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Assessment of domino effect: State of the art and research Needs

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ABSTRACT

High-impact low-probability (HILP) accident scenarios in industrial sites are raising a growing concern. Domino effect was responsible of several catastrophic accidents that affected the chemical and process industry, as well as critical infrastructures for energy as oil refineries. However, there is still a poor agreement on assessment procedures to address escalation hazard resulting in domino scenarios. The present study presents a review of the work done in the last 30 years in the field, and a critical analysis of available tools and knowledge gaps concerning domino effect assessment. The analysis of scientific publications concerning domino effect in the process industry resulted in a database of more than 60 documents, addressing three main issues: past accident analysis, models for equipment damage, risk assessment and safety management of domino scenarios. The methods, models and tools developed make now possible the quantitative assessment of domino scenarios in risk analysis and in safety management of industrial sites. Nevertheless, a number of open points still remain, where existing tools may be improved and uncertainty may be reduced.

1. Introduction

The growing public concern caused by high-impact low-probability (HILP) accident scenarios raised the attention in the scientific and technical literature on the analysis of the so called "domino effect" [108]. Domino effect was responsible of several catastrophic accidents that took place in the chemical and process industry ([3]; CCPS, 2000; [65,85]). Nevertheless, domino effect is a well-known hazard in many industrial fields [17]. Although an increasing interest can be inferred from the available scientific publications, this subject has been afforded by a relatively limited number of authors. As a result, there is still a poor agreement on the main definitions of domino effect, and the specific features of domino scenarios are still poorly known [109]. Table 1 reports a summary of domino effects definitions. As shown in the table, most definitions are complementary and stress specific features of domino scenarios. The more comprehensive definition, encompassing most aspect of others, is that given by Reniers and Cozzani [108], that will be applied in the following.

Since there is not a widely accepted definition of domino effect, most of the studies on domino effect are carried out independently and focus either on very particular aspects of accident escalation process, as vulnerability models, or on the definition of methodologies for hazard and/or risk assessment of domino scenarios. This was evidenced in a recent comprehensive review of the state of the art of domino effect assessment [108]. Fig. 1 shows the number of relevant publications on domino effects published in scientific journals in the period 1985-2014 divided by topic. As shown in the figure, many of the papers published were aimed at the study of equipment damage mechanism and at the development of vulnerability models. A quite high number of papers aimed at the inclusion of domino accidents in quantitative risk assessment, while a more limited number of studies were dedicated to innovative safety management tools for domino accidents and to the historical assessment of domino events through the analysis of past accident databases. Further details on publications addressing domino effect are reported in Table 2.

The present contribution is aimed at assessing the progress on domino effect assessment and at providing a critical review of the most important studies on domino effect carried out in the last 25 years on three specific key points: i) past accident analysis; ii) vulnerability models for equipment damage; iii) quantitative risk assessment and safety management of domino scenarios. A summary of the contributions analysed, with particular focus on the progress provided by each reference to the overall knowledge concerning domino effect analysis is reported in Table 2. The final aim of the present analysis is to understand how the progress on such issues may affect the assessment of domino hazard, and to identify weak points of actual methodologies and possible directions of future

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Table 1
Definitions of "Domino Effect" provided in the literature.

Author (s)	Definition
[53]	The effects of major accidents on other plants on the site or nearby sites.
[11]	A loss of containment of a plant item which results from a major incident on a nearby plant unit.
[81]	An event at one unit that causes a further event at another unit.
[63]	A chain of accidents or situations when a fire/explosion/missile/toxic load generated by an accident in one unit in an industry causes secondary and higher order accidents in other units
[34]	A cascade of accidents (domino events) in which the consequences of a previous accident are increased by the following one(s), spatially as well as temporally, leading to a major accident.
[124]	The effect that loss of containment of one installation leads to loss of containment of other installations.
[20]	An accident which starts in one item and may affect nearby items by thermal, blast or fragment impact.
[125]	An accidental phenomenon affecting one or more installations in an establishment which can cause an accidental phenomenon in an adjacent establishment, leading to a general increase in consequences.
[31]	A loss of containment in a Seveso installation which is the result (directly and indirectly) from a loss of containment at a nearby Seveso installation. The two events should happen simultaneously or in very fast subsequent order, and the domino hazards should be larger than those of the initial event.
[98]	A major accident in a so-called 'exposed company' as a result of a major accident in a so-called 'causing company'. A domino effect is a subsequent event happening as a consequence of a domino accident.
[85]	A factor to take account of the hazard that can occur if leakage of a hazardous material can lead to the escalation of the incident, e.g. a small leak which catches fire and damages by flame impingement a larger pipe or vessel with subsequent spillage of a large inventory of hazardous material.
[25]	Accidental sequences having at least three common features: (i) a primary accidental scenario, which initiates the domino accidental sequence; (ii) the propagation of the primary event, due to "an escalation vector" generated by the physical effects of the primary scenario, that results in the damage of at least one secondary equipment item; and (iii) one or more secondary events (i.e., fire, explosion and toxic dispersion), involving the damaged equipment items (the number of secondary events is usually the same of the damaged plant items).
[45]	A major accident in a so-called secondary installation which is caused by failure of a so-called external hazards source.
[8]	The propagation of a primary accidental event to nearby units, causing their damage and further "secondary" accidental events resulting in an overall scenario more severe than the primary event that triggered the escalation.
[108]	An accident in which a primary unwanted event propagates within an equipment ('temporally'), or/and to nearby equipment ('spatially'), sequentially or simultaneously, triggering one or more secondary unwanted events, in turn possibly triggering further (higher order) unwanted events, resulting in overall consequences more severe than those of the primary event.

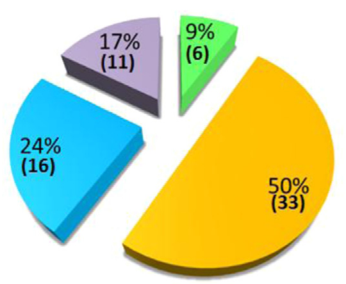

Fig. 1. Scientific publications on domino effect in the period 1988–2014 divided by topic.

studies, in order to fill the gaps that prevent an exhaustive scientific description of domino effect.

2. Past accident analysis

The analysis of past accidents is a powerful tool to understand and analyse domino scenarios. Past accidents are in fact the only source of "experimental data" available in this field. Reports on accidents involving domino effect can be obtained from the scientific literature, from technical reports and in specific databases. The analysis of domino accidents gives the possibility of investigating specific features of escalation scenarios: the events that more frequently trigger a domino sequence, the more frequent escalation sequences, the hazardous substances that are more prone to be involved in these accidents, etc. However, a survey of domino accidents has inherent difficulties, the most significant being the lack of detailed information, in spite of a few cornerstone studies present in the field.

The paper of Kourniotis et al. [76] reports the analysis of a set of 207 major accidents retrieved from competent authorities reports and well established accident databases. The ratio of domino accidents on the total number of accidents analysed is of 0.386. Accidents have up to 600 recorded fatalities. Data are analysed statistically in order to obtain the probability-fatality (p–N) distribution curves, expressing the probability p that a domino accident results in at least N fatalities. Probabilities were calculated considering the overall number of accidents in the database.

Differences in the shape and parameters of the distribution curves were observed when comparing that obtained for the entire set of accidents analysed to that obtained when only domino accidents are considered. The comparison showed that the occurrence probability of multiple fatalities is higher as a consequence of domino accidents than as a consequence of a generic accident (see Fig. 2). The conclusion is that domino scenarios show, in general, a higher severity with respect to conventional scenarios.

The study of Ronza et al. [117] is not specifically focused on domino effect. However it performed a survey of 828 accidents in port areas recorded in the MHIDAS database [88]. A total of 108 out of the 828 accident records considered were domino accidents. Conditional probability event trees were built to identify the event sequences of the accident scenarios where a domino effect was observed. The most frequent event sequences experienced were: fire to explosion, loss of containment (LOC) to fire to explosion, and LOC to flammable gas dispersion to explosion.

The investigation of Gómez-Mares et al. [44] was focused on the study of accidental scenarios involving jet fires. A total of 84 accidents involving jet fire were analysed. Event trees where obtained from available data in order to identify the probability of first and second level domino scenarios. In 27% of the cases, the sequence identified by the event tree analysis was LOC to jet-fire