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Introduction of the human factor in the estimation of accident frequencies through fuzzy logic

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ABSTRACT

The frequency of occurrence of an accident scenario is one of the key aspects to take into consideration in the field of risk assessment. This frequency is commonly assessed by a generic failure frequency approach. Although every data source takes into account different variables, aspects such as the human factor are not explicitly detailed, mainly because this factor is laborious to quantify. In the present work, the generic failure frequencies are modified using fuzzy logic. This theory allows the inclusion of qualitative variables that are not considered by traditional methods and to deal with the uncertainty involved. This methodology seems to be a suitable tool to integrate the human factor in risk assessment since it is specially oriented to rationalize the uncertainty related to imprecision or vagueness. A fuzzy modifier has been developed in order to introduce the human factor in the failure frequency estimation.

In order to design the proposed model, it is necessary to consider the opinion of the experts. Therefore, a questionnaire on the variables was designed and replied by forty international experts. To test the model, it was applied to two real case studies of chemical plants. New frequency values were obtained and together with the consequence assessment, new iso-risk curves were plotted allowing to compare them to the ones resulting from a quantitative risk analysis (QRA). Since the human factor is now reflected in the failure frequency estimation, the results are more realistic and accurate, and consequently they improve the final risk assessment.

1. Introduction

Ensuring safety in the chemical industry is a very complex task. This complexity derives from the variety of variables that have to be considered when analysing safety aspects, such as process hazards, natural hazards or human errors, and their relative interactions. Markowski et al. (2010) established that the process industry has been continually developing its design methods to overcome the hazards which pose significant risks to life safety. With the aim of establishing how safe a chemical plant or process is, a parameter called risk has to be used. Risk can be quantified by calculating and then combining (often multiplying) the frequency and the magnitude of all the accidents that could occur in a specific plant, process or equipment (Casal, 2007).

The frequency of an accident scenario is a key aspect in the risk assessment and it is commonly assessed by a generic failure frequency approach. The frequencies currently used in the chemical industry are based on historical data of incidents and the accuracy of their calculations is based on the quality of the data used. There are different sources of generic failure frequencies, for instance the Reference Manual Bevi Risk Assessment (RIVM, 2009), the Failure Rate and Event Data for use within Risk Assessments of the Health and Safety Executive (HSE, 2012), and the Handbook of Failure Frequencies of the Flemish Government (2009). The differences between them rely on the factors considered for their calculation and on the way the failures have been classified.

Although each of the aforementioned sources takes into account different variables, aspects such as the mechanical failures or the human factor are not explicitly detailed. Furthermore, the human factor is a variable, that it is commonly excluded because of the complexity of its quantification and the uncertainty associated. Frey and Rubin (1992) pointed out that it is a common practice when handling uncertainties to just ignore them or to use simple sensitivity analysis. However, the current management of human factors has been increasingly recognized as playing a vital role in the control of risk. Health and Safety Executive (HSE, 2012), which

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is one of the sources of generic frequencies, recognizes that it is widely accepted that the majority of accidents in the chemical industry are generally attributable to human as well as technical factors. Skogdalen and Vinnem (2011) established that the errors caused by the human factors have been one of the major causes of the worst accidents in industry. In this sense, human actions may initiate or contribute to the accidents' occurrence.

Considering this, it seems necessary to introduce the human factor, and the causes that lead to it, in the frequency calculation. To achieve this aim, in the present paper, fuzzy logic has been used. This methodology it is based in the quantification of the uncertainty caused by the imprecision or ambiguity of the data (Gentile et al., 2001) and allows the inclusion of qualitative variables usually not considered by traditional methods. Therefore, using fuzzy logic the human factor is going to be introduced in the failure frequency estimation by the development of a fuzzy frequency modifier. This methodology permits to reduce the inevitable uncertainty involved in the calculation of the frequencies, and to obtain more accurate and realistic values for both the frequency and the risk. The results obtained with fuzzy logic will be compared with other risk assessment methods.

2. Frequency calculation

Evaluating the frequency of an accident is essential in risk assessment since risk is calculated by multiplying the frequency in which an event occurs (or will occur) by the magnitude of its probable consequences (Casal, 2007). Since the frequency of an event will be adjusted by the fuzzy frequency modifier, consequently the overall value of the risk will be modified. The frequency calculation strongly depends on the quality of the failure rate data used, which is also notoriously laborious to collect. Therefore, in many cases there is not sufficient information available. The uncertainty present may be associated with the lack of real time and up-to-date data for equipment failure rates, the difficulties in the inclusion of the influence of human errors, and with the wrong selection of the variables to analyse. Beerens et al. (2006) established that an important source of uncertainty in the results of risk assessment is caused by the use of different data sets for failure frequencies.

It is commonly agreed that the frequency calculation depends also on other variables that are not taken into account in the accident databases. There exist different variables that may affect the calculation of this frequency and they have to be examined in order include them later on the final calculation. Databases do not often consider, in a direct way, important factors that should be included, such as human factors, mainly because those kinds of factors are complex to quantify. However, these databases contain generic failure frequencies values that can be used as a basis and play a very important role in risk assessments. Hauptmanns (2011) pointed out that a typical problem present in this field is the fact that these assessments are often performed without discussing the applicability of generic reliability data. This is the case of the well know methodology for risk assessment QRA (Quantitative Risk Assessment) which is a powerful analysis approach used to help manage risk and improve safety in many industries (Arendt and Lorenzo, 2010), this methodology creates risk contours or iso-risk lines in order to represent the risk and relies on the frequency and consequences of the accidents. These iso-risk contours can be changed if a modification it is done either in the frequency of the accident or their consequences (Seguí et al., 2014).

In this risk assessment studies, it is a common practice to correct the standard values of frequencies, obtained from the aforementioned databases, by multiplying the value by different factors. As an example, when an accident can involve a potential domino effect, the frequency value is often multiplied by 2 (RIVM, 2009). The same happens with other factors such as the number of operating hours and number of tanks. Following this approach, in the current study the standard value of frequency will be multiplied by a fuzzy frequency modifier obtained through the fuzzy logic methodology, including in this way the effects of the human factor. The application of this methodology is detailed in the next section.

3. Fuzzy methodology

The aim of this paper is to include the human factor into the industrial risk analysis, and this is done through the creation of a coefficient that modifies the values of the generic failure frequency, based on fuzzy logic (and hence the name of "fuzzy frequency modifier").

This modifier will vary in a range from 1 to 1.5. This choice has been done taking into account the HSE statement, which assets that in the petrochemical industry the accidents attributed to human error account up to 50% (HSE, 2005). This means that in the best case (when there are no factors associated to human activities that can cause an accident), the generic failure frequency will not be changed by the fuzzy modifier, so its value will be equal to 1. In the worst case, when all the adopted parameters representing the human factor assume the maximum value (largest influence on the accident frequency), the fuzzy frequency modifier will get the maximum value equal to 1.5, so that the generic failure frequency can increase up to 50% of its initial value.

The first step of the methodology (Fig. 1) requires the identification of variables that are relevant to the system (inputs and outputs). Then, the identified variables have to be fuzzified, which means that their values need to be converted into fuzzy numbers. This is known as the *fuzzification* process and is done using fuzzy sets (FS), linguistic variables and membership functions (MF). Once the inputs and outputs have been fuzzified, they have to be connected. This is done through the fuzzy inference process with the use of fuzzy rules and implication and aggregation processes. At the end, the process has to be inverted: from the linguistic parameter, it is necessary to obtain a crisp numeric value by the *defuzzification* process that gives the final output, which will be the value of the fuzzy modifier. All these steps will be further explained in detail.

3.1. Identification of the variables

As the HSE guidance (HSE, 2005) states, a simple way to view human factors is to think about three aspects: the job, the individuals and the organization, and how they affects people's health and safety-related behaviour. Based on this classification, a selection of the variables was made in order to create the model for this study. This selection considers that the overall human factor is composed of three different factors representative of three basic categories: Organizational Factor, Job Characteristic Factor and Personal Characteristic Factor. Each of these factors is further characterized by the influence of the basic variables shown in Fig. 2 and explained next.

3.1.1. Organizational factor

This factor refers to the conditions provided by the company to generate a safe environment. This includes the communication between the different levels of the hierarchy, the incidents reporting culture, the conditions the company sets to recruit external personnel and the instructions that the organization gives to their employees in order to perform the job in the safest way possible. It takes into account three parameters: Contracting, Training and Communication & Reporting.

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