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Quantitative assessment of domino scenarios by a GIS-based software tool

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Abstract

A software procedure was developed for the quantitative assessment of domino effect. The procedure was based on a systematic methodology for the identification of domino scenarios and for the assessment of consequences and expected frequencies of the escalation events. A geographical information system (GIS) platform was interfaced to the domino assessment software. The implementation of plant lay-out data to the GIS allowed the automatic identification of the possible targets of escalation effects by the software procedure, and a straightforward calculation of the contribution to individual and societal risk indexes caused by the possible domino scenarios. The procedure was applied to the analysis of several case-studies based on actual plant lay-outs. The results evidenced that the approach allows the quantitative assessment of risk caused by escalation events with a limited additional effort with respect to that required by a conventional QRA. The use of a GIS-based software was a key element in the limitation of the effort required for the quantitative assessment of domino scenarios. Moreover, the results of the case-studies pointed out that the estimation of risk increase due to domino events is an important tool for an effective assessment and control of industrial risk in chemical and process plants.
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Keywords: Domino effect; Escalation; Accidental scenarios; Quantitative risk analysis; Major accident hazard

1. Introduction

The propagation of a primary accidental scenario causing one or more than one secondary event, resulting in the escalation of consequence severity is usually indicated as a "domino" accident (CCPS (Center for Chemical Process Safety), 2000; Lees, 1996). Domino accidents are among the more severe major accidents that may take place in chemical and process plants, as evidenced by the case histories reported in a previous study (Khan & Abbasi, 1999). In spite of this, the assessment of domino accidental events is still an open problem. Even if the legislation for the control of major accident hazards calls for a thorough analysis of in-site and off-site hazards caused by domino events (e.g. see art. 8 of the European Council Directive 96/82/EC, 1996, better known as the "Seveso-II" Directive), a well accepted methodology for the analysis of accident escalation is still missing. Several technical standards introduce preventive measures, as safety distances, thermal insulation or emergency water deluges, in order to control and reduce the probability of domino events. A few studies proposed qualitative methodologies for domino assessment (Cozzani & Zanelli, 2001; Delvosalle, 1998; Gledhill & Lines, 1998; Kourniotis, Kiranoudis, & Markatos, 2000). Several contributions were dedicated to specific aspects of the problem, as the assessment of expected escalation frequencies by equipment damage models. Simplified approaches based on empirical models for equipment damage probability following the primary event were proposed by several authors (Bagster & Pitblado, 1991; Cozzani, Gozzi, Mazzoni, & Zanelli, 2001; Khan & Abbasi, 1998a; Latha, Gautam, & Raghavan, 1992; Pettitt, Schumacher, & Seeley, 1993). Upgraded models for equipment damage were also developed, specifically aimed to the assessment of escalation probability (Cozzani & Salzano, 2004a; Gubinelli, Zanelli, & Cozzani, 2004). More recently, a tool for

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the management of off-site domino hazard was also proposed (Reniers, Dullaert, Ale, & Soudan, 2005a).

A comprehensive approach for the estimation of the expected frequencies of escalation events was proposed by Khan and Abbasi (1998b, 2000, 2001), based on a systematic assessment of the damage probabilities of equipment items falling within the damage radius of the primary accident. Few other studies afforded the development of complete and comprehensive methodologies, suitable for the application to the analysis of domino hazard in process plant (Contini et al., 1996; Morris, Miles, & Copper, 1994). However, the relevant amount of computational resources required by the assessment possibly were not available at the time, thus forcing to the introduction of oversimplifications. Moreover, these methods were mainly addressed to the evaluation of the expected frequencies of domino events, and not to consequence assessment.

The implementation of the "Seveso-II" Directive, requiring off-site domino effect assessment also in the framework of land-use planning pointed out the deficiencies in the current practices for the assessment of domino hazard (Reniers, Dullaert, Ale, & Soudan, 2005b), evidencing the need of a more detailed and extended analysis of escalation hazards.

The present study focuses on the development of a software procedure for the quantitative assessment of domino effect, based on a systematic methodology for the quantitative assessment of the contribution of domino effect to industrial risk. The implementation of the plant lay-out to a geographical information systems (GIS) allowed the definition of a simplified procedure for the identification of possible domino targets, based on the availability of a limited set of data on the vulnerability of plant equipment items. The procedure was applied to the analysis of case-studies based on actual plant lay-outs. The contribution of domino events to risk indexes was calculated and discussed. The results also evidenced that the use of GIS-based tools also makes possible an easy introduction of information on off-site vulnerability, thus allowing the identification of possible off-site targets of domino effect.

2. Quantitative assessment of domino scenarios

2.1. Definition and identification of domino scenarios

The following definition of domino effect will be assumed in the present study: an accident in which a primary event propagates to nearby equipment, triggering one or more secondary events resulting in overall consequences more severe than those of the primary event. An accident is usually considered a "domino event" only if its overall severity is higher or at least comparable to that of the primary accidental scenario. Thus, the propagation is relevant only if it results in an "escalation" of the primary event. Four elements may thus be considered to characterize a domino event:

(i) A primary accidental scenario, which triggers the domino effect.
(ii) A propagation effect following the primary event, due to the effect of escalation vectors caused by the primary event on secondary targets.
(iii) One or more than one secondary accidental scenarios, involving the same or different plant units, causing the propagation of the primary event.
(iv) An escalation of the consequences of the primary event, due to the effect of the secondary scenarios.

Domino accidental scenarios result from the escalation of a primary accidental event. The escalation is usually caused by the damage of at least one equipment item, due to the physical effects of the primary event. The loss of containment that follows the damage may result in a secondary accidental scenario, and more than one secondary scenario may take place if the primary event results in the damage of more than one unit.

Thus, the quantitative assessment of domino accidents requires the identification, the frequency evaluation and the consequence assessment of all the credible domino scenarios, including all the different combinations of secondary events that may be originated by each primary event. The identification of the credible domino scenarios should be based on escalation criteria addressing the possible damage of equipment due to the physical effects generated in the primary scenarios. The use of threshold values to identify the possible domino targets is a common practice in the analysis of domino hazard. An extended discussion on the procedures for the identification of the possible domino scenarios is reported elsewhere (Cozzani & Zanelli, 2001). Tables 1 and 2 summarize the escalation vectors (the physical effects of the primary scenarios) and the detailed escalation criteria selected to identify the credible domino scenarios (Cozzani, Gubinelli, Russo, Salzano, & Zanelli, 2004; Cozzani, Gubinelli, & Salzano, 2005; Cozzani & Salzano, 2004b).

In the present study, the analysis of escalation was limited to the secondary scenarios that may directly derive from the damage of secondary equipment caused by the primary event. Thus, only "first level" escalation events were considered in the approach. The possible further escalation of the secondary scenarios was neglected in the analysis for the sake of simplicity, although the methodology may be applied as well to the assessment of the further escalation of the secondary events (domino chains).

The possibility of domino events caused by lacks in emergency procedures or by errors in emergency management following toxic releases was not considered.

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