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Thresholds for domino effects and safety distances in the process industry: A review of approaches and regulations

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ABSTRACT

Domino effects resulting in cascading events in the chemical and process industries are well known causes of severe accident scenarios. Although the threats due to domino effects are recognized since at least three decades, this is still a controversial topic when coming to its assessment. A number of different approaches are proposed in technical standards and in the scientific literature. The present contribution aims at providing a critical revision of the procedure for the identification of domino effect scenarios. An overview of current regulations for domino effect assessment is provided. The criteria resulting from the regulations are compared and discussed in the light of recent developments concerning escalation hazards and safety distance assessments.

1. Introduction

The Mexico City disaster, that took place in November 1984 [1], called for 542 fatalities and huge destruction, is possibly one of the most known domino accidents that ever affected an industrial site. Since then, a specific concern on domino accidents was raised in the chemical and process industry. Also to comply with the requirements of the legislation (EU Directives), technical standards and preventive measures, such as safety distances, fireproofing and emergency water deluges were introduced to control and reduce the probability of domino events [2]. However, the complexity of domino scenarios caused lack of a common approach to their assessment. Thus, a number of different approaches are proposed in the literature for the analysis of domino effects.

As a consequence of the difficulties in the technical assessment and safety management of domino scenarios, different tools and even different values for safety distances are adopted in different countries [3]. Moreover, not even a single well accepted definition of what should be intended as a domino scenario is present in the literature, in technical documents and in regulations [4]. In particular, there is disagreement in the literature concerning the key elements in domino scenarios: propagation in space (from one process or storage unit to another), propagation in time or escalation (intended as an overall increase) of final consequences with respect to those of the primary accident.

Larsen et al. [3] addressed several problems that inspection services from European Member States experience when it comes to the follow-up of the current legislation concerning domino effect between adjacent industrial sites. One of the most important challenges remarked in the report is the lack of criteria for the identification of "domino clusters", intended as establishments among which accidents may propagate resulting in an external domino effect. Another problem is the insufficient harmonization between the different European countries with respect to the domino effect. A report of Larsen et al. [3] remarks that sites may be classified as "domino establishment" or not depending on the country where they are sited, due to the different criteria being used in the EU Member States for the identification of domino clusters.

In the present contribution, starting from an up-to-date definition of what constitutes a domino effect, a review of escalation thresholds and safety distances for domino effects is provided, with the aim of defining a procedure that may lead to the selection of appropriate values, based on a physically-sound analysis of escalation mechanisms.

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Table 1
Domino effect definitions.

Author (s)	Domino effect definition
Council Directive 96/82/EC [6]	Domino effects, where establishments are sited in such a way or so close together as to increase the probability and possibility of major accidents, or aggravate their consequences.
Health and Safety Executive, COMAH regulations [10] The United Kingdom	In some circumstances a major accident at one COMAH establishment might be triggered by an incident at another COMAH establishment (the so-called domino effect). The initiating event needs not necessarily to be a major accident itself but must be at a COMAH establishment, either top-tier or lower-tier, and involve a defined dangerous substance.
Cozzani et al. [15] Italy	Accidental sequences having at least three common features: 1) a primary accidental scenario, which initiates the domino accidental sequence; 2) 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; 3) 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).
Delvosalle [8] Wallonia (Belgium)	A cascade of events in which the consequences of a previous accident are increased by following one(s), as well spatially as temporally, leading to a major accident.
Gorrens et al. [9] Flanders (Belgium).	A major accident in a so-called secondary installation which is caused by failure of a so-called external hazards source.
Vallee et al. [7] France	An accidental phenomenon affecting one or more installations in an establishment that can cause an accidental phenomenon in an adjacent establishment, leading to a general increase in consequences.
Reniers and Cozzani (2013) [4]	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, that may in turn trigger further (higher order) unwanted events, resulting in overall consequences more severe than those of the primary event.

Top-tier and lower-tier establishment: see Article 3 of Seveso-III Directive [5]

2. Definition of domino effect

In the following paragraphs, the parameters that should be looked at in order to understand the escalation possibility and in order to identify domino scenarios are discussed. Actually, no universally-accepted definition of a domino effect exists in the technical and scientific literature, possibly due to the complexity of such events and due to the different perspectives that may be adopted in their analysis. Nevertheless, defining what should be considered as a domino accident is not a mere academic exercise, since several technical standards as well as the European legislation specifically demand the assessment of “domino effects”. For example, Article 9 of the European Directive 2012/18/EU [5] requires to identify establishments that may be affected by the domino scenarios and demands to include such scenarios in safety reports and in major accident prevention policies.

Due to the inexistence of a non-polysemous formalization to describe the domino effect phenomenon, most of the EU Member States' competent authorities refer to the definition given by Article 8 of Council Directive 96/82/EC [6]. Table 1 reports such definition as well as alternative definitions adopted in EU Member States and proposed in the literature.

As Table 1 clearly shows, the definition of domino effect provided in the Seveso Directives only considers accidents that propagate from one establishment to another establishment (external domino effect) and omits the so-called internal domino effects [4]. This definition is unchanged in Article 9 of Directive Seveso-III. If the definition provided by EU legislation is adopted, safety managers may meet regulatory requirements (safety report, major accident prevention policies, licensing) without assessing part of the risk resulting from escalation possibility, and specifically that of escalation from one to another plant unit inside the same Seveso establishment. Another obvious limit of the definition reported in the Seveso Directives is that it concerns only Seveso installations. An accident in one Seveso plant can affect a nearby installation not falling under the obligations of Seveso Directives, or vice-versa. For these reasons, some EU Member States proposed their own definition. In France the Ministry of Ecology and Sustainable Development adopts the definition given by Vallee et al. [7] (see Table 1). In Belgium, Wallonian practices use the definition proposed by Delvosalle [8], whereas the Flemish Ministry of Environment, Nature and Energy adopts the definition given by Gorrens et al. [9] (see Table 1). In Italy no specific official definition is yet available, although several guidance documents and draft decrees recognize domino effects being possible, not only across different Seveso establishments, but also from one unit to another within the same establishment. In the United Kingdom (UK), in order to implement the Seveso II Directive, a slightly different definition of domino effect is reported in the Control of Major Accident Hazard (COMAH) Regulations [10] (see Table 1).

As evident from the critical analysis of Table 1, no agreement is present when the definition of domino effect is considered. This also emerged from rather different interpretations given to the concept of domino effect in an expert workshop recently organized [11].

In order to avoid jumbling this perception and adding confusion, it may be interesting to go back to studies that have pointed out the sequential nature of events leading to an accident, so as to remove ambiguity. This was remarked for the first time by Heinrich [12] with respect to accident modeling, introducing what has become known as the “domino theory”, where the author described the accident as a chain of independent events that occur in particular order, causing harm [13]. However, the domino theory is not to be confused with the “domino effect” phenomenon, the latter constituting the focus of this paper. Indeed, Heinrich's domino theory does not join the meaning of domino effect as it was defined in Table 1, since it does not consider the propagation of a major accident that occurs in one unit to the other nearby units. Heinrich's theory only discusses and explains the sequence of events that led to an occupational accident.

In order to unambiguously identify the character of the domino event under consideration, Reniers [14] proposed a classification, which categorizes domino events according to the various features that domino scenarios may have. Four categories are suggested, each having two subcategories: category.1 (internal or external), category.2 (direct or indirect), category.3 (temporal or spatial), and category.4 (in serial or parallel).

With the purpose of standardizing the domino effect definition intended to progress towards a non-polysemous formalization to describe the phenomenon and converge to a broad consensus, at least within the scientific community, Reniers and Cozzani [4] have proposed a further definition of domino effect, also reported in Table 1. This encompasses all specific aspects found in most domino event definitions, including the four categories cited above [14] as