al., 2007). A secondary aim of our analysis was to establish the need for reinforcing safety measures for this type of work.

As an information source for the analysis, we implemented a survey of workers who were interviewed as they performed a range of work tasks at more than 2 m above floor level (on ladders, structures, scaffolding or platforms). The use of information obtained during or immediately after the risk activity in prompt/no-delay interviews have enabled some authors to draw interesting conclusions on the causes of falls from a height (Kines, 2003). In our opinion, the use of information collected in the course of a task allows the circumstances of immediate relevance to an accident to be better analysed. In general terms (Bird and Germain, 1990), the causes of accidents at work can be classified on immediate causes (both substandard practices and substandard conditions) and basic causes (both personal and job factors). In the case of worker accidents caused by falls, the adoption of worker unsafe behaviours contributes directly or indirectly to around 90% of incidents (Holnagel, 1993). This unsafe behaviour can be directly related to substandard practices (using protective equipment incorrectly or removing safety devices), but also to substandard conditions (the existence of inadequate protection or incorrect task location). Worker inexperience, lack of motivation and fatigue are basic causes which often underlie immediate causes. In the present work, the questions posed are specifically related to worker behaviour (how the task is performed, the reasons for the application of alternative safety measures...) but also to substandard conditions (difficulties in applying legislations) which can condition the worker decisions.

Furthermore, issues in regard to immediate behaviour and decision-making – generally not recorded in accident reports – constitute non-measurable and non-quantifiable variables that are better modelled as categorical variables (or at least as ordinal variables). Although categorical variables are difficult to incorporate in conventional statistical techniques, they can be easily be analysed using BNs.

## 2. Materials and methods

### 2.1. Information sources

The data used to build the BNs was obtained from questionnaires administered to 393 workers employed in 103 small and medium enterprises in the construction, industrial and services sectors. The companies were all located in the Vigo region (north-western Spain), and the survey was conducted between 2003 and 2006. The following two kind of tasks were analysed:

#### 2.1.1. Tasks performed using ladders

A total of 147 questionnaires were administered to workers on ladders, generally working at a height of around 3.5 m above floor level. These workers were questioned in regard to:

- The duration of the task.
- Experience in the job.
- Knowledge of the mandatory use of a safety harness and problems with safety harness use. (Spanish legislation requires safety harness to be used by workers on ladders performing tasks at heights of 3.5 m or more above floor level and by workers required to apply effort or adopt positions that might place them in danger [Real Decreto 1215/1997]).
- Specific training received on the risks associated with the use of ladders.
- Degree of hazard perception.
- Previous incidents or accidents using ladders.

#### 2.1.2. Tasks performed on structures, scaffolds, platforms and/or auxiliary equipment

The 246 remaining questionnaires were administered to workers using other kinds of auxiliary equipment, such as structures, scaffolds or platforms. The height at which they were working at the time they were surveyed was about 2 m above floor level. Questions dealt with the following issues:

- The duration of the task.
- Experience in the job.
- Knowledge of the minimum height at which it is mandatory to apply specific protective measures. (For these types of structures, the Spanish law requires collective protective measures to be applied to workers performing tasks at heights above 2 m [Real Decreto 1627/1997; Real Decreto 486/1997]).
- Practical problems encountered in applying protective measures, according to the type of work being done and its duration.
- Specific training received on the risks associated with the use of auxiliary equipment.
- Reasons for incorrect posture (in the event of observing a worker adopting an incorrect posture while performing a task).
- Degree of hazard perception and perceived importance of adopting appropriate and safe postures.
- Previous incidents or accidents using this type of equipment.

### 2.2. Definition of the variables

The questions posed during the surveys enabled information to be extracted on the circumstances surrounding work tasks that could play a role in triggering an accident. Some circumstances are related to personal factors considered to be a basic cause of accidents (Bird and Germain, 1990), such as work experience or inadequate training. Other circumstances reflected in the questionnaires responded to behaviour patterns that could act as immediate causes of accidents (substandard practices) and whose measure

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