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Quantitative occupational risk model: Single hazard

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ABSTRACT

A model for the quantification of occupational risk of a worker exposed to a single hazard is presented. The model connects the working conditions and worker behaviour to the probability of an accident resulting into one of three types of consequence: recoverable injury, permanent injury and death. Working conditions and safety barriers in place to reduce the likelihood of an accident are included. Logical connections are modelled through an influence diagram. Quantification of the model is based on two sources of information: a) number of accidents observed over a period of time and b) assessment of exposure data of activities and working conditions over the same period of time and the same working population. Effectiveness of risk reducing measures affecting the working conditions, worker behaviour and/or safety barriers can be quantified through the effect of these measures on occupational risk.

1. Introduction

Occupational Health and Safety constitutes one of the most important factors of the wellbeing of modern society. Occupational accidents in particular represent one of the major sources of risk today. Understandably occupational risk has received substantial and ever-increasing interest from the scientific community. The goal has always been to improve safety and decrease the number of accidents.

Methods used to manage accident prevention in companies include accident analysis, accident investigations and safety inspections providing information on causes of accidents amongst particular groups of employees. A number of studies describe the distribution of injuries in terms of person, place and workplace characteristics [1–6]. Accident data have been analysed using descriptive statistics [7], factorial analysis [8], variance analysis [9], multiple regression [10–12] and fuzzy methods [13–15].

During the last decade a number of attempts for a more systematic and consistent approach to quantitative occupational risk assessment have appeared in the literature. A model has been developed to predict the frequency of occupational accidents in offshore oil and gas industry, based on direct, corporate and external factors [16]. Quantified risk for various occupational groups in Sweden based on the number of accidents and relevant exposure has been calculated [3]. Artificial neural networks and a fuzzy inference system have been proposed to assess occupational injury risk indexes and predict number of injuries [17–19]. Finally an exposure – damage approach for occupational risk quantification in workplaces involving dangerous substances is proposed [20].

A very popular technique for accident modelling, particularly in the chemical industry, is the bow-tie representation [21,22]. The value of this model lies mainly in its suitability for qualitative analysis. It combines a fault tree, the left hand side of the model, representing the safety barriers that if failed lead to an accident, and an event tree, the right hand side of the model, representing the safety barriers put in place to mitigate the consequences of the accident. Since the bow-tie representation includes a fault tree it exhibits the same type of restrictions i.e. binary events for both the basic events and the top event (Centre Event in this representation).

To increase the flexibility of the fault tree bow-tie models several analysts have proposed the use of Bayesian networks. These models have been applied in both major accidents [23,24] and occupational risk quantification [25,26]. A Bayesian Network (BN) is an acyclic graph with nodes corresponding to the events of a fault tree or an event tree, connected with arcs representing the probabilistic dependences among nodes. These probabilistic dependences are providing a more flexible representation of the logical relationship among events than that provided by the AND/OR gates of a fault tree. All these models, since they consist of discrete events, are equivalent to the state-space of the system partitioned according to the particular logic of the system under analysis (see for example [27]).

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Nomenclature

z:	number of Primary Safety Blocks (PSB) in a single-hazard model
v_i	number of states of the ith PSB
b_i	state of the ith PSB (b_i=1,2,...,v_i)
B	number of states of the system of the z PSBs
y:	number of Support Safety Blocks (SSB) in a single-hazard model
u_i	number of states of the ith SSB
s_i	state of the ith SSB (s_i=1,2,...,u_i)
S	number of states of the system of the y SSBs
$X=B$xS	number of states of the combined set of the z PSBs and the y SSBs
x_i	ith state of the combined system of the PSBs and the SSBs
$\mathbf{x}$	$\{x_i\}$ set of all system states of the combined set of PSBs and SSBs
$\mathbf{x}_1$	subset of x containing those system states that are successful
X_1	number of states in $\mathbf{x}_1$
$\mathbf{x}_2$	subset of $\mathbf{x}$ containing those system states that result in a recoverable injury
X_2	number of states in $\mathbf{x}_2$
$\mathbf{x}_3$	subset of x containing those system states that result in a permanent injury
X_3	number of states in $\mathbf{x}_3$
$\mathbf{x}_4$	subset of $\mathbf{x}$ containing those system states that result in a fatal injury
X_4	number of states in $\mathbf{x}_4$
w_i	coefficient of relative importance of the ith PIE

This paper presents the single hazard model developed in the framework of the Occupational Risk Model (ORM), a research project under the auspices of the Ministry of Social Affairs and Employment in the Netherlands. The initial and more general form of the model has been presented in [28]. This logical model is a generalised bow-tie model allowing for multistate events and similar to a BN. Owing to the nature of available data to quantify the models in ORM a modified model has been developed. In this model the Left Hand Side (LHS) and the Right Hand Side (RHS) of the traditional bow-tie have been merged together taking the form of an influence diagram. In this model the Centre Event represents an accident (e.g. fall from a height) **and** a health consequence. Two classes of components have been considered: one representing the primary safety barriers connected with strict logic relationships (AND/OR and other) and one representing other support safety barriers that simply influence the probabilities of occurrence of the members of the first group.

The model has been developed so that it could be quantified on the basis of two sources of data: (i). Detailed descriptions of work related accidents that occurred in the Netherlands over a certain period of time and investigated by the Dutch Labour Inspectorate of the Ministry of Social Affairs and Employment. The most serious work related accidents, reportable under Dutch Law [29] (those leading to death, permanent injury or hospitalisation) are covered; (ii) Exposure assessment, this being an assessment of the time during which the Dutch working population that generated the number of accidents in (i) were exposed to the various hazards. In addition, the frequencies of working conditions, linked to the onset of accidents, and present in the workplace were assessed. This second source of data was generated through surveys of the Dutch working population at a national level. The availability of data in this particular form has influenced some details of the model but the methodology and the structure of the model has a wider application. The rest of the paper is organised as follows:

Section 2 outlines the single-hazard model that links the probability of an accident with a reportable consequence from a single hazard with a number of broadly defined factors and conditions of the workplace. Section 3 introduces the concept of Probability Influencing Entities (PIEs) which allows the extension of the single-hazard model to include more concrete and specific factors and conditions of the working environment without the exponential increase in the size of the model. Section 4 presents the concept of risk-reduction measures. Section 5 demonstrates the use of the model and the associated computer tool through an example. Section 6 discusses the main characteristics of the models and finally Section 7 summarises the conclusions.

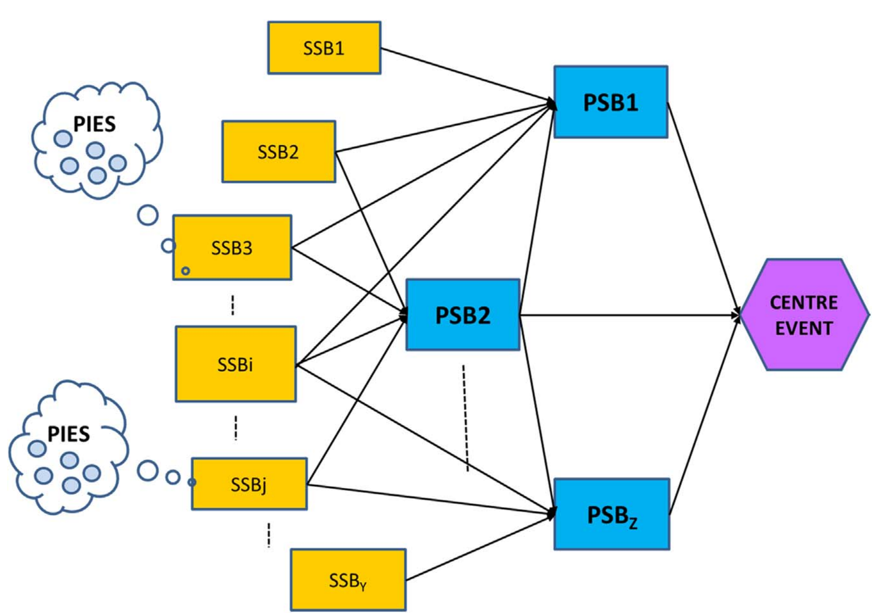

Fig. 1. Single –hazard logical model in the form of an influence diagram.