Historical Analysis Of Accidents Involving Domino Effect

F. Clini[1], R. M. Darbra[2] and J. Casal[2]

[1]Dipartimento di Ingegneria Chimica, Mineraria e delle Tecnologie Ambientali. Università di Bologna.Via Terracini, 28. 40126. Bologna (Italy)
[2]Centre d'Estudis del Risc Tecnològic(CERTEC).Department of Chemical Engineering. Universitat Politècnica de Catalunya. Diagonal 647, 08028-Barcelona. Spain.

A study of 261 accidents involving domino effect has been carried out. The main features have been analyzed: origin, causes, consequences and most frequent sequences. The analysis has shown that the most frequent causes are external events (31%) and mechanical failure (30%). The storage areas (37%) and process plants (27%) are by far the most common places where domino accidents have occurred. The most common sequence in the event trees resulted to be explosion–fire (21%), followed by release–fire–explosion (15%) and fire–explosion (14%).

1. Introduction

Domino effect has been defined as *"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"* (Delvosalle, 1996). Due to the significance of this phenomenon for the process industry (it has been specifically introduced into the last version of the Seveso Directive), the analysis of the main features of the domino effect is quite interesting for risk analysis.

Diverse authors have published surveys on domino effect (Abdolhamidzadeh et al., 2009, Kourniotis et al., 2000), although the number of accidents analyzed in these surveys was relatively reduced.

This paper presents a study of the different scenarios where domino effect accidents occurred. Aspects such as frequency over the time, accident sequences type (e.g. jetfire–explosion–gas cloud), origin (e.g. transport, storage), causes (e.g. human, external), population affected and consequences were analyzed. From this information, some conclusions are drawn concerning the occurrence of this type of phenomenon and the possibility of applying certain safety measures to reduce its probability.

2. Methodology and selection criteria

The main source of information for this survey has been MHIDAS Database (Major Hazard Incident Data Service) (MHIDAS, 2007) (November 2007 version, with 14,168 records). MHIDAS is managed by the SRD (UK Health and Safety Executive). The database contains incidents from over 95 countries; all the information is taken from public-domain information sources. Other databases have been also consulted: MARS, FACTS and ARIA, together with a detailed research on internet on each accident

During the research on this database as well as in the other aforementioned sources, the following scenarios were considered:

- Incidents occurred during processing, loading/unloading, transportation (trains, lorries, ships…) and storage of chemicals
- Incidents caused by natural events or human errors which lead to domino effect.

After this first selection a second filter was applied, excluding those incidents starting with a sabotage or terroristic attack or involved military equipment or explosives.

One of the critical points that emerged in the development of this historical analysis was the criteria adopted to choose if an incident involves or not domino effect. The first step was to take into account the definition of domino effect (Delvosalle, 1996). This definition could be read in very different ways, especially referring to the word "*temporally*". Therefore, the following criteria have been established:

- If an accident occurs and as a consequence another accident (secondary accident) happens temporally or spatially with a magnitude either equal or higher to the previous one, this scenario is considered domino effect.
- When an accident occurs and originates as a secondary event a release (gas or liquid) without further consequences, it is not considered to be a domino effect. But it is considered domino effect if it involves the following situations: a) a gas cloud of a toxic material, b) a gas cloud of a flamable material that later ignites/explodes.

According to this criterion, a third additional selection was done. Therefore, an exhaustive analysis of the accidents was carried out in one-by-one basis.

3. Results

3.1 Distribution of accidents over time

As it can be seen in Figure 1, there is a significant increase in the number of accidents over the time, from 1950 up to 1970-1990, decreasing later over the last two decades.

This behaviour has also been appointed by other studies of accidents in chemical plants and port areas (Oggero et al., 2006, Darbra et al., 2004).

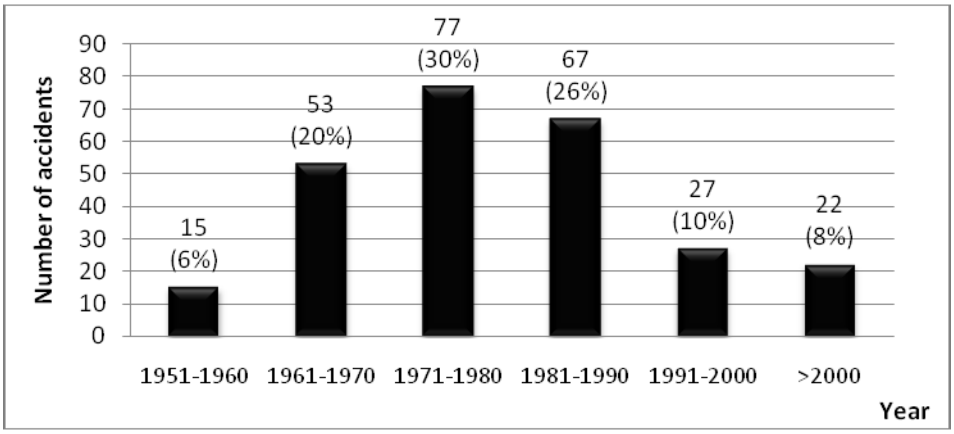

Figure 1. Distribution of the accidents over the time

The trend found in this graph is due to different factors: on one hand, the access to the information about accidents has improved gradually over the time; on the other hand, the chemical industry has undergone a continuous expansion: more and larger process plants and storage areas. The peak of accidents is reached in the 70's, where both the better access to incident data and the great expansion of chemical plants revealed the problematic situation of the domino effect. Later –in the last two decades– the improvement of safety, development of risk analysis techniques and the establishment of more restrictive directives and regulations led to a decrease of the number of accidents involving this phenomenon.

3.2 Accident Location

The accidents were divided into three categories according to the place where they occurred :

1. European Union (24%) (accidents occurred in countries that at that moment were not part of EU –though now are– are not included in this category).
2. United States, Canada, Australia, Japan, New Zealand, Norway (57%).
3. Rest of the world (19%).

More than 80% of the accidents occurred in the most developed countries. The massive presence of huge plants and consequently consistent transportation and storages in these countries explains the entity of the results, but nonetheless a certain loss of data in the rest of the world must be taken into account, especially in the early years of the databases.

3.3 Causes

With reference to the generic causes of a domino accident, *external events* and *mechanical failure* have both scored over 30% (table 1). *Human error* is the cause of 21% of the occurred accidents. External events are somewhat unpredictable, but the significant contribution of human errors suggests that training of professional people should be improved.

Table 1. General cause of the accidents.

Number of events	Cause	Frequency
82	External events	31%
78	Mechanical failure	30%
54	Human factor	21%
46	Impact failure	18%
30	Violent reaction	11%
11	Instrument failure	4%
7	Upset process condition	3%
3	Services failure	1%

3.4 Origin

The database used considers different categories to designate the place or activity in which the accident occurred. As it can be seen in Figure 2, the most critical area is Storage (37%), followed by Process (27%) and Transportation (19%).

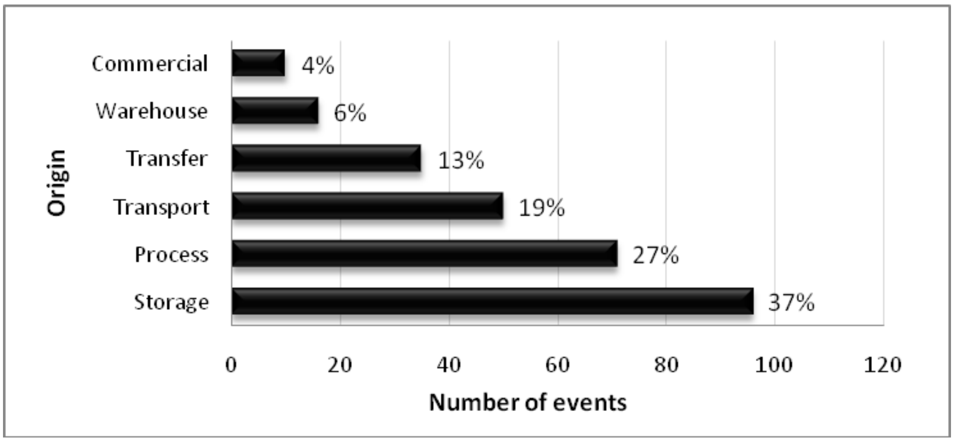

Figure 2. Origin of the accidents

It is important to improve safety in storage areas and warehouses, as they are the most probable starters of a domino effect (transfer operation, as loading/unloading are significantly hazardous, being involved in 13% of all accidents) generally located near the process area.

3.5 Incident type

The accidents have been classified into four different types: Fire, Explosion, Release and Gas Cloud. The most typical primary incidents for a domino effect sequence are fire (43%) and explosion (41%). However, one of the limitations of MHIDAS is the fact that release category is not present as an incident type for some accidents, although from the abstract one could understand that a leak has occurred.

These results are consistent with the event trees analysis, according to which the initial event is a release in 41% of cases and then most likely a fire follows. In case of an accident starting with an explosion (35%), fire follows preferentially. If fire occurs first (24%) a following explosion is expected (69%). However, the most probable global sequence is an explosion followed by fire, which occurred in 21% of the accidents, followed by the sequence release–fire–explosion (15%) and fire–explosion (14%).

3.6 Population affected

The population affected by the accidents is divided into three variables according to the entity of the consequences suffered: number of deaths, number of injured and number of evacuees. Table 2 summarizes all the information available on these three categories. The last column shows the accidents that had information on these variables.

Concerning the number of deaths, 57% of the accidents with available data presented fatalities, being the most common likely group the one that involved from 1 to 10 deaths. In total 1410 people died. The accident that caused more deaths happened in San Juan Ixhuatepec, Mexico, 1984, where a series of explosions and BLEVEs destroyed 50 out of 54 LPG vessels in a combustible storage, killing approximately 500 people.

Table 2. Number of accidents involving dead, injured and evacuated people when information available.

	0	1-10	11-100	101-1000	1001-10000	>10000	Total
Dead	80	85	17	2	-	-	184
Injured	53	68	47	6	1	-	175
Evacuee	19	13	10	22	23	4	91

The total number of injured is 5,696. In 20% of accidents there were no injured, 26% involved between 1-10 injured and only in 7 cases there were more than 100 injured. The accident that caused most injured happened in San Juan Ixhuatepec, described above, injuring 3,818 human beings.

In the 91 accidents where information was available, 441,455 people were evacuated. Around 50% of the accidents involved among 100-100,000 evacuees. The worst accident involved the evacuation of 200,000 people, once again the incident of San Juan Ixhuatepec.

4. Conclusions

The historical analysis has shown that the frequency of domino effect accidents has decreased over the last two decades. Most of these accidents have occurred –as could be expected– in the most industrialized countries (from which, furthermore, more information is available). The most frequent sequences are explosion–fire, release–fire–explosion and fire–explosion. From the analysis of the causes, although the most frequent ones are *external events* and *mechanical failure*, a relatively high frequency is found for human error. This would indicate the need to further promote the training of employees, as well as an additional improvement of safety measures, specially in storage areas.

Acknowledgments

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References

Abdolhamidzadeh, B., Rashtchian D., Morshedi M., Statistical survey of domino past accidents, 2009, 8th world congress of chemical engineering, Montreal 317

Carol S., J.A. Vílchez, J. Casal, Study of the severity of industrial accidents with hazardous substances by historical analysis, J. Loss Prev. Process Ind. 15 (2002) 517–524.

Darbra R.M., Casal J., 2004, Hystorical analysis of accidents occurred in seaports, Safety Science 42 85-98

Delvosalle, C., 1996, Domino Effects Phenomena: Definition, Overview and Classification. First European Seminar on Domino Effects. Leuven.

Gómez-Mares M., Zárate L., Casal J., 2008, Jet Fires and the domino effect. Fire Safety Journal 43, 583-588.

Kourniotis S.P., Kiranoudis C.T., Markatos N.C., 2000, Statistical analysis of domino chemical accidents, Journal of Hazardous Materials 71 239–252

MHIDAS, 2007. Major Hazard Incident Data Service, OHS_ROM, Reference Manual.