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Analysis of domino effect in the process industry using the event tree method

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ABSTRACT

Domino scenarios are known to have severe consequences that need to be considered in Land-Use Planning. A domino effect can be initiated by several types of primary accidents, which are usually caused by a loss of containment (LOC). This study focuses on the development of a specific model for the assessment of domino scenarios based on event tree analysis. The model provides the identification of the event sequences and the accident scenarios following a LOC. A ranking based on the criticality of domino scenarios is also provided. An illustrative case study was used to demonstrate the procedure. The results confirmed that the proposed method is an effective decision support tool for domino effect prevention, allowing the identification of the most dangerous storage or process units with respect to domino effect scenarios.

1. Introduction

Chemical and Oil & Gas facilities are present worldwide and for economic, environmental reasons and legal requirements the production sites are usually located in industrial clusters, with production sites from different companies close to each other. The growing attention to the issue of sustainability, caused by the population growth and by the impact on the environment of industrial activities led to the introduction of the concept of industrial ecology (Korhonen, 2001), and to propose the concept of Eco-Industrial Parks. In such sites, many companies integrate their activities in order to improve efficiency in the use of resources and environmental performance. However, integration and linkage among activities requires proximity between plants in industrial parks and eco-industrial parks, thus increasing the likelihood of accidents involving domino effects.

Escalation leading to a domino accident scenario significantly increases the overall severity of a major accident (Hemmatian et al., 2014; Reniers and Cozzani, 2013). This is due to the spread of the accident in both space and time, with obvious consequences on the criticality of individual and societal risk. As clearly evident from past accidents as the Mexico City event (Pietersen, 1988), such scenarios may strongly affect the surroundings of a chemical cluster and need to be considered in Land-Use Planning. Taking into account domino scenarios in the assessment of major accident hazards is required by European legislation. More precisely, safety reports issues on industrial sites falling under requirements of the former Seveso-II Directive (European Commission, 1997) and of the present Seveso-III Directive (European Commission, 2012) should address domino scenarios, both within the site and potentially involving neighboring facilities. However, no well accepted method exists to date for the assessment of domino hazards (Antonioni et al., 2009; Cozzani et al., 2013; Necci et al., 2015). Consequently, there is not yet a widely used or a commercially available software tool able to deal with domino effect. The few available tools can be classified into two categories, according to their objective and the approach used. The first category of tools provides the ranking of equipment based on escalation probability and severity. Within this category there are software packages that provide a simplified assessment based on a limited set of input data, aimed at providing a preliminary screening of domino hazard, as DomPrevPlanning (Reniers and Dullaert, 2007) or Domino XL 2.0 (Delvosalle et al., 2002). The second category of tools is aimed at including domino effects in Quantitative Risk Analysis (QRA). This type of tools provides detailed results, often presented in the form of commonly used risk indexes such as individual or societal risk, but require complete and detailed input data. The domino version of Aripar-GIS software developed by Cozzani et al. (2006a) and the

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DOMIFFECT software proposed by Khan and Abbasi (1998) belong to this category of tools.

The model developed in the present study is based on a topography of the industrial area of concern, including the characteristics of each unit and accounting for protection and mitigation barriers. It combines the estimation of damage probability due to overpressure and heat radiation proposed by Cozzani and Salzano (2004), Cozzani et al. (2006a) and Landucci et al. (2009) and escalation threshold values suggested by Cozzani et al. (2006b).

To identify the reference accident scenarios resulting from the release of hazardous materials, generic event trees provided by recent publications (Delvosalle et al., 2006; Vílchez et al., 2011) were adapted to the purpose of the study. The methodology developed can be used as a decision support tool, providing the identification of the possible accident propagation paths and their estimated frequencies. Furthermore, based on the likelihood and severity of the sequences identified, a ranking of accident propagation paths and of hazard associated to equipment involved in the most dangerous paths are also provided. Thus, the method should contribute in allowing safety managers to have a more clear idea of equipment hazard and risk according to the likelihood of escalation.

2. Methodology

The methodology developed is schematized in Fig. 1. As shown in the figure, the approach is based on two main stages. The first is the identification of accident propagation paths, that was implemented using the MATLAB® software and Visual Basic for Applications (VBA) to enable an easy input procedure and output analysis in Microsoft Excel®.

The second stage is the identification of the most dangerous equipment. It consists in prioritizing equipment involved in the propagation paths according to their likelihood to cause/propagate domino effect. The algorithm that performs this phase was coded in VBA. Details on these two stages are given below.

2.1. Identification of accident propagation paths

Loss of containment (LOC) can be considered as the most recurrent initiating event of accident sequences in the process industry (Mannan, 2014). LOCs cause hazards that could vary according to several parameters including:

- Operating conditions (e.g., temperature and pressure).
- Characteristics and type of the failed equipment (storage/process vessel).
- Type of leakage (continuous, instantaneous).
- Phase (liquid, gas or two-phase) and category (flammability, reactivity[1] and toxicity) of the substance released.

For these reasons, the three classes of LOCs mentioned in the Purple Book (Uijt de Haag and Ale, 2005) and summarized in Table 1 were considered in the present study as the critical events able to give rise to a domino effect. Six steps are needed to identify the propagation paths of the domino events. These steps are summarized by the first stage of the flow-chart shown in Fig. 1 and detailed in the following subsections.

2.2. Input data

In the first step of the methodology, the required data to apply it are collected and stored. Table 2 summarizes the information required. The different equipment considered by the model and the corresponding generic failure frequencies for leaks and instantaneous releases considered (LOCs) are represented in Table 3. The generic frequencies of LOCs used are those given by databases, issued from statistical data analysis (AMINAL, 2009; Uijt de Haag and Ale, 2005). Specific failure frequency data rather than the proposed generic LOCs frequencies may be used. The specific frequencies may be available from the safety report of the plant or may be calculated by fault-tree technique.

2.3. Selection of relevant domino sources

All the equipment belonging to the area of concern are considered as possible targets in order to assess the severity of a given domino accident. However, only equipment items processing or storing flammable, highly flammable or extremely flammable substances according to the Classification, Labelling and Packaging (CLP) Regulation (European Commission, 2008), are considered as relevant sources of domino events (see Table 3).

The selection of relevant hazardous equipment is an important step of the risk analysis procedure, as it allows to reduce the time needed for the application of the method. The primary sources (installations) that have the propensity to cause domino accidents can be determined either using the safety report of the plant or through risk assessment. A procedure such as the one proposed in the Methodology for the Identification of Major Accident Hazards (MIMAH) (Delvosalle et al., 2006) may be used. The method for the selection of relevant hazardous equipment in the MIMAH methodology is a part of the "Vade-Mecum" proposed by the Walloon Region (Ministry of Walloon Region, Belgium, 2015), which is a guideline for the writing of the Seveso safety report. In the MIMAH methodology, equipment containing hazardous substances are first identified as potentially hazardous equipment. Then, a selection of relevant hazardous equipment is performed, based on the quantity of hazardous substance in the equipment. Three thresholds are set, they depend on the hazardous properties of the substance, its physical state, its vaporization tendency and its location with respect to another hazardous equipment. The MIMAH procedure is general and can be easily adapted to site-specific or country-specific thresholds to comply with local regulations.

As an alternative, the method described in the Instrument Domino Effects (IDE) (RIVM, 2003) can be used. The latter performs the selection of critical equipment in three steps, based on the comparison of real distances separating the equipment, and effect distances calculated for predefined threshold values. The major advantage of this procedure is that the IDE provides calculated effect distances and thus, facilitates the application of the method. However, the IDE effect distances correspond to thresholds proposed by Dutch legislation (Alileche et al., 2015). Therefore the use of this procedure to comply with regulations or standards based on different domino thresholds is not straightforward, since it requires to calculate the specific effect distances of accidents.

2.4. Selection and characterization of LOCs able to trigger escalation

Based on historical experience and statistical analysis of past accidents, we know that the severity of primary accident scenarios following a loss of containment depends on the type of equipment where the release occurs, on the substance involved and also on the intensity of the LOC (Cozzani et al., 2006b). Therefore, the selection of a LOC as a possible critical event is based on its ability to spread the accident.

Table 4 shows the expected primary accidents that can occur following a LOC depending on the type of installation and on the substance hazard.

[1] The reactivity of a substance denotes its susceptibility to flame acceleration.

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