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The significance of domino effect in chemical accidents

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A historical survey was performed on 330 accidents involving domino effect, occurred in process/storage plants and in the transportation of hazardous materials; only accidents occurred after 1st-January-1961 have been considered. The main features – geographical location, type of accident, materials involved, origin and causes, consequences, domino sequences – were analyzed, with special consideration to the situation in the developing countries and compared to those from other previous surveys. Among the involved substances, LPG was the most frequent one, followed by liquid hydrocarbons. Process plants (38.5% of cases) and storage areas (33%) were the most common settings; 10.6% of past domino accidents occurred in transfer operations. The ratio between "two-step" and "three-step" domino accidents was found to be 6. A specific analysis of the accidents (84) occurred in the 21st century was performed, comparing them with the total set of accidents. Finally, a set of specific recommendations inferred from the results is provided.

1. Introduction

Recent surveys have emphasized the importance of the domino effect in the occurrence and severity of the major accidents that take place in the process industry and in some closely related activities, such as the transportation of hazardous materials (Abdolhamidzadeh, Abbasi, Rashtchian, & Abbasi, 2010, 2011; Darbra, Palacios, & Casal, 2010). Escalation criteria have been proposed to assess the near-field effects of fire and explosion (Cozzani, Gubinelli, & Salzano, 2006). The main features of domino accidents have been recently analyzed by diverse authors in the book "Domino effects in the process industries. Modelling, prevention and managing" (Reniers & Cozzani, 2013). The diverse chapters of this book clearly show the complexity of domino effect accident scenarios and the many ways through which the escalation and propagation of accidents can take place.

Although an increasing interest can be inferred from the publications found in the literature, this subject has been treated by a relatively reduced number of authors. As a result, the main domino effect features and trends are still poorly known.

Diverse definitions and interpretations about the meaning of the domino effect are available; Reniers (2010) published a list of them. For the purpose of this survey, the definition proposed by Delvosalle (1998) will be used to select the accidents. According to him, a domino accident can be defined as "a cascade of events in which the consequences of a previous accident are increased both spatially and temporally by the following ones, thus leading to a major accident".

Domino effect can be analyzed through different approaches. Amongst them, the analysis of past accidents seems to be a powerful tool. Past accidents are in fact the only source of "experimental data" available in this field, data for which a high price has been paid. The analysis of these accidents gives the possibility of knowing diverse aspects of domino effect: the usual events that initiate it, the most frequent sequences, the substances that are more prone to be associated to these accidents, etc. However, such a survey has certain implicit difficulties, the most significant one being the lack of information.

Accidents involving domino effect can be found from the specialized literature, from reports of certain institutions and in appropriate databases. However, often the information thus obtained is not complete; this implies a reduction of the sample size when a statistical treatment must be performed, with the consequent loss of significance of the results obtained.

Several historical surveys have been published on this subject. Bagster and Pitblado (1991) studied the frequency and likelihood of domino accidents in a pioneering work. Kourniotis, Kiranoudis, and Markatos (2000) performed a survey on a total of 207 accidents, of which 80 involved domino effect; their sequences (ratio of accidents with one or two domino effects) and their consequences on

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the population were analyzed. Ronza et al. (2003) studied 108 accidents occurred in port areas which involved as well domino effect. With a much more specific approach, Gómez-Mares, Zárate, and Casal (2008) published a survey on accidents involving jet fires, 50% of which had been the primary event of a domino effect sequence. Darbra et al. (2010) performed a historical analysis on 225 accidents involving this effect. Shortly after, Abdolhamidzadeh et al. (2011) published another survey on 224 accidents also involving domino sequences. In these last two papers the main features of the accidents were analyzed: substances involved, origin, primary events, consequences, etc. In Darbra et al. (2010) the accident sequences were studied through the relative probability trees. In Abdolhamidzadeh et al. (2011) a list of the accidents studied was included. The results of these two surveys differed in some aspects, essentially because of the difference in the respective sets of data (geographical location of accidents). Thus, aspects such as the severity of accidents over the years or their frequency as a function of time were different.

Therefore, it seemed of interest to perform a wider analysis including both sets of data (avoiding repetitions); thus, the two collections (Abdolhamidzadeh et al., 2011; Darbra et al., 2010) were merged and screened, adding also new accidents occurred in the recent years.

Although this survey is in some aspects similar to the previous ones, it deals with a much larger number of accidents. This allows a specific and new analysis of the accidents occurrence and features in developing countries (in which industry is developing quickly), as well as a comparison with the situation in the industrialized ones. In addition, a specific analysis of accidents occurred in the period 2000–2013 has been also done.

2. Methodology

The survey was performed by using both databases and other sources of information. Many data were obtained from the Major Hazard Incident Data Service database (MHIDAS, 2007) (November 2007 version, containing 14,168 records), managed by the UK Health and Safety Executive. This database covers incidents recorded from the beginning of the 20th century until 2006 in over 95 countries, and each record is classified according to different fields (e.g. cause, origin) to facilitate automatic processing. Other databases also consulted were the Major Accidents Reporting System (MARS, 2012), through which EU member states report industrial accidents in a standard format, overseen by the Major Accident Hazards Bureau (MAHB) of the European Commission Joint Research Centre; the Failure and Accidents Technical Information System (FACTS, 2010), a database for accidents involving hazardous materials created by TNO Industrial and External Safety; and the Analyse, Recherche et Information sur les Accidents database (ARIA, 2012), created in 1992 by the French Ministry of regional Planning and the Environment. However, when analyzing a specific accident in these databases the information is often incomplete, the description is rather short and details on the accident sequence are lacking. This requires a detailed search for specific information on most accidents, which can be performed by consulting accident reports from different sources. Among these, the US Chemical Safety Board (CSB, 2012), the U.S. National Transport Safety Board (NTSB, 2012) and the U.S. National Fire Protection Association (NFPA, 2012), are some examples of trustable internet resources.

When different accident databases and other resources are used to collect accident data, the volume of information increases significantly. Therefore, the search and retrieval of data become difficult and in some cases – especially when accidents involve more than one substance – information can be duplicated. In order to avoid this situation, a database was created using Microsoft Access. By doing so, the information on accidents from the different databases was centralized and, as a consequence, storage, retrieval, edition and analysis of accidents became much easier.

In order to identify the different domino accidents from the databases, keywords related to domino effect were selected. Once the accidents were gathered, clear criteria to define if they involved a domino effect were established. In this way, a proper selection of accidents was done. The criteria used in this selection were the following:

- Domino effect occurs when a first accident in a unit (e.g. an explosion) triggers a second one in another unit (e.g. release and fire in a tank). This is known as a spatial domino accident.
- It is also considered a domino effect when a first accident in a unit (e.g. a jet fire from a vessel impinging on the vessel wall) originates a second one (e.g. BLEVE of the vessel) in the same unit. This is known as a temporal domino accident.
- In the case that "two" accidents are essentially simultaneous, this is not domino effect. They should be considered practically as the same accident; for example: the explosion in a floating roof tank followed immediately by a fire in the same tank.
- This study has only taken into account accidents occurred after 1st-January-1961. This is due to the fact that before this date (half a century ago) the type of industry was essentially different from the present one (control, safety, management, etc.) and, therefore, those accidents would not be much useful nowadays to find common trends and reach sound conclusions.
- This survey considers accidents occurred in process plants, in storage areas and in the transportation of hazardous materials (road, rail and ship). Moreover, it also includes accidents that have occurred because of natural events such as earthquakes or floods.
- Accidents occurred in military premises (ammunition, etc.) or with fireworks have not been considered.

After applying these criteria, the number of selected accidents was reduced considerably; however, the accuracy and quality of the domino accidents' sample was increased. Finally, a collection of 330 accidents was obtained. This is the largest sample of domino accidents analyzed until now in a scientific journal.

3. Accident analysis

In this section the main features of the selected domino accidents are analyzed.

3.1. Distribution of accidents according to time and location

The evolution of the accidents frequency as a function of time has been plotted in Fig. 1. As it can be seen, the 70's is the decade with the highest percentage of accidents (23.9%); after an exceptional decrease in the 90's, the frequency increases again in the first decade of the 21st century to the previous values.

The location of the domino accidents was also studied, as the main features of the process industry, as well as legislation and risk-planning policies – which have an effect on the occurrence and severity of accidents-, can change from one country to another. Although it is not easy to make such clusters, finally, by applying both political and development-based criteria, the accidents were classified in three main groups depending on the country where they had occurred:

1. the European Union (21.8%),
2. other developed countries: Australia, Canada, Japan, New Zealand, Switzerland, Norway and the United States (54.5%),