Scenario Evaluation of Domino Effects in Process Industries: A Review

Nishita Vishwakama, P. A. Arun, Abhishek Nandan, and B. P. Yadav

1 Introduction

Recent reviews shows accidents in process industries involves various disturbances in environment and due to human factor around 24.6% of the accident has occurred (Darbra et al. 2010). Accidents are well-defined as unexpected incidences which may lead to injury, fatal accident, property damage and production loss. Without knowing reason behind any accident, it is very difficult to implement preventive measures, therefore this review concentrates mainly on cause of accidents and sources which includes fire and explosion. Chain of accidents can be understand by discussing various theories developed for accident prevention and investigation. Due to the combination of behavioural and environmental reasons many accidents become catastrophic. Some of the behavioural factors which may contribute to an accident such as poor physiological condition, inactive mental condition, inadequate attitude, poor technical skills and knowledge. In process industry, Unsafe acts and unsafe practices majorly contribute to an catastrophic incidents. In order to overcome from these problems, there are several theories came into existence such as domino theory and multiple causation theory (Figs. 1 and 2), which is an product of domino theory, developed by W. H. Heinrich in 1931. As Domino accident is the string of many new accident which follows the game of toppling of each wooden block above the next one starts a sequence in which every toppling follows other block and so on, which is called "domino effect".

Although, many definition and analysis are published by authors earlier, but recognition of probable risk has not discussed by them. Recognition of the probable risk of domino effect is firstly addressed in its Directive 82/501/EC and further hazard identification and its consequences has been also addresses in its successive versions Directive 96/82/EC and Directive 2003/105/EC. It also recommends protective measures

N. Vishwakama · P. A. Arun · A. Nandan · B. P. Yadav (✉)
University of Petroleum and Energy Studies (UPES), Dehradun, Uttarakhand 248007, India
e-mail: bikarama@gmail.com

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Fig. 1 The domino theory

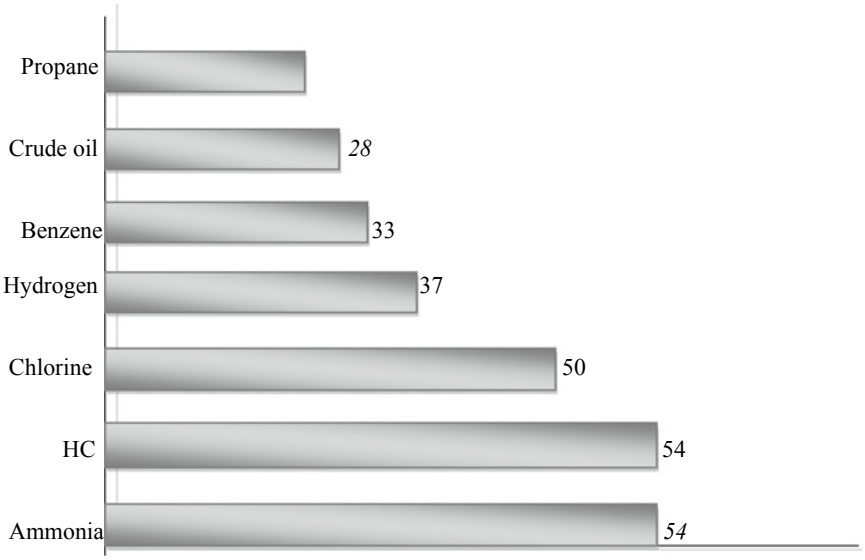

Fig. 2 Number of accidents took place due to toxic release (Khan and Abbasi 1999)

like safe distances between equipments, storage and transportation techniques. To know the reason behind the accidents and to create their control measures along with their prevention, it is important to understand about and find out from history of past accidents.

Following are the results found by inventory of past domino accidents (Table 1).

Table 1 Past accident data

Past causes and areas of accidents	Percentage affected (%)
Explosions	57
Fire	43
Storage areas	35
Transportation of hazardous materials	19
Combinations	
1. Explosion-fire	27.6
2. Fire-explosions	27.5
3. Fire-fire	18

1.1 Rationale Behind Domino Effect

Several authors give their interpretations related to domino effect. As per Lees, Dangerous occurrences can be obtained by the leakage of any hazardous material which may be considered as a factor for increasing potential of any hazard. He also included about consequences of domino accident which may cause an initiating event in any separate element (Lees 2012).

Bagster make clear report on domino effect which is based on management loss of a plant as severe accident always take place on a nearby plant or an equipment (Kadri and Châtelet 2013).

Delvosalle gave his explanations based on type of installations as consequences of domino effect are different for different type of installations. It may be primary installation, where major accident cant take place or it may be secondary installation, where accident must be severe one and its extend causes major damage and it may lead to the source for primary accident. According to As chain of accidents may take place with numerous type of installations, that's why Delvosalle defines domino effect in 1996, like a chain which involves many kinds of installations (Delvosalle 1996).

Gledhill and Lines told about this effect, according to Controls of Major Hazards (COMAH), by considering adjacent or nearby severe hazard installations. He proposed his logic for domino effect by considering loss of primary containment and its associated failure on any severe hazard. He preceded his work along with the COMAH regulations (Kadri and Châtelet 2013).

A domino effect is a series of accidents which consists of accidents due to fire, explosion, missile, projection or any other hazardous matter. According to Khan and Abbasi (1999) its catastrophic consequences affect one operational section of a process unit which further affects secondary accidents in other operational units. This has the potential in which it has the maximum probability of dangerous occurrences in major chemical and process industries, generated by an incident happened in one section which affect secondary section of same unit (Khan and Abbasi 1999).

Article 8 of SEVESO—II tells about the existence of domino effect by its likelihood or probability of occurrence with the possible consequences. It also tells about its effect which is increasing day by day, lead to dangerous occurrences in any form of accidents because of the area and proximity of these type of establishments which play very important role in inventories of dangerous substances. Basic Guidelines related to severe accidents with its preventive measures are stipulated in the second version of SEVESO in Europe (Kadri and Châtelet 2013).

According to AIChE-CCPS, domino effect is a chain of an incident which start ignited in one material and transfer its affect to the other item by means of heat, blasts or its section impact which can increase in its severity and their consequences which may also effect its failure frequencies (Kadri and Châtelet 2013).

Some of the author have also explained domino effect by mentioning various parameters like type of accident, type of equipment used, location, temperature and many more. As per Reniers explain domino accident as internal domino, deals

with occurrences of accident within the boundaries of a single organisation while External domino explain occurrences of multiple accident at a time which may take place outside the boundaries of the plant where primary accident occurs. Severity of consequences of external domino is more than that of internal domino, as it depends on the exposed area and the equipment involved (Reniers 2010).

A recent rationale defines domino effect in such a way that a primary incident propagates to nearby equipment which may trigger its primary or secondary unit, results in more severe effect than those of the initial triggered event (Reniers 2010).

Features of Domino System are:

1. Collaboration or connection between environment and its associated system.
2. For the generation of accidents in the form of chains, overall source is the only reason which can generate accident sequences; it can be control from the source only.
3. Organisational system along with the influence of human factors may also trigger the effect of domino system.
4. There are various physical parameters upon which source and aimed targets may depend, such as temperature, concentration or pressure with the variation of time intervals.

2 Historical Reviews on Domino Effect

In the historical review of domino effect, in this review paper catastrophic effects of some chemicals in various refineries, petroleum industries and chemical industries shall be discussed as follows:

In India, its very common to find many clusters of process industries in which they have common marginal walls 0f one or more than one operational industries. Various chemicals affects industries due to various reasons like fire, explosion, toxic release and its combination. According to many surveys, Ammonia is the most responsible chemical for the major hazards. Up to 1997, Out of 1744 accidents, accidents was due to their combinations.

One of the most important reason for catastrophic effect in industries is Toxic release which involves in fire and explosion. This is the only reason for Bhopal disaster which was happened in 1984 in which MIC (methyl iso-cynate) was responsible for the severe damage because toxicity of MIC is very high as it undergoes in an exothermic reactions when it comes in contact with water (Khan and Abbasi 1999).

Some more severe accidents happened in several refineries and chemical industries as follows:

- In 1996, BLEVE was the reason which destroys refineries in France and killed many firemen and workers who were working in that refineries as Propane vapour spreads all over the area and some major undesired events has been occured (Khan and Abbasi 2001).

- In 1997, More than 55 people were killed and many people got injured in huge fire expansion in Hindustan Petroleum Corporation Limited where many terminals, containers and tank farms were devastated at operational unit of Vishakhapatnam.
- In 1921, Oppau Works covered with cloud of explosion in a extent of 3 s, had the capacity to destroy all over plant in a span of 3 s with a very huge earthquake like shock. This explosion caused by the ignition of ammonium sulphate and ammonium nitrate which converts its physical nature from blasting powder into a baked cake in the storage section (Khan and Abbasi 1999)
- In 1987, In Purification column of Ethylene oxide, decomposition of C_2H_4O took place due to which chains of blasts and missiles has been formed and a catastrophic explosion took place in a process industry of Belgium (Lees 2012).
- In 1978, During filling of LPG in Storage vessels got over pressured due to breakdown of a relief valve and pressure gauge. These vessels got cracked and leakage of LPG got started in the city of Texas in one of the petrochemical factory which got ignited and results into a huge fire ball which shattered all the storage containers with its projectile shot (Vilchez et al. 1995).

3 Inherent Sources of Domino Effects

Probable sources of domino effect depends upon their nature and are also connected with their commencing events. It may be initiated by many contributed events like fires, explosions and toxic releases. Fire consists many catastrophic sources like diffusion flame of volatile liquid called pool fire, ignited fire by a mixture of air and dispersed flammable substances called flash fire, a ball consists combustible or explosives called fire ball and with a release of hydrocarbon flames called jet fire which can produce disastrous damage. As like fires, Explosion have a capacity to produce projectile shots like a missiles which can cause extensive damages with the influence of flammable material produces Confined vapour cloud explosions (CVCE), Vented explosions, Dust explosions and vapour cloud explosions. To prevent these explosions, Chemical and process industries give explosion venting to protect indoor's equipment or buildings from extreme internal pressure. One of the most dangerous sources of domino effect is the toxic release having an immediate release of toxic air-gas mixture, liquid-gas mixture or liquid-liquid mixtures.

3.1 Fire and Explosion in Process Industries

As per National Fire Protection Association, an average of 37,000 cases occur in Chemical and manufacturing industries every year.

Main causes of large fires are flammable liquid and gases, hot work, faulty equipments and its components, Pipe work and its fitting breakdown, amalgamating operations and some other factors. Flammable materials has higher contribution (17.8%)

for the exposure of fires in chemical industries while Release of hot materials which causes overheating contributes 15.6% and Maintenance works involves piping and fittings which contributes 11.1%, Electrical breakdown contributes 11.1%, Cutting-welding process contributes 11.1% and other factors contributes 28.7% (NFPA 1852).

Based on the frequent location of occurrence, Explosions may take place as per location like enclosed process areas, Outdoor structures, Yards, Tank farm, Boiler house and others. Different proportions for fire exposure as per location such as Enclosed process area in chemical industries contributes 46.7%, Outdoor structures contributes 31.7%, Boiler house contributes 3.3%, tank farm contributes 3.3% and others contribute 8.3% (Lees 2012).

There are many other contributing factors like equipment breakdown (26.7%), flammable liquids or liquefied gases (8.3%), human actions (18.3%), undesirable events (18.3%), faulty design (11.7%), blockage (11.7%),), long replacement time (6.7%), inadequate control of combustion (5%), insufficient relief of explosion (5%), etc. (Lees 2012).

3.2 Accident Analysis

Characteristics of accidental release depend upon many factors such as location type, site status, material released and material phase.

3.2.1 Application Area

It consists of different locations like refuelling station, Tank area, chemical plant, processing plant, factories, warehouses, and others having different number of incidents like 278 incidents covered under chemical plant, 96 incidents covered under refinery, 187 incidents covered under factory, 47 incidents covered under storage depot, 28 incidents covered under tank yard, 15 incidents covered under fuel station, 38 incidents covered under other sections and 232 were unknown (Khan and Abbasi 1999).

3.2.2 Work Site Analysis

Site work also affects the different types of operations and may cause damage at workplace. It includes standard operations, Storage and Handling, Loading and Unloading facilities, Modification, testing, safeguarding, start up, shut down and some unknown process. Their contributes differs according to situation at workplace in which 343 incidents took place under normal operations having high contribution, 103 incidents took place under Storage and handling department, 33 incidents come under loading or unloading, 146 incidents took place under modification and maintenance work,

18 incident took place under contractor work along with 5 testing incidents, Also many Incidents took place when shut down and start up process were going to take place as start up contributes 42 incidents while shut down contributes 18 incidents and 128 incidents were unknown (Khan and Abbasi 2001).

3.2.3 Released Material

Based on the material released, many toxic substances are responsible for immediate accidents which demands pre investigations for risk assessments. There are many gases which are accountable for disastrous damage such as Crude oil, Steam, petroleum NH_3, HC, Cl_2, H_2, C_6H_6, Natural gas, C_3H_8, C_4H_{10}, Styrene, Naphtha, Fuel oil, HCl, H_2SO_4, C_2H_4, H_2S, H_2O, N_2, O_2, Vinyl chloride, LPG, etc. Major contributor for fire and explosion in terms of toxic release are Hydrogen, ammonia, crude oil, chlorine, hydrocarbons, Benzene and propane. Their contribution in accidents shown in graph as follows:

3.2.4 Unignited Materials

Based on Dispersion of Unignited material there are substances having different behaviour such as many materials come up from flammable sources which are not corrosive but may be irritant. They are also responsible for destruction in chemical industries as they are classified as with the number of accidents:

1. Flammable substances
2. Toxic materials
3. Materials having both characteristics flammable as well as toxic
4. Unignited gas
5. Vapour cloud
6. Ignition of material by spill
7. Ignition of material by Jet
8. Ignition of material by the influence of Spray
9. Corrosive substances (Fig. 3).

According to some reviews, fire or explosion or its combination are the most responsible factor for the dangerous occurences which takes place due to fires, flash fires, pool fire, jet fire, BLEVE, explosions followed by fire and flash fire. Loss of containment for different kinds of equipment is also one of the major reason for domino accidents in process industries.

Their contributions are different as per type of accidents (Lees 2012) as shown in Table 2.

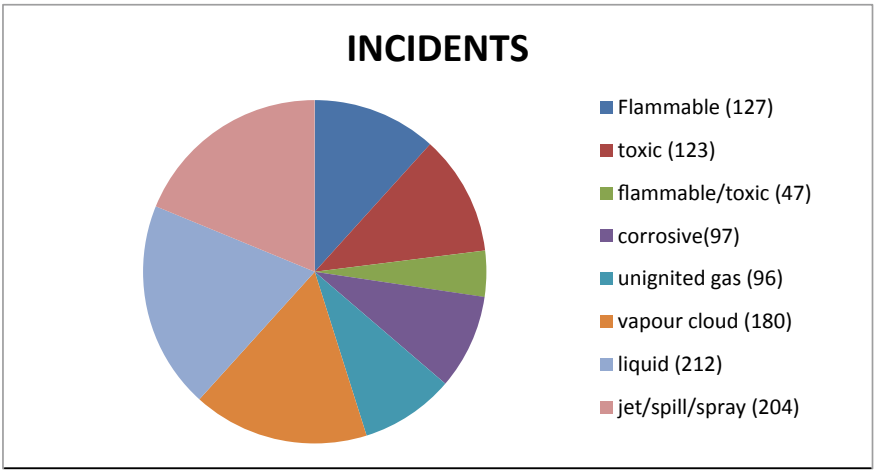

Fig. 3 Accident contribution with respect to different section (Vilchez, Sevilla et al. 1995)

Table 2 Resons for various accidents

Reason behind fire/explosion accident	Number of accidents
Due to fire and its flashes	156
Due to pool fire	4
Due to jet fire	1
Due to fire ball	7
Due to BLEVE	4
Explosion → fire	77
Explosion → flash fire	2

4 Causes of Domino Effect

4.1 Root Causes

By identifying the causes of accidents, with the help of MHIDAS database, there are various techniques to prevent them from occurring again. According to (López López 2017), categories may use for common causes: external events, mechanical breakdown, errors produced by human actions, failure due to impact reaction, failure due to violent reaction, equipment and its component failure, disturb process state and service break down. Contribution behind accidents are vary from situation to situation. As there are two main causes of accidents such as 29.2% accidents covered under external events and 35.2% accidents covered under mechanical failure. As like two, 24.6% of the accidents were due to human error and these contribution had increased as per Darbra et al. survey (2010). As according to his detailed studies, generic causes were human errors or external events but along with failure due to

impact reaction, failure due to violent reaction, equipment and its component failure and service failures were also responsible for domino effects in chemical industries. As accidents connected with human factor had significantly increased from 24.6 to 33% in industrialized countries which shows the poor health and safety culture with worse safety induction trainings in the organisations of many developing countries. Most of the service failures has occurred due to deviations in operation as loss of containment is one of the cause for component failures. As per many reviews there are several reason for loss of containment such as ruptures of containers, welding failures, vibration, overstressing, corrosion, internal and external explosions and many more.

4.2 Peculiar Causes

There are many causes which are particularly indicates some of the specific section of an industry like leakage areas, maintenance works, etc. As discussed above there are some main causes by which domino effect got ignited and started making more chains of accidents such as Mechanical failure, external events, impact failure, violent reaction, instrument failure and service failures (Hemmatian et al. 2014).

4.2.1 Mechanical Breakdown

Mechanical Failures is the general cause in which 35.2% accidents were occurred in which there are some specific areas due to which severe damages may take place like overpressure, overheating, other metallurgical failure, Leaking coupling. Leaking valve, Hose, Corrosion, Fatigue, etc. Moreover, many operational failures may also take place like weld failure, brittle failure, use of incompatible materials, overloading, etc. According to his studies, 16.1% accidents were due to Overpressure only. It is a foremost root cause of domino effects according to his studies (Delvosalle 1996) 16.5% of domino accidents happened due to overpressure. As per MHIDAS database, Out of 105 accidents, 66 accidents were caused due to explosion involving nearby appliances, moreover it was due to overpressure (López López 2017).

4.2.2 External Agents

Somewhere, External agents or events are also possible causes of domino accidents in which fire and explosion had took part at large scale in most of the industries. External events includes various causes specifically fire, explosion, lightning, earthquakes, flooding, sabotage, design error, etc. Somehow, many operative events also come under this such as general maintenance, general operation, management, draining accident, overfilling, connection failure. In this, highest contribution had came from Fire, explosion and lightning. 49% of the domino accidents occurred due to fire and

explosion each. As like both, 14% accidents occurred due to lightening (Darbra et al. 2010).

4.2.3 Failures Due to Impact Behaviour

Accidents occurred under the influence of shock applied over short span of time or a force having a high intensity, those accidents come under the impact of such entity or force that may lead to severe damage. Impact failure includes rail accident, heavy object, road accident, ship-land clash, ship-ship clash, confined outburst, instrument breakdown, etc. Accidents due to trip, failure of controller and indicator also come under impact failure. Due to the high impact, rail accident is the foremost cause of domino accident as 70% of accidents were occurred under such failure (Wu et al. 2015).

4.2.4 Service Breakdown

Service failure includes services associated with electricity and water supplies. By name, its very easy to get higher contribution for domino effect as electricity connected with most of the risky or dangerous occurrences. 80% of the accidents happened due to electricity.

4.3 Origin

According to the MHIDAS database, There are many classification for the area or event from which origination of any accident took place such as Transportation, Loading-unloading, storage areas, process plants, warehouses, waste storage areas, etc. Some cases were unknown as they were almost 176 in numbers in which cause of origination of accidents were not found. According to Vilchez and Sevilla, there were specified number of accidents which was responsible for the origin of domino accidents as mentioned (Fig. 4).

Above distribution shows the maximum contribution were due to transportation only with 39.1% of accidents followed by Process Plant (25%) and Storage plant (18%) (Vilchez et al. 1995).

5 Estimation and Prevention

Now-a-days, in chemical processing industries, computer-aided tools has been used to find the likelihood of accidents involving domino effect. To evaluate and prevent domino accidents which includes fires, explosion or hazardous material

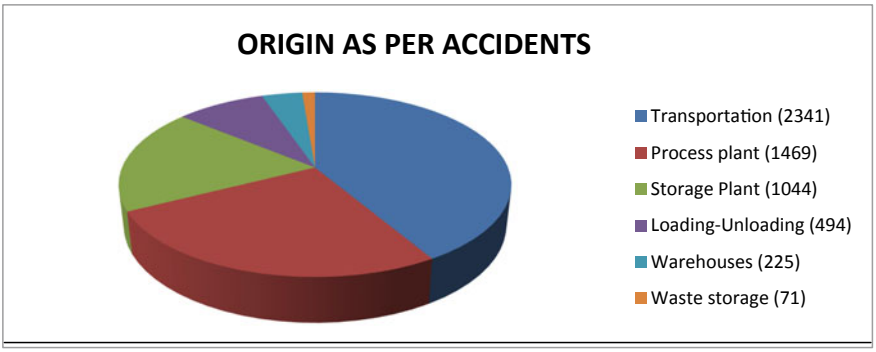

Fig. 4 Origin of accidents (Vilchez, Sevilla et al. 1995)

release in storage areas and chemical based process areas. In this paper, there are many programmed based tools and hardware based analysis has been done by using MAXCRED, DOMIFFCT, ARIPAR, ATLANTIDE, GeOsiris, MiniFFECT, DomPrevPlanning and Vulnerability assessment which are reviewed here on the basis of historical surveys.

5.1 MAXCRED

MAXCRED (MAXimumCREDible rapid risk assessment) encoded in C++ language developed in object oriented architecture, which allow to demonstrate accident models and harm probable estimation. This tool attuned with DOS and WINDOWS operating system.

Main menu of MAXCRED consist of many options such as data, accident scenario, analysis, graphics and file having module box of different cases by which severe damage may occur.

Following are the procedures which depicts five important steps of MAXCRED (Khan and Abbasi 1998a, b) (Fig. 5).

There are many models used in MAXCRED such as Box model and model plume path for heavy gas dispersion, flare model for flash fire, Gaussian dispersion model for light gas dispersion, etc. Also, Second version of MAXCRED can use in chemical

Fig. 5 Procedure for MAXCRED

Fig. 6 Procedure to carryout DOMIEFFECT

process area which simulates each and every accidents in a quantitative manner (Khan and Abbasi 1998a, b).

5.2 DOMIFFECT (Domino Effect)

Same panel of authors also prepared one of the tool based on methodical domino method called DOMIFFECT. It is use in chemical processing plants and in many industries also. It is computer based tool operates with object-oriented architecture which was encoded in C++ language. Basically it contains six elements on which simulation of accidents can be done such as data related to accident scenario, accident analysis, Domino, user interface and graphics. It is a menu driven software which is capable of evaluating possible hazards, handling different events according to the situations, moreover, it estimates probability of domino accident with their consequences. It is a software based on the method by which outcomes can be precisely determined with the help of probabilistic study (Khan and Abbasi 1998a, b)

Following are the important steps involved in DOMIEFFECT (Khan and Abbasi 1998a, b) (Fig. 6).

5.3 Aripar (AnalisideiRischiIndustriali E Portualidell'Area Di Ravenna)

The ARIPAR Project had worked on targeted quantitatively assessment where risks are connected with various type of processes, storage and transportation of various hazardous substances. It challenges to evaluate risks form several process plants for the calculation of various level of risks due to different type of installations. This is a software can be used on the basis of probit correlations. There is an upgraded version of ARIPAR which is based on probabilistic approach for risk assessment of complex processes which includes transportation also (Egidi et al. 1995).

5.4 ATLANTIDE

ATLANTIDE is a software had created to execute various models and to implement various consequences of domino accident that may occur in process or storage areas. It is used where location is allotted for Storage of highly flammable liquids or gases like LPG and for processing plants where heavy gas dispersion which involves hazardous process like BLEVE and fireball. This software used to evaluate all possible framework with the help of lagging indicators which indicates primary accidents according to different releases, features or mode of operation of any plant. By the help of coding, substances which are considering by this software are LPG, Propane and Butane with their chemical and physical properties such as density, flammable range, vapour pressure, etc. After that once user starts operating these points of interest with relevant operating conditions then meteorological situations are introduced to start the analysis which includes temperature, velocity of wind and relative humidity (Ditali et al. 2000).

5.5 DPP Toolkit

DomPrevPlanning is a tool used to determine the effects of domino system according to the order of priorities in an industrial plant on different levels of work. Depending upon the various experiments performed by authors, tool comes with an aim of preventing domino accidents in a chemical industries and various manufacturing industries. This software basically works on three components such as Guidelines for quantative risk assessment, reference manual for failure frequency figures and instrument domino effect (IDE). On the basis of above components, it also analyzes risks associated with domino system, installation in industrial facilities along with the various classifications (Reniers and Dullaert 2007).

5.6 Vulnerability Assessment

It is an evaluation technique which is used to examine safety parameters of plant items if a failure occurs in a nearby item. This is usually performed by placing 3D grid over the layout of the plant and specifying a grid coordinate for all process items by providing distances between items. The possible hazards of the various process items need to be identified along with their effect on other process items.

6 Results and Conclusion

In recent years, research interest on domino effect and its consequences has increased but research work is still less as compared to other portions of problems in process industries. As domino effect happens in many major incidents in various industries and has been increasing significantly. But still some of its main features are unknown.

In this paper, the study on domino accidents are covered from various databases and past accidents with different parameters such as its root causes, includes different kinds of failures, and peculiar causes which includes different kind of breakdowns and operation failures due to fire and explosions. In our work, some of the aspects has also discussed, includes its origin which quantifies the accidents as per different area such as transportation, storage, disposal and prevention techniques to find the likelihood of accidents which involves Domino effect.

There are various operation failures took place during Loading/unloading operations and in storage facilities which caused a major number of domino accidents. By providing improved version of training and guidance, all came to know that human error is also one of the main causes of accidents which has been identified while operators are working in industrial plants.

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