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A multi-plant emergency response plan for tackling major fire accidents in chemical clusters

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ABSTRACT: In chemical industrial areas, the so-called chemical clusters, there are many dangerous chemical process units and storage equipment. Major fire accidents in the chemical clusters may cause huge losses due to domino effects happening outside the boundaries of one chemical plant. Therefore, managing these multi-plant crisis situations are essential to contain and control the fire, to safeguard employees and anyone nearby who might be affected and to minimize damage to property or the environment. However, multi-plant emergency response planning is not identical to that of a single company. In 2013, Reniers & Faes (Reniers & Faes, 2013) proposed an emergency planning approach at chemical cluster level. Accordingly, this paper aims to present a multi-plant emergency planning tool in case of major fire accidents so that the emergency levels and respective response actions at individual companies within the cluster can be identified.

1 INTRODUCTION

Chemical and oil and gas facilities have an undeniable influence on global economy and play a key role in maintaining and creating our modern daily life. Due to some factors such as environmental conditions, social motives and legal requirements, most of the chemical plants are located in clusters (Reniers & Soudan, 2010). The integration and linkage between the activities of the companies within the industrial areas leads them to be near each other, thus a major accident during operation may cause substantial consequences both inside and out-side the premises of an establishment, leading to more failures and resulting in loss of lives and huge property and environmental damages.

In an industrial area, multi-company (external) domino effects are the most dangerous major accidents that can happen (Reniers, 2010). During the crisis situation, gas clouds, overpressure and radiation effects do not delay to claim their influence. For instance, when the fire thermal radiation received by nearby tanks exceeds a certain threshold and the duration exceeds a certain time, secondary accidents may occur. Thus, an efficient and timely emergency response may prevent domino effects triggered by fire.

There have been many approaches for handling major emergency situations for individual plants in the chemical industry (Phong 1989, CCPS 1995, Kourniotis et al. 2001, Mannan 2013). However, in chemical industrial areas has been given considerably less attention to multi-plant emergency response planning, and it is not identical to that of single companies. Managing multi plant emergency situations needs the involvement of several emergency response teams of different plants as well as local and national authorities. There should be no problem in the communications or misunderstanding between the involved parties.

In this regard, Reniers & Faes (2013) proposed an emergency planning approach at chemical cluster level, the so called "multi-plant emergency planning matrix". They suggested the development of a matrix that creates an overview of emergency levels for individual plants within a cluster in order to help them as to how to respond to a catastrophic event in a pre-agreed procedure. Each emergency level indicates the necessary actions needed to be taken in each company when a major accident occurs within the chemical cluster.

Following the work of Reniers & Faes (2013), the present study is aimed at presenting a framework for a systematic procedure for analyzing major fire accidents consequences and domino effects, determining emergency levels based on multi-criteria decision matrix and providing response actions for the identified emergency levels.

To meet the aim of the proposed paper the methodology is discussed in the next section. The application of the methodology is described through a chemical cluster in Section 3, while Section 4 concludes this article.

2 METHODOLOGY

In order to implement a comprehensive and practical multi-plant emergency response planning for major fire accidents, a multi-stage approach that consist of three main stages is schematized in Figure 1. Details of these three stages are given below.

2.1 *Stage I: Systematic analysis of credible fire accidents*

In the first step, the required information to apply the procedure is collected and stored. The input data based on Council Directive (2012) is consist of

i. Equipment data (type of equipment: pressurized, atmospheric, process vessel, etc.; process conditions: volume, dimension, form, etc.; the location of the equipment)
ii. Hazardous Material (operation and storage conditions: temperature and pressure, physical phase and mass inventory)
iii. Meteorological conditions (weather temperature, relative humidity, wind direction and speed, atmospheric stability class.

Next step is identifying the equipment items processing or storing flammable chemicals that fall within requirements of Council Directive (2012). Then, for each installation a set of release scenarios based on the different classes of loss of containment (major, minor or instantaneous) is considered for the selected accident sources. Table 1 present the selected criteria for major and minor leak sizes by Failure Rate and Event Data (FRED) (2012).

These scenario outcomes (such as pool fire and jet fire) have physical effects on people, properties and the environment, mainly due to thermal radiation. In this study, ALOHA software is used to assess the effects of final scenario outcomes. A set of endpoints are considered for evaluation of the consequences. These endpoints are given by the levels of thermal radiation that cause specific effects on people or property. Then the effect zones are calculated as radial distances from the release source within which the values of thermal radiation are higher than the specified endpoints. Table 2 summarizes the selected criteria (level of concerns) for such adverse impacts on humans.

Some major accidents such as pool fires, jet fires, and Vapour Cloud Explosion (VCE) may lead to secondary events inside and outside the company fences, i.e., (internal and external domino effects (Cozzani et al. (2006). In this study in order to determine which units in neighboring companies are impacted by the primary fire scenario the escalation heat radiation vector exerted on the nearby units are compared with predefined threshold values in pool fire and jet fire primary scenarios (15 kW/m^2 and 50 kW/m^2 for atmospheric and pressurized target equipment, respectively) (Cozzani et al., 2005). The

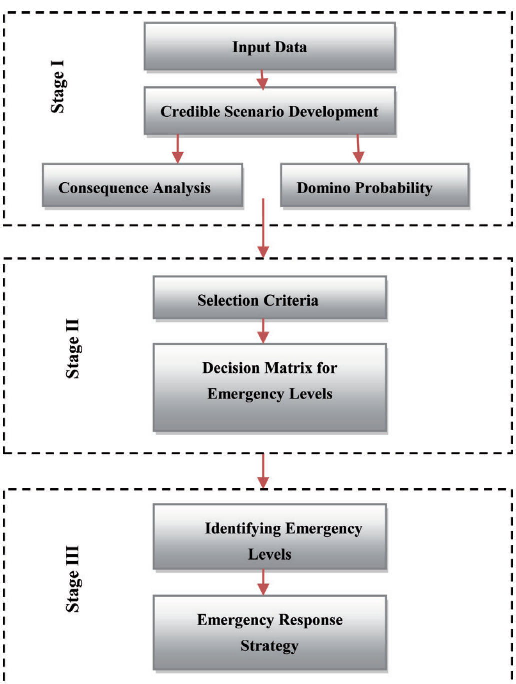

Figure 1. Flow chart of the developed methodology.

Table 1. Leak size category for different vessel types (FRED, 2012).

Vessel type	Major leak size (mm)	Minor leak size (mm)
Atmospheric tank V (m^3) >12000	1000	300
Atmospheric tank V (m^3): 12000–4000	750	225
Atmospheric tank V (m^3): 4000–450	500	150
Compressors	Rapture > 110	75

Table 2. Selected criteria for different fire threat zones (CCPS, 1989).

Physical effect	Level of concern	Impact
Thermal radiation (kW/m^2)	37.5	100% lethality in 1 minute Sufficient to cause damage to process equipment
	12.5	1% lethality in 1 minute first degree burns in 10 seconds
	4	Sufficient to cause pain to personnel if unable to reach cover within 20 sec and blistering of the skin

escalation vectors well above the relevant thresholds are strong enough to cause credible damage to the nearby units. To estimate the probability of domino-induced accidents, the damage probabilities of target units are calculated using Probit values, Y (Cozzani et al., 2005). Having Y determined, the damage probability, P, can be calculated as $P = \phi\,(Y–5)$, where ϕ is the cumulative density function of standard normal distribution (Khakzad et al., 2013).

2.2 *Stage II: determination of emergency levels*

A criteria table is developed that shows the severity of the fire accidents consequence, ranking from minor to very severe, and the likelihood of external domino effects, ranking from unlikely to almost certain based on the calculated domino probability (P) on target equipment in neighboring companies. Table 3 summarizes these criteria.

A simplified 4 × 4 matrixes is used based on the ranking criteria on Table 3 to determine the level of emergency of an accident within the companies of chemical cluster. The matrix is presented in Figure 2.

As suggested by Reniers and Faes (2013), five levels of emergency from level 0 (Informative alert) to Level 4 (catastrophic accident) have been considered based on the magnitude of the emergency situation:

Inside the company fence ≤ Level 1
Inside the cluster ≤ Level 3
outside the cluster ≤ Level 4

2.3 *Stage III: multi-plant emergency response*

Emergency response strategy is established based on the identified accidents' emergency level at individual plants in the cluster, and the heat radiation foot-print maps of the accident scenario. These strategies indicates general response procedures at each level regarding to the industrial best practices (Schauer et al 2013, Alberta Energy Regulator, 2009) in oil and gas industry.

Domino Probability

Consequences	1	2	3	4
1	Level 0	Level 1	Level 1	Level 2
2	Level 1	Level 1	Level 2	Level 3
3	Level 1	Level 2	Level 3	Level 4
4	Level 2	Level 3	Level 4	Level 4

Figure 2. Emergency level decision matrix.

Table 3. Ranking criteria for classification of major fire scenarios.

Consequence category	Description	Accident escalation category	Domino probability (P)	Description
1-Minor	– No injuries or fatalities o-site, – No/minor environmental impact (only within company fences)	1-Unlikely	$P < 10^{-6}$	– The incident is contained or controlled and it is unlikely that the incident will escalate.
2-Important	– First aid treatment or hospitalization for onsite workers in the company – Environmental impact on-site incident site area only and/or minor offsite impact	2-Moderate	$10^{-6} \le P$ 0.001	– the primary accident may cause additional hazards for nearby target units (exposed to lower levels of fire radiation)
3-Severe	– Possibility of widespread on-site fatalities and life-threating injuries within more than one company in chemical cluster – Very large environmental impact on-site (inside cluster) and/or large offsite impact	3-likely	$0.001 \le P$ 0.1	– Nearby target unit are exposed to higher levels of fire radiation
4-Very Severe	– Possibility of any offsite fatalities from large-scale toxic or flammable release; possibility of multiple onsite fatalities (inside cluster). – Major environmental impact on-site and/or offsite	4-Almost certain/ already happening	$0.1 \le P \le 1$	– Nearby target units are within the hot zone and being exposed to very high levels of fire radiation

3 AN EXAMPLE

3.1 *Case study*

In order to exemplify the developed methodology, a chemical cluster that includes three chemical plants is considered. The layout of chemical cluster and process installations placement at each chemical plant is depicted in Figure 3.

Consider a leakage from a 300 mm hole in an ammonia Tank (TK1) in Plant B, leading to a burning puddle. The related process information of TK1 and the selected meteorological parameters to calculate the consequence of the release is reported in Tables 4 and 5.

Figure 3. Chemical cluster layout.

Table 4. TK1 process data.

Category	Data	Unit
Equipment type	Vertical atmospheric tank	
Hazardous material	Ammonia	
Height	21.4	m
Diameter	30	m
Capacity	15000	m^3
Filing degree	90	%
Temperature	–40	°C
Pressure	0.069	bar

Table 5. Case study meteorological conditions.

Conditions	Weather data
Stability class	D
Wind speed (m/s)	7
Wind direction	WSW
Temperature (°c)	20
Relative humidity%	75

3.2 *Result and discussions*

Figure 4 shows the pool fire footprint and the effected chemical plants within the cluster. All the three plants are within the radiation impact zones. Some parts of Plant A receives radiation heat flux of 4 kW/m^2 that may cause second degree burn for the on-site personnel. Plant B, where the accident happened, is being exposed to high levels of radiation heat flux more than 37.5 kW/m^2 and there would be serious injuries or fatalities for on-site workers, and also other installations in Plant B are affected by fire serious injuries or fatalities for the on-site workers, and also other installations in the site B are affected by fire (internal domino effect may happen). Plant C is within the radiation hot zone, there could be serious injuries on-site while some units in Plant C such as TK3 (atmospheric tank) are being exposed to high radiation levels and there is a chance that escalation occurs (external domino effect). The results in Table 6 clearly indicate the domino probability in the effected plants for the selected installations.

By ranking (from Table 3) the consequence severity of the accident and the calculated domino probability of individual plant from Table 6 and using the proposed decision matrix (Fig. 2) the emergency level for each company is listed in Table 7.

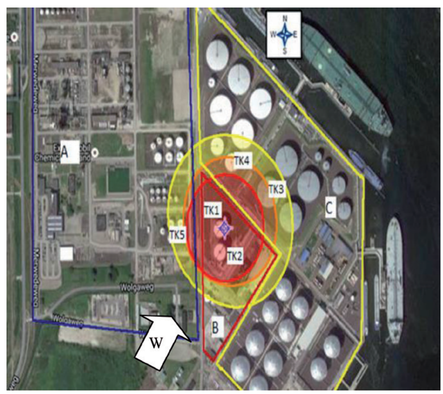

Figure 4. Pool fire at TK1, footprint-effected zones calculated by ALOHA.

Table 6. Calculated damage probability for selected facilities in the cluster.

Primary Sc.	Target unit	Esc. Vector	$I_{t.v.}$ kW/m^2	V m^3	I kW/m^2	P
TK1pool fire	TK 2	Radiation	15	15000	63.5	0.094
	TK 3		15	62000	37.5	0.426
	TK 4		15	18000	29.1	0.003
	TK 5		15	5000	12.3	1.023E-07

$I_{t.v:}$ Radiation threshold value, V: Target unit volume, I: Received radiation, P: Domino probability.

Table 7. Emergency levels for pool fire scenario at TK1.

Scenario	ER Level at Plant A	ER level at Plant B	ER level at Plant C
TK1 pool fire	Level 1	Level 3	Level 3

Since the emergency levels for each chemical cluster are identified, the emergency response strategies can be established for plants A, B and C as follows:

For emergency level 3 (Plant B & C):

- Confirm the Fire event
- Start The " Fire Alarm" for site personnel
- Raise the "Evacuation Alarm"
- Notify emergency services and off-site emergency community services
- Notify neighboring companies
- Evacuation of personnel in the upwind direction
- Assess the incident and determine emergency pan zones (hot, warm, cold)
- Maintain contact by radio with the emergency personnel at the scene and Incident Commander at neighboring companies
- Activate emergency shutdown / Isolation of the release source, if possible
- Start firefighting procedure,
- minimize fire exposure on nearby vessels, cool nearby equipment
- Secure the affected area and limit plant access
- If needed, provide additional fire personnel
- Arrangements for meeting incoming external response groups at forward control point (FCP)
- Continual monitoring of wind/ weather conditions
- Responders stand by a safe distance until area is declared safe.

For emergency Level 1 (Plant A):

- Confirm the emergency alarm
- Raise Evacuation alarm / advice to go to shelter
- Evacuation of personnel in the upwind direction
- Minimize fire exposure on affected vessels
- If needed, provide additional fire brigade personnel for incident site

4 CONCLUSIONS

Multi-plant major fire accidents are among complex situations to be managed and responded effectively. In order to help decision makers determine proper response strategies at individual companies within a chemical cluster during a major accident, a user friendly decision matrix was developed to determine the emergency levels. Each emergency level indicates an overview of related actions needed to be taken when a major fire occurs.

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