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Scenario Selection for Land Use Planning Purposes around "Seveso" Establishments

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The protection of the population and the environment around Seveso establishments at risk of major accidents asks for a sound basis in the approach to Land Use Planning (LUP). In particular, the selection of adequate accident scenarios is a critical issue. This study proposes a validated procedure aimed at the systematic identification of reference accident scenarios for LUP purposes. A draft table of accident scenarios is generated, based upon an improved version of the MIMAH methodology (originally developed within the EC FP6 ARAMIS project). The draft table is then reviewed and validated by simplified HazOp analysis and other relevant techniques. Possible accident scenarios are then assessed for LUP relevance against criteria accounting for expected severity, frequency and time scale of scenarios. The influence of prevention and mitigation barriers is also taken into account. The proposed procedure is demonstrated by its application to a LNG regasification terminal.

1. Introduction

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 accidents and establishing adequate safety distances, defining areas where land use restrictions may be maintained. The European Union (EU) Directive 96/82/EC (Seveso-II Directive, (EC, 1996)) 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. Apart from the unavoidable differences in methods and criteria (both inside and outside the EU), any LUP approach actually has the same starting point: evaluating the risks of credible major accident scenarios considered for a given site of interest. Due to the large number of factors involved (hazardous substances properties, technology adopted, presence of safety barriers, etc.) a very large number of potential accident scenarios can be generated during a hazard identification process. Several previous benchmark studies have shown how inappropriate selection of accident scenarios may lead to a considerable reduction of the effectiveness of LUP and population protection (Christou et al., 2001, 2011; Cozzani et al., 2006).

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The present study proposes a discrimination procedure to identify accident scenarios to be used in LUP decision making. A procedure, based on a improved version of the MIMAH (Methodology for the Identification of Major Accident Hazards, developed within the FP6 EU project ARAMIS) methodology (Delvosalle et al., 2006), was developed for a consistent identification of validated event trees. A consultation matrix is proposed for ranking LUP relevance of accident scenarios, Four main criteria are investigated: (a) frequency, (b) severity, (c) presence and effectiveness of safety barriers, as implemented by good practice, and (d) time scale of the scenario (Christou et al., 2006).

The developed procedure was applied to the analysis of reference installations, representative of the hazardous substances among the most commonly handled in Europe. The result of this activity was a set of reference accident scenarios for a matrix of 12 different hazardous materials and 5 types of installations (e.g. liquid storage, pipework). The results can further be used in order to populate a LUP guidance knowledge system for supporting a more consistent LUP assessment practice across the EU. The case study presented here concerns the specific assessment of a LNG regasification terminal.

2. Methodology

The methodology developed aims at the identification of the accident scenarios. It is independent of specific risk-based or consequence based approaches. It can be applied to both existing and new plants and requires the typical basic input information needed for risk assessment studies. In the present framework, an accident scenario contains the event sequence starting from an unwanted Loss of Containment event and ending with a dangerous phenomenon (e.g. pool fire) (Christou et al., 2006).

An improved version of the MIMAH methodology was developed to identify possible accident scenarios. The use of the MIMAH approach can be justified as being reasonably representative of the current state-of-the-art in accident scenarios identification (Delvosalle et al., 2006). The set of accident scenarios generated through this procedure is then revised and integrated with the results obtained from other identification techniques (e.g. HazOp, past accident analysis). The revised and validated set is finally screened against specific criteria in order to assess its relevance within the LUP context.

2.1 Identification of accident scenarios

The first step of the procedure generates a draft list of critical events for each of the hazardous equipment present in the plant. The procedure described by MIMAH (Delvosalle et al., 2006) is followed, but a few integrative actions were required to allow for the classification of some categories of hazardous equipment not originally considered (e.g. gasometers, truck loading/unloading facilities). A general rule is proposed based on geometrical and functional similarities (Table 1).

MIMAH provides a set of generic fault trees and event trees that can be easily associated to each CE thereby yielding a preliminary list of causes and accident chains. However MIMAH cannot customise generic fault trees and event trees on a case by case basis. Therefore, a set of heuristic criteria is proposed for preliminary customization (Table 1). This preliminary screening may remove some of the branches or LOCs from the trees, but adding new branches in the bow-tie requires a structured approach. Hence, the preliminary list of accident scenarios are validated and integrated by the following techniques:

Analysis of past accident databases. The main major accident databases (MHIDAS, eMARS, ARIA, etc.) are searched to recover data about accidents involving the addressed substance/reference installation. Though most accident records usually do not provide sufficiently detailed information to characterize the release event, the final scenarios and the relevant clusters of causes can be identified.

Analysis of standard scenarios proposed by guidelines. Technical and guideline documents are consulted to verify that the preliminary list of accident scenarios is complete and sufficiently representative with respect to the common practice. Examples of such guidelines are the Dutch “Purple Book” (Uijt de Haag et al., 2005) and the API standard 581 (API, 2000).

Safety Reports. Safety Reports for similar Seveso installations can support the proposed failure modes, final scenarios and primary causes. However, site-specific factors must be evaluated carefully.

Hazard and Operability Analysis. A HazOp analysis of the installation scheme is performed. A generic reference scheme will be defined in the absence of a specific one. The HazOp analysis identifies and provides information about (i) top-events that should be considered; (ii) failure chains leading to the top-events; and (iii) clusters of causes leading to the top-events.

2.2 Selection criteria for the scenarios relevant for LUP

This step ranks the list of accident scenarios previously generated according to the interest for LUP purposes. Only accident scenarios that have potential off-site consequences should be considered for LUP purposes. However, such elimination criterion is applicable only when information is available about a specific plant lay-out and substance inventory and related accident scenario consequences have been assessed. The potential off-site consequences cannot always be assessed “a-priori” through a conservative approach. Thus, a semi-quantitative consultation matrix is developed to rank the accident scenario criticality (Table 2). The matrix considers four key criteria, according to the guidelines on LUP issued by the EC Major Accident Hazards Bureau (Christou et al., 2006): (1) frequency, (2) severity, (3) time scale of the scenario and (4) presence and effectiveness of safety barriers. The consultation matrix applies to the LOC events and to all final events associated to an accident scenario. The most conservative category deriving from the application of the different criteria is associated to the accident scenario. The consultation matrix proposed in Table 2 can be easily modified to account for specific LUP criteria and/or for site-specific data.

Frequency. In the present context, the expected accident scenario frequency is used exclusively as an indicator for the accident scenario criticality. It should be noted that several EU LUP approaches do not accept frequency as an actual cut-off criterion. In this study a 10^{-6} events/year threshold value is proposed, based upon a conservative analogy with individual risk acceptability thresholds (Ale, 2002; Christou et al., 1999; Mannan, 2005). Since several accident scenarios can contribute to the final individual risk value, those having expected frequencies between 10^{-8} and 10^{-6} events/year are considered to be reasonably relevant for LUP purposes (**type a**). A survey of past accidents can provide a short-cut appraisal of the frequency criterion: accident scenario can be reasonably included (**type a**) if more than 2 % (or at least 2) of the accidents involving the installation and material are caused by the concerned LOC. This promotes inclusion of the scenarios that occurred more than once.

Severity. Accident scenarios having only “short-range” consequences, without triggering domino effects, can be disregarded for LUP purposes. Despite technical literature reporting that jet fires, pool fires and confined explosions are likely to have only local consequences, a-priori exclusion seems not conservative. Hence severity ranking of the accident scenarios considers only **type a)** and **b)** classes.

Time scales and delays. The time scale of the accident scenario reflects the available time to activate and implement measures for mitigating off-site consequences as far as (reasonably) possible. Three factors mainly define the time scale of a scenario: (i) source term; (ii) ignition and ignition delay;

Table 1: Reference customization criteria introduced for the identification of accident scenarios

Task	Criteria	Example
Identify hazardous equipment category (EQ)	For equipment not included in original EQ classes of MIMAH, select EQ based on geometrical and functional similarity	Loading/unloading facilities, hoses and connection arms are considered as the likeliest geometrical class “EQ10 - pipe network”
Customize the generic tree	Exclude causes due to material properties	Eliminate causes like “internal combustion/ explosion” for non flammable/reactive materials
	Exclude causes due to equipment characteristics	Eliminate causes like “leak/rupture of internal high pressure source” if utilities such as HP steam coil are not present
	Exclude causes due to operation characteristics	Not consider scenarios like “filled beyond normal level” if material is in gas/vapour state
Customize the generic tree	Exclude non relevant events due to properties of the contained material	Eliminate fire scenarios for non-flammable materials
	Propose conditional exclusions depending upon the verification of specific additional information	Check if initial concentration and temperature of a water ammonia pool may yield toxic concentrations in air
	Mark with warning notes the specific scenarios that may occur only under particular enabling conditions	Only the release of LNG over water can give raise to a Rapid Phase Transition scenario

Table 2: Consultation matrix for exclusion criteria (DP: dangerous phenomenon)

Accident Scenarios	Type a) scenarios *Should be considered for LUP*	Type b) scenarios *May be considered for LUP depending on the specific LUP criterion adopted*	Type c) scenarios *May reasonably not be considered for LUP*
Frequency	≥ 10^{-6} events/year ≥ 2 % and ≥ 2 accident scenarios reported	< 10^{-6} events/year < 2 % and < 2 accident scenarios reported	--- ---
Severity	Possible DP include: fireball, VCE, flash-fire, toxic dispersion	Possible DP only include: jet fire, pool fire, confined explosion	---
Time scale	Possible DP include: fireball; confined explosion; toxic dispersion (H); flash-fire (H); vapor cloud explosion (H)	Possible DP include: pool fire (H); jet fire (H); toxic dispersion (L); flash-fire (L); vapor cloud explosion (L)	Possible DP only include: pool fire (L); jet fire (L)
Safety barriers	Procedural, active or no barriers	Passive barriers	Inherent barriers

* H: DP following catastrophic failure or failure of large diameter pipe
L: DP following release from low equivalent diameter rupture

(iii) time evolution of the dangerous phenomenon. However not all these factors can be effectively used to discriminate the relevance of accident scenarios for LUP purpose.

The time scale component related to the source term depends upon the intensity of the LOC. Typical "large" release rates occurring in very short time periods are likely to lead to off-site consequences, requiring the accident scenario to be considered for LUP.

Dangerous phenomena such as fireballs and confined explosions have time scale of the order of seconds, thereby making any mitigation action virtually impossible. Pool fires and jet fires do have significant time duration, thus enabling to prevent off-site consequences. For accident scenario involving dispersion, the time-lapse available for mitigation measures is again dependent on the source term: formation of cloud in catastrophic or large continuous releases is almost instantaneous; on the other hand, low-intensity continuous releases can be effectively mitigated (e.g. shut-down system).

Safety barriers. The presence of safety barriers can make some scenarios irrelevant for LUP purposes. However the credit given to the effectiveness of safety barriers may be different, depending upon the context and the specific national regulations or control authorities. A conceptual hierarchy of barriers exists: inherent, passive, active and procedural. The general belief is that procedural or active safety barriers do not influence significantly LUP relevance (**type a**). On the other side, passive barriers may lead to scenario exclusion, depending on the adopted LUP criterion (**type b**). Inherent safety barriers reasonably enable the exclusion of a scenario, independently of any other criteria (**type c**).

3. Case Study – LNG terminal

The developed procedure was applied to a case study concerning an on-shore LNG (liquefied natural gas) regasification terminal. The terminal receives LNG from carrier ships docked at the plant berth. Articulated arms are employed for unloading and a vapour compensation line is present in order to allow vapour return to carrier tanks. The LNG is stored as cryogenic liquid in two full containment storage tanks. The regasification line consists of the tank's submerged pumps, a re-condenser, booster pumps and vaporizers. Boil-off gases from the storage tanks are compressed and sent to the re-condenser. Figure 2 shows the plant location and layout.

A preliminary list of critical events and bow-ties was obtained from the application of the modified MIMAH. In a few cases only, the definition of the critical events required the introduction of assumptions concerning geometrical and functional similarities (e.g. loading/unloading arms). The validation phase, resorting to structured methods (e.g. HazOp) and past accident analysis was crucial in defining specifically tailored bow-ties. Figure 1 shows an example of the potential accident scenarios identified. It can be observed that the customization of units and materials affects the accident scenarios identified (e.g. LNG and its vapours are simple asphyxiant). The same figure also report the results obtained by applying the screening matrix of Table 2 and evidences the contribution given by the single DP. For each dangerous phenomenon, the three main criteria identified in the consultation matrix were quantified and classified according to the three classes proposed for accident scenarios. Reported frequencies were estimated from the reference values for LOC frequencies and ignition probabilities proposed in TNO's Purple Book (Uijt de Haag et al., 2005).

Critical event	Secondary critical event	Tertiary critical event	Dangerous Phenomenon	Freq. (1/y)	Freq. Type	Sev.	Sev. Type	T.S.	T.S. Type
Breach on the shell in vapour phase (CE6)	Gas jet	Gas dispersion	VCE	$2x10^{-5}$	**a**	VCE	**a**	7b	**b**
			Flash-fire	$3x10^{-5}$	**a**	FF	**a**	6b	**b**
			High concentration of gas	$5x10^{-5}$	**a**	HC	**b**	5b	**b**
		Gas jet ignited	Jet-fire	$1x10^{-6}$	**a**	JF	**b**	4b	**c**

Figure 1. Example of accident scenarios identified for the re-condenser column (C01) and application of the screening matrix. VCE: vapour cloud explosion.

The safety barrier criterion is not explicitly evidenced in Figure 1. As a matter of fact, no passive barrier can completely prevent accident scenarios for the units analyzed, as confirmed by the analysis of the bow-ties of interest. On the contrary, the introduction of inherent safety barriers may prevent a few accident scenarios. For instance this is the case of the vessel collapse (CE11) for the re-condenser column, where vessel design inherently protects from vacuum implosion.

Figure 1 shows the contribution of the single final outcomes to the scenario classification. Significant variations in classes may occur among the different criteria, confirming that all the four criteria are necessary to obtain a comprehensive figure of the LUP relevance of the scenario.

When accident scenario are ranked considering the more conservative ranking among all the criteria, a large number of Type a) accident scenarios (i.e. "must be considered for LUP") are identified. This is an expected result, since the plant deals with highly flammable liquefied gas. Type b) accident scenarios are identified for the sections where less dangerous materials are handled (e.g. diesel fuel).

Finally, Figure 2 provides an example of damage areas calculated for the accident scenarios identified above. The contours identify the "worst case" zone where damage effects exceed a given thresholds (possible lethal effects according to Italian LUP legislation (D.M.09/05/2001, (Ministero dei Lavori Pubblici, 2001)) were considered). The figure shows that some accident scenarios may not extend

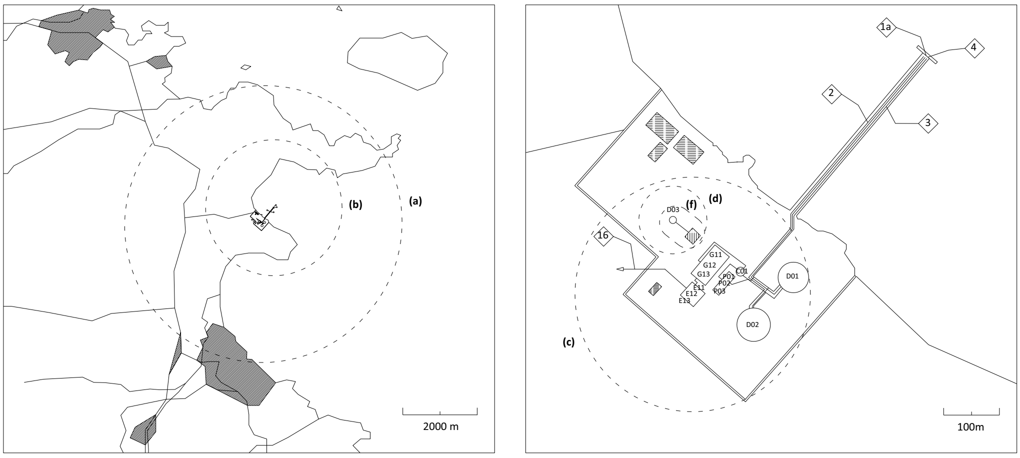

Figure 2. Site assumed for plant location (left panel) and layout (right panel). Worst case damage contours: (a) storage tank; (b) LNG arm; (c) vaporizer; (d) diesel tank; (f) diesel pipework.

beyond plant limits. Thus, they can be neglected for LUP purposes. On the contrary, LUP measures are needed also in areas located far beyond the plant boundaries due to the more severe scenarios that may affect the site (Christou et al., 1999, 2006; Cozzani et al., 2006).

4. Conclusions

A procedure to support the identification and ranking of accident scenarios for land-use planning purposes is developed. Although the procedure is based on the framework provided by the EU Directive 96/82/EC (EC, 1996), it retains a generic structure that allows its application also in other Countries that implement different LUP criteria. The procedure incorporates a modified MIMAH procedure specifically developed for the identification and the validation of accident scenarios. A consultation matrix is defined to help achieving consistency in LUP decision making.

The methodology is applied to a case-studies of industrial interest. Altogether, the results suggest that the preliminary identification and characterization of a set of “LUP-relevant” accident scenarios can be achieved by the proposed approach. Therefore, it can be effectively applied to generate possible input for a knowledge system aiming at a more consistent widespread implementation of LUP criteria in the EU.

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