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Reference criteria for the identification of accident scenarios in the framework of land use planning

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ABSTRACT

Land use planning (LUP) around industrial sites at risk of major accidents requires the application of sound approaches in the selection of credible accident scenarios. In fact, the 'technical' phase of LUP is based on the identification and assessment of relevant accident scenarios. An improper choice of scenarios may critically affect both the 'technical' phase of risk assessment and the following 'policy' phase concerning decision making on land-use restrictions and/or licensing. The present study introduces a procedure aimed at the systematic identification of reference accident scenarios to be used in the gathering of technical data on potential major accidents, which is a necessary step for LUP around Seveso sites. Possible accident scenarios are generated by an improved version of the MIMAH methodology (Methodology for the Identification of Major Accident Hazards). The accident scenarios are then assessed for LUP relevance considering severity, frequency and time scale criteria. The influence of prevention and mitigation barriers is also taken into account. Two applications are used to demonstrate the proposed procedure. In both case-studies, the proposed methodology proved successful in producing consistent sets of reference scenarios.

1. Introduction

Major accidents in industrial facilities may trigger severe off-site consequences. The large number of off-site casualties which occurred following the San Juan Mexico City (Mexico, 1984) and Bhopal (India, 1984) disasters provided compelling evidence that adequate separation distances should be maintained between hazardous facilities and densely populated areas. Moreover, the events of Enschede (Netherlands, 2000) and Toulouse (France, 2001) evidenced that separation distances can slowly be eroded over time, resulting in hazardous facilities being encroached by urban development. The prime goal of an effective land use planning (LUP) policy around major accident hazard sites is protecting the population from the consequences of severe outcomes and establishing adequate minimal safety distances that define the areas where land use restrictions need to be maintained. The European Union (EU) Directive 96/82/EC (Seveso-II Directive) addresses two key aspects of LUP: separation between hazardous installations and residential and other sensitive areas (i.e. safety distance) and the systematic technical framework for its assessment and scrutiny. However, the Directive itself does not provide any detailed guidance on how LUP regulations should be implemented by the EU Member States (MS) into their National LUP policies, since besides the technical elements a number of other aspects need to be considered (technological, social, cultural and economic, etc.) (Tugnoli, Santarelli, & Cozzani, 2011).

LUP activities include a "technical" phase (identification of scenarios, assessment of consequences, etc.) and a "policy" phase (acceptability criteria, zoning, permits, etc.). While the second one may be strongly influenced by country specific factors, a general rule that defines appropriate safety distances is currently unavailable, even when considering only the merely technical point of view. Several EU MS (e.g. Netherlands, United Kingdom and France) have developed and implemented specific methodologies, regulations and policies (Christou, Amendola, & Smeder, 1999; Christou, Gyenes, & Struckl, 2011). For instance, the PHADI methodology for land use planning advice in United Kingdom (HSE, 2011) and the implementation of the ELECTRE III multi-criteria ranking in hazard zoning in France (Salvi, Merad, & Rodrigues, 2005) are among the more recently proposed technical tools for supporting LUP decisions around major hazard installations.

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Apart from the inevitable differences in methods and criteria (both inside and outside the EU), any LUP approach actually has the same starting point: a technical evaluation of the risks of credible major accident scenarios considered for a given site of interest. Such a technical basis, which should be obtained by a transparent, consistent and assessed methodology, is necessary for any sound LUP and licensing negotiation or decision process.

Due to the large number of factors involved (hazardous substances properties, processes, presence of safety barriers, etc.), a very large number of potential accident scenarios can be generated during a hazard identification process. Hence a prioritization procedure is required to make the accident scenario analysis practicable and justified in terms of human resources, time and costs. Thus, the major difficulty to overcome is identifying the credible accident scenarios among the possible ones. Such identification procedure must guarantee that the identified accident scenarios are consistent among all major hazard plants. This is a critical aspect, as the evaluation of appropriate safety distances strongly depends upon the accident scenario considered. Several previous benchmark studies have shown how the set of accident scenarios considered has a strong impact on the final results of a hazard analysis or risk assessment. This may lead to a considerable reduction in the effectiveness of LUP and population protection (Christou et al., 2001, 2011; Cozzani, Bandini, Basta, & Christou, 2006; Delvosalle et al., 2005; Pey, Lerena, Suter, & Campos, 2009).

The present study proposes a systematic procedure to generate reference accident scenarios necessary to build the technical basis of LUP decision-making. The procedure therefore may constitute a preliminary screening step, providing an input to other technical tools used in the decision phase of LUP: e.g. PHADI (HSE, 2011), ELECTRE III-based hazard zoning (Salvi et al., 2005), and RISKCURVES (Van Het Veld, Boot, & Kootstra, 2007). As a starting point, accident scenario identification is based on an extended version of the MIMAH methodology (Methodology for the Identification of Major Accident Hazards), developed within the FP6 EU project ARAMIS (Delvosalle, Fievez, Pipart, & Debray, 2006). A new systematic two-stage validation procedure is then introduced to work out a table of relevant scenarios. The first stage of the validation procedure provides practical guidelines on the integration of the draft table of scenarios with the results from the screening of past accidents and from a simplified HazOp assessment. In the second stage of the validation, decision criteria are introduced to select the relevant scenarios on the basis of four driving issues: (a) frequency, (b) severity, (c) presence and effectiveness of safety barriers, as implemented by good practice, and (d) time scale of the scenario (i.e. time of evolution of the scenario, which affects the possibility to mitigate off-site consequences).

Two applications of the procedure are presented. The first case-study analyses a matrix of five generic reference installations and 12 hazardous substances. From this pre-screening, reference accident scenarios are identified and they can be further used to populate a knowledge system for supporting a more consistent LUP assessment practice across the EU. The second case-study concerns the specific assessment of a LNG regasification terminal.

2. Methodology

The proposed procedure in the present study aims at the identification of the accident scenarios which can be relevant for LUP purposes around major hazard establishments classified as Seveso sites, independently of specific risk-based or consequence-based approaches later adopted in the decisional phase of LUP (Cozzani et al., 2006). The proposed procedure can be applied to both existing and new plants and requires the typical input information needed for risk assessment studies (CCPS, 2000; Mannan, 2005; Uijt de Haag & Ale, 2005). In the present framework, an accident scenario contains the event sequence starting from an unwanted Loss of Containment (LOC) event and ending with a final dangerous phenomenon (e.g. an explosion, a pool fire, etc.) (Christou, Struckl, & Biermann, 2006).

To this purpose an improved version of the MIMAH methodology was developed for identifying possible accident scenarios. MIMAH is a step-by-step methodology for the identification of accident scenarios, which is carried out with the development of generic fault and event trees. The methodology is based on a taxonomy of equipment and of properties of the hazardous substances, and includes a database of reference fault and event trees (Delvosalle, Fievez, & Pipart, 2004). The use of the MIMAH approach can be justified as being reasonably representative of the current state-of-the-art in accident scenarios identification, since it was originally developed within the EU FP6 ARAMIS project (Delvosalle et al., 2006).

A two-stage systematic procedure is then applied to the draft table of potential accident scenarios obtained by MIMAH to work out the relevant scenarios that should be reasonably considered for LUP. In the first stage, the draft table is revised and integrated with the results obtained from a layered approach based on specific identification techniques. In the second validation stage, practical rules are provided to select the accident scenarios relevant in the LUP context from the general list obtained in stage I. An outline of the main steps of the method is shown on Fig. 1. The figure demonstrates the linear step-by-step structure of the method. Table 1 presents in detail the correlation between the proposed method and the original steps of the MIMAH procedure.

2.1. Identification of accident scenarios

The first step of the proposed procedure generates a draft list of critical events for each of the hazardous equipment present in the plant. Even though all of the relevant steps of the MIMAH procedure are adopted (see Table 1), the practical application of the original version of the method requires a few integrative actions to overcome some of its limitations (see e.g. the reference customization criteria reported in Table 3).

Step 1 of the original MIMAH calls for the collection of the information needed for the assessment (general data about the plant, description of processes, description of equipment and pipes, substances stored or handled and their hazardous properties). Given the context of a LUP assessment this information should be readily available (e.g. from the plant safety report).

Using the information collected, substances and equipment are classified according to a pre-defined taxonomy (step 2 of original MIMAH). The classes in the original MIMAH procedure (Table 2) did not provide an explicit classification of some categories of hazardous equipment (e.g. gasometers and truck loading/unloading facilities). A general rule was proposed to bridge this gap: the unclassified equipment items are assigned to the most appropriate MIMAH equipment (EQ) class on the basis of geometrical and functional similarities (Table 3).

The original MIMAH contains a step devoted to the selection of the hazardous equipment (step 3). This is based on an indexing approach, where the mass of hazardous material is compared to a threshold quantity. Since the current procedure is applied in the context of a LUP assessment, this step is not necessary (Table 1), as critical equipment items should have been already identified.

Loss of Containment (LOC) events, also called critical events (CE), are associated with the equipment using the reference tables of the original MIMAH procedure, which accounts for the