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Reference:
Hosseinnia Behnaz, Khakzad Nima, Reniers Genserik.- Multi-plant emergency response for tackling major accidents in chemical industrial areas
Safety science - ISSN 0925-7535 - 102(2018), p. 275-289
Full text (Publisher's DOI): https://doi.org/10.1016/J.SSCI.2017.11.003
To cite this reference: https://hdl.handle.net/10067/1469450151162165141

Multi-plant Emergency Response for Tackling Major Accidents in chemical Industrial Areas

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ABSTRACT: Emergency response planning for major accidents in the chemical industry is essential to protect the public and workers' health and safety, to reduce the environmental impacts, and to accelerate the resumption of normal operations. So far, much attention has been given to developing and implementing emergency planning in single chemical plants. However in chemical industrial parks also called chemical clusters, which consist of a number of different plants, considerably less attention has been given to multi-plant emergency response planning. Nonetheless, an emergency planning approach can be developed at the cluster level. In such an approach, an overview can be established on how companies within an industrial park respond to a catastrophic event in a pre-agreed procedure. This paper presents a methodology for developing a multi-plant emergency response decision tool in order to determine plant emergency levels for major accident scenarios within the cluster and the respective response strategies. This way, a crisis situation within the chemical cluster can be handled in a much faster way than is the case today.

Keywords: Chemical Industrial Parks; Domino effects; Emergency response planning; Decision matrix.

1 INTRODUCTION

Chemical and oil & gas facilities have an undeniable influence on the global economy and play a key role in maintaining and creating our modern day life. Due to some factors such as environmental conditions, social motives and legal requirements, most of the chemical plants are located in clusters (Reniers and Soudan, 2010). The integration and linkage between the activities of companies within industrial areas leads them to be near to each other. Hence, a major accident in the cluster may cause more substantial consequences both inside and outside the premises of the establishment than those of a similar accident in a detached single plant.

During a major accident, toxic gas clouds, overpressure waves and heat radiation effects do not delay to claim their toll. Therefore, emergency planning as mitigation measure plays a key role in reducing the risk of accidents by avoiding fatalities and injuries, protecting the environment and accelerating the resumption of normal operations. Many guidelines are published by civil protection authorities or specialized organizations to assist the work of emergency planners for handling emergency situations in chemical industries. Examples includes the CCPS (1995), the U.S Federal Emergency Management Agency (FEMA, 1996), the Oil and Chemical Industries Safety Studies Group in France (GESIP, 2001), UK Health and Safety Executive (HSG191, 2009), the European Union "Seveso-III" directive (Council directive, 2012), and Incident management system for oil and gas industry (OGP, 2014). These guides are based on the lessons learned from past disasters and represent the current knowledge and practices on emergency planning within single chemical plants. In addition to these guidelines, several references addressed the emergency response planning in chemical industry from different aspects in case of a major accident at a chemical plant (such as: Phong, 1989; Ramabrahmam et al., 1996; Kourniotis et al., 2001; Tseng et al., 2008; Lin et al., 2009; Zhong et al., 2010).

However, in chemical industrial parks, considerably less attention has been given to multi-plant emergency response planning. In these industrial areas, other plants may be affected than only the company where the major accident originates. In such, multi-company (external) domino effects are the most dangerous major accidents that can happen (Reniers, 2010). The Mexico City event in 1984 (Lees, 1996) and the Buncefield disaster in 2005 (Investigation B.M.I, 2006) are clear evidence of the possible devastation in case of such accidents. Thus, to maintain a state of preparedness within not only single chemical plants but also within the entire chemical cluster, efficient multi-plant emergency response planning is essential.

Reniers and Faes (2013) suggested the development of a "matrix" that creates an overview of how companies within the cluster should respond to a catastrophic event in a pre-agreed procedure. In their approach, major accident scenarios of each company in the chemical cluster are placed on the vertical axis, and the companies that may be affected by these scenarios are placed on the horizontal axis of the matrix. The emergency level for every company of the cluster can then be mentioned in every cell of the matrix. Each emergency level indicates the necessary actions needed to be taken in each company when a major accident occurs within the chemical cluster (see figure 1).

Plant A Major Scenarios	Plant A	Plant B	Plant C	Plant D
SCEN-01	Level 1	Level 2	Level 2	Level 1
SCEN-02	Level 3	Level 1	Level 3	Level 2
SCEN-03	Level 1	Level 2	Level 0	Level 1
SCEN-04	Level 2	Level 3	Level 2	Level 0
….				
….				

Figure 1- Multi-plant emergency response matrix example (based on Reniers & Faes, 2013)

Managing multi-plant emergency situations needs the involvement of emergency response teams (e.g., incident commander, safety management and staff, fire brigades, etc.) of different plants as well as local and/or national authorities. There should be no miscommunications or misunderstanding between the parties involved. As a result, organizing and implementing such emergency planning procedures and measures is more challenging and complicated than thought at first sight. Inspired by Reniers and Faes (2013), the present study is aimed at developing a practical decision making matrix for the determination of emergency levels and subsequent emergency response strategies.

The developed methodology is presented in the next section. The application of the methodology is illustrated in Section 3, while Section 4 concludes this paper.

2 METHODOLOGY

2.1 Overview of the methodology

Developing a comprehensive and practical multi-plant emergency response planning needs identifying what to prepare for, and how to respond. Therefore the approach consists of three main stages as schematized in Figure 2. The first stage consists of a systematic review of onsite hazards for individual companies within the chemical cluster: selecting credible accidents scenarios, analyzing accident outcomes and their probability of causing cross-company domino effects. In the second stage, a criteria table for prioritizing accident scenarios is stablished. The prioritization takes into considerations the likelihood of external domino effects due to different escalation vectors (heat radiation, overpressure) on target equipment in neighboring companies, the likelihood of toxic release scenarios based on the dispersion distances, and the consequences of scenarios. The third stage concerns determining the decision matrix according to the criteria table, for evaluating the emergency levels. Furthermore, response strategies (communications, actions and resources) are identified for every emergency level. Details of these three stages are given in the following sections.

2.2 Stage 1: systematic analysis of onsite hazards

2.2.1 *Input data*

The first step in assessing the hazards in a chemical plant is to define the accident scenarios. In order to properly predict the physical effects of chemical release scenarios, source information and environmental parameters needs to be defined. Table 1 shows the input data required for Stage 1.

Table 1-Information needed for the procedure

Data	Required Information
Equipment	Number of major equipment belonging to each company Type of the equipment (pressurized/atmospheric storage/process vessel, etc.) Volume, length, diameter, form (cylindrical/ spherical) of the installation, Fire mitigation systems (firefighting systems, etc.) The location of the equipment, Filling degree
Hazardous Material	Operating/storage conditions (temperature and pressure) Physical phase Mass inventory
Meteorological conditions	Weather temperature Relative humidity Wind direction and speed Atmospheric stability class

2.2.2 *Selection of the hazard sources*

All the equipment belonging to a company can be considered as a possible source of causing accidental release. However, only equipment items processing or storing flammable or toxic chemicals that fall within the requirements of the Seveso-III Directive (Council directive, 2012) are considered. Then, based on factors such as the quantity of chemical substances in the equipment, the

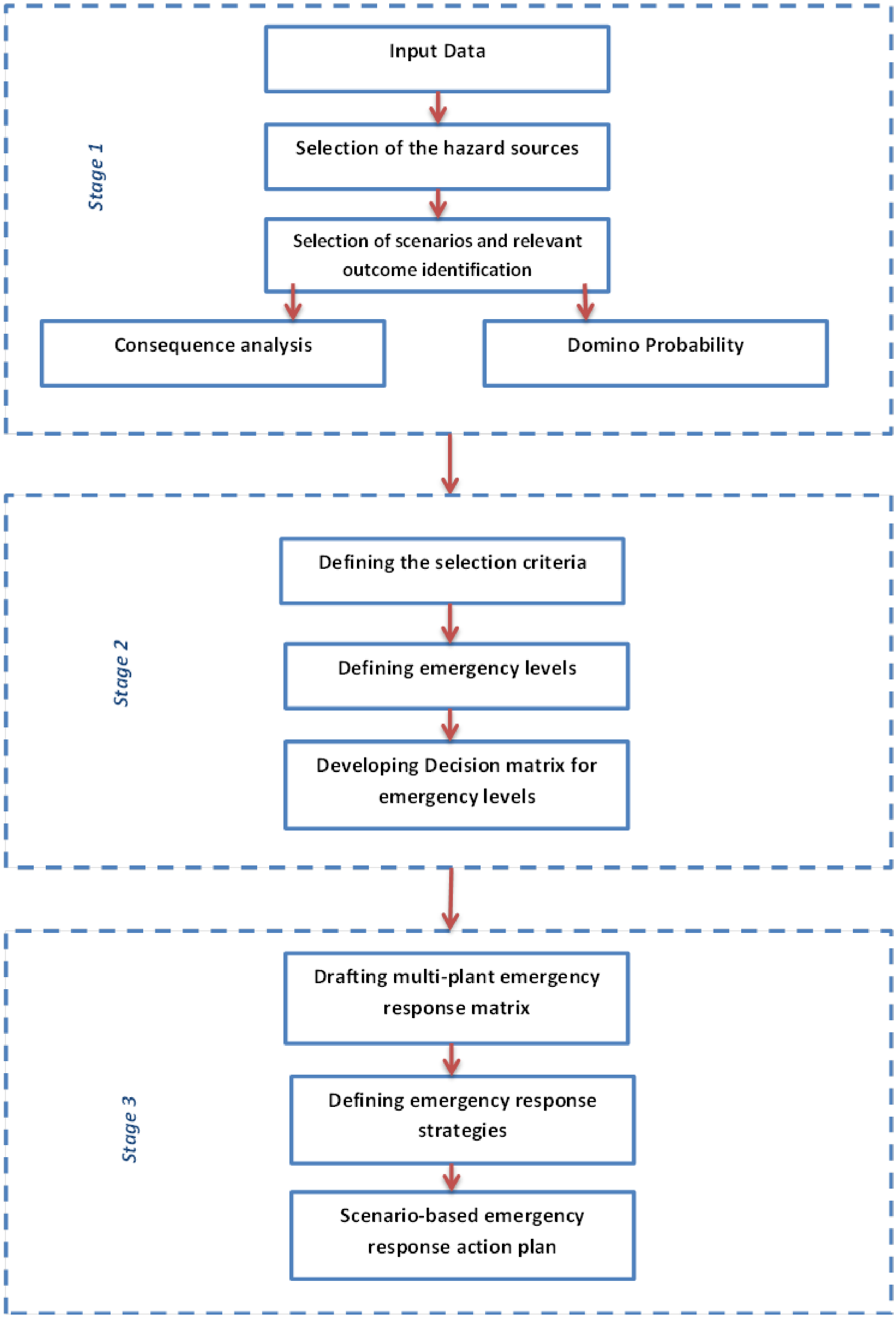

Figure 2- The developed methodology flow chart

hazardous properties of the substance and its location with respect to neighboring companies' hazardous equipment, the possible accident sources are determined.

2.2.3 *Selection of scenarios and identification of their relevant outcome*

The design and safety precautions for storage tanks and other process installations minimize the likelihood of an incident; however an accidental release might happen in each installation. Loss of containment (LOC) is one of the most frequent initiating events in accident sequences in the process industry (Mannan, 2013). In consequence analyses of LOC events, the release scenarios for selected hazard sources are defined with a spectrum of leak sizes. Although all possible leak sizes ranging from pin hole to maximum connection diameter are likely to happen in an installation, generally, those recommended by references such as OGP (2010a, b), UKOPA Fault database (2000) and Failure Rate and Event Data (FRED, 2012) for quantitative risk assessment are considered. In this study, the FRED (2012) recommended leak size category is considered due to its wide data range for various process equipment with different process conditions. Table 2 shows the major and minor leak size category used in the present study. In addition to these LOC events (major and minor leakage), instantaneous release of the complete inventory for each hazard source is considered as well.

Table 2- Leak size category for different process equipment (FRED, 2012)

Equipment type	Capacity (m^3)	Major leak size (mm)	Minor leak size (mm)
Atmospheric tank	>12000	1000	300
Atmospheric tank	12000 – 4000	750	225
Atmospheric tank	4000 – 450	500	150
Chlorine pressure vessel		50	6
Compressors		> 110*	75

*Rapture

Scenario outcomes depend on several parameters including operating conditions (e.g., temperature and pressure), type of the failed equipment (storage/ process vessel), leakage characteristics (major, minor or instantaneous), release phase (liquid, gas or two-phased) and the released hazardous material category (flammability, explosivity, reactivity and toxicity).To determine the final outcomes of each initiating event (LOC), the event tree technique is used based on the available literature (Uijt de Haag and Ale, 2005; Vilchez et al., 2011). Figure 3 depicts the general event tree that was generated in this study.

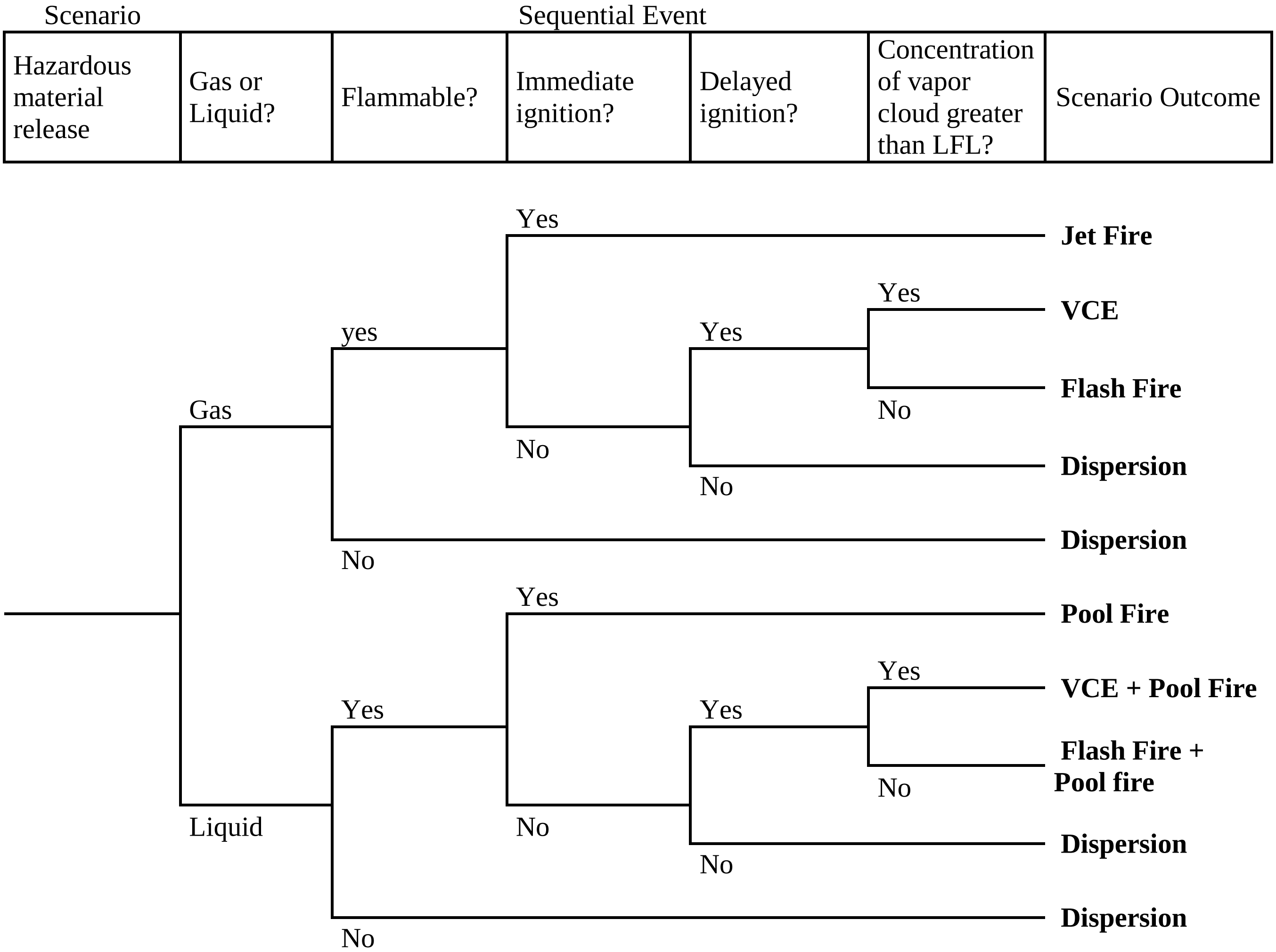

Figure 3- Generated event tree for LOC events

2.2.4 *Consequence analysis*

The LOC events' outcomes (such as pool fire, jet fire, etc.) have physical effects on people, properties and the environment, mainly due to thermal radiation, blast overpressure, and toxicity exposure. In this study the ALOHA software (2016) is used to assess the effects of final scenario outcomes. A set of thresholds are considered for evaluation of the consequences and emergency response zones. These thresholds are given by the levels of thermal radiation, overpressure, or toxic concentration that cause specific effects on people and/or property. Subsequently, the effect zones are calculated as radial distances from the release source within which the values of thermal radiation, overpressure, or toxic concentration are higher than the specified endpoints. Table 3 summarizes the selected criteria "level of concerns" used in the present study to calculate the physical effects.

2.2.5 *Domino probability identification and assessment*

Some of the primary events may lead to secondary events inside and outside the company fences (internal and external domino effects). According to Cozzani et al. (2006) domino effects may be

Table 3- Selected criteria for different 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
Overpressure (bar)	0.55	Nearly complete destruction of houses,
	0.24	Steel frame building distorted and pulled away from foundation
	0.69	Partial demolition of houses
Toxic dispersion (10 min exposure)	AEGL-3	Severe, Permanent life threating health effects
	AEGL-2	Irreversible or other serious effects.
	AEGL-1	Notable, non-disabling, and reversible effects.

initiated by one or more events such as pool fire, jet fire, fire ball, VCE, BLEVE, etc. In this study, in order to determine which units in neighboring companies are possibly impacted by the primary event, the escalation vectors (such as heat radiation and overpressure) exerted on the nearby units are compared with predefined threshold values (Cozzani et al., 2005) (see Table 4). The 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 should be calculated. Different methods have been proposed to calculate damage probabilities (Eisenberg et al., 1975; Vilchez et al., 2001; Cozzani et al., 2005). Probit functions have been widely used because of their simplicity and flexibility. Using Probit functions, first a Probit value, Y (Cozzani et al., 2005), is calculated as $Y = a + b \text{ Ln } (EV)$, where EV is the magnitude of the escalation vector or a related parameter, and a and b are constant coefficients. Having Y determined, the damage probability, P, can be calculated as $P = \phi\ (Y-5)$, where ϕ is the cumulative density function of a standard normal distribution (Khakzad et al., 2013).

2.3 Stage 2: determination of emergency levels

2.3.1 *Defining selection criteria for ranking credible accident scenarios*

Three different ranking criteria have been provided to ensure that the incidents are classified by each company in the chemical industrial park in a similar way based upon the severity of the incident and its potential impact on the company, the cluster, and the public. In the criteria table the consequences of accidents for people and for the environment are rated from minor to very severe. The damage probability of domino effects due to fire and explosion scenarios affecting target equip-

Table 4-Escalation threshold values for domino probability calculations (Cozzani et al., 2005)

Escalation vector &primary scenario	Target equipment	Threshold value
Radiation		
Flash fire	All	Unlikely
Fireball	Atmospheric	Credible only in the case of engulfment
	Pressurized	Unlikely
Pool fire and jet fire	Atmospheric	15 kW/m2 for more than 10 min
	Pressurized	50 kW/m2 for more than 10 min
Overpressure		
All overpressure scenarios	Atmospheric	0.22 bar
	Pressurized	0.17 bar

ment in neighboring companies is categorized in four domains. A number of relevant escalation scenarios is analyzed for different process equipment and based on the calculated damage probabilities, four cut-off levels for probabilities are defined. Table 5 provides the respective details for accidents' consequence level and damage probability levels. Furthermore, in case of toxic release scenarios, the accidents will be categorized based on their dispersion distances.

2.3.2 *Definition of emergency levels*

When an accident occurs in a company within a chemical cluster, the magnitude of the emergency can vary in scale. There is not necessary a direct correlation between the size of a release and the scale of the emergency. For example, a small release of chlorine gas in one company within a chemical cluster may affect people outside the boundary of the facility and therefore be classed as a 'Level 3' emergency. By comparison, a large release of a corrosive acid that is contained within a company fences could be classified as a 'Level 1' emergency.

As suggested by Reniers and Faes (2013), five levels of emergency from level 0 (Informative Alert) to Level 4 (High-High Alarm) have been considered based on the severity of the accident and the scale of the emergency. For instance, if the accident outcome impacts outside the boundary of the cluster, the emergency level at companies within the cluster can be levels 0 and 1 (the companies that are less affected), levels 2 and 3 (the companies that are most affected) and level 4 (the companies that their accident outcomes reach outside the cluster). Table 6 provides a more specific definition of the emergency levels.

Table 5-Ranking criteria for classification of credible accident scenarios

Consequence category	Description	Escalation category	Damage probability (P)	Description
Minor	- No injuries or fatalities on-site, - No/minor environmental impact (only within company fences)	Unlikely	$P < 10^{-6}$	- The incident is contained or controlled and it is unlikely that the incident will escalate. - There is no chance of additional hazards for nearby companies.
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	Moderate	$10^{-6} \leq P < 0.001$	- the primary accident may cause additional hazards for nearby companies (exposed to lower levels of fire radiation or blast overpressure)
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	likely	$0.001 \leq P < 0.1$	- Nearby companies are exposed to higher levels of fire radiation / blast overpressure
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 (e.g., large-scale toxic contamination of public waterway)	Almost certain/ already happening	$0.1 \leq P \leq 1$	- Nearby companies are within the hot zone and being exposed to very high levels of fire radiation / blast overpressure

2.3.3 *Decision matrix*

A simplified 4 x 4 matrix is used based on the ranking criteria of Table 6 to determine the level of emergency of an accident within the companies of the chemical industrial park. In the matrix, the expected consequences of the accident are placed on the vertical axis while the probabilities of domino effect triggered by fire or explosion scenarios and dispersion distances of toxic release scenarios are put on the upper and lower, respectively, horizontal axes. The matrix is presented in Figure 4.

2.4 Stage 3: multi-plant emergency response plan

All data needs to be put in one overview. The major accident scenarios of each company are placed on the vertical axis, and the companies that may be affected by these scenarios are placed on the horizontal axis of the matrix. The emergency level identified from the decision matrix is shown within each cell of the matrix (see Figure 1). Each Emergency level indicates the planning requirements and the responsible people when a specific accident scenario occurs within the chemical cluster. Appendix A provides an example for the emergency levels general requirements and emergency response organizational chart.

Domino Probability

Consequences	Unlikely	Moderate	Likely	Almost Certain
minor	Level 0	Level 1	Level 1	Level 2
Important	Level 1	Level 1	Level 2	Level 3
Severe	Level 1	Level 2	Level 3	Level 4
Very Severe	Level 2	Level 3	Level 4	Level 4
	Inside Company	Inside Cluster	Outside Cluster	National Concern

Toxic Dispersion

Figure 4- Emergency level decision matrix

.4.1 *Defining emergency levels strategies*

During a major accident situation there should be no miscommunication or misunderstanding issues between the involved response parties. Therefore, the next step is to define the response strategies in form of a multi-plant emergency matrix in order to manage different types of the major accidents' outcomes for the identified emergency levels. The response strategies address the responsive actions expected from each single plant in the cluster in order to manage emergency situations with the same know-how, including:

- Assessing the emergency situation
- Attempting to control the emergency situation
- Limiting the spread and impacts on nearby process facilities
- Protecting the health and safety of on-site and offsite people
- Alerting the other companies within the cluster
- Communicating with offsite emergency services
- Etc.

Table 6- Emergency levels definition for multi-plant emergency planning

Emergency Level	Alarm type	Definition	Related actions needs to be taken
Level 0	Informative	- Notification type of alarm for neighboring companies	- No action required by neighboring companies
Level 1	Pre-alarm	- There is a Small release of flammable gas / liquid or toxic gas with localized effect zone, - Limited to a single plant area - Notification type of alarm for neighboring companies to increase alertness /	- The plant and its related department can control the accident by itself, even without further support from outside. - No action required by neighboring companies - mutual aid between nearby companies may be needed
Level 2	Alarm	- An major Incident occurs within one company in the cluster - The incident is having, or has the potential to have an effect beyond the company fences and have impact on neighboring companies within the chemical cluster - Limited to the cluster boundaries	- The incident cannot be effectively and safely managed or contained at the site by operational staff - Emergency staff of cluster can be called on to control the accident - mutual aid between nearby companies is needed
Level 3	High Alarm	- A catastrophic accident occurs within one company in the cluster and have large impact both within the cluster and beyond the cluster boundary (surrounding community)	- As long as the accident needs other support from outside, the regional emergency response would be launched.
Level 4	High-High Alarm	- A catastrophic accident occurs within one company in the cluster and have large impact both within the cluster and beyond the cluster boundary (national /multi regional crisis)	- Decision reserved for the national crisis center or multi regional emergency response leadership.

2.4.2 *Scenario specific detailed action plan*

Since the emergency response strategies are defined for the different types of emergency situations, scenario specific detailed action plans are established. These action plans are part of a pre-plan technique that is widely used in the chemical industry (CCPS, 1995). The action plans are presented in a form of a table that shows a series of steps (based on the emergency strategies) that need to be followed when responding to an emergency situation based on its dispersion map (impact zones) and the evaluated emergency levels at individual plants within the industrial park. The table also includes the necessary resources (internal and external) such as the emergency communication systems, the alarm system and the emergency equipment (personal protective clothing, first aid, firefighting systems and etc.) and the responsible personnel (onsite and offsite) assigned to fulfill the responsive functions.

3 CASE STUDY

3.1 Case study introduction

In order to show the potential of the developed methodology, a chemical industrial park consist of three chemical plants has been considered. Each company holds various types of process installations and chemicals. The layout of the chemical cluster and the location of the selected hazardous sources within each plant are depicted in Figure 5. A set of meteorological parameters (wind velocity and direction, weather stability class, etc.) was chosen to calculate the consequence of the release as reported in, Table 7. The information related to the selected hazardous sources in every chemical plant is provided in Table 8.

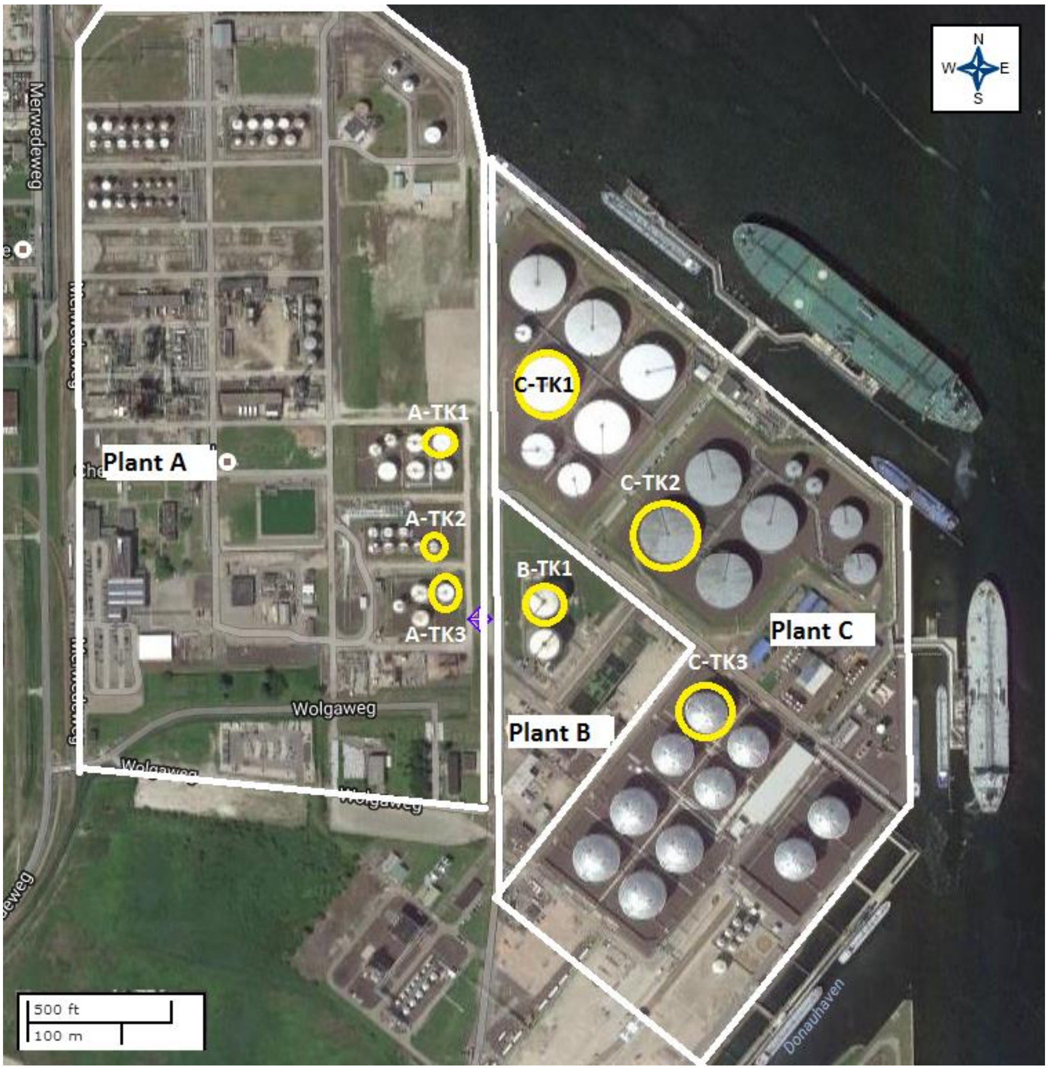

Figure 5- Cluster layout and the selected hazard sources location

Table 7- Case study meteorological conditions

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

Table 8-Information related to the selected hazard equipment and the process conditions considered in the case study

Chemical Plant	Hazard Source ID.	Type	Hazardous materials	Process Condition					
				Phase	T (°C)	P (bar)	C (M^3)	D (m)	H (m)
Plant A	A-TK1	Atmospheric tank	n-Butanol	Liquid	25	1.03	5000	20	15.9
	A-TK2	Pressurized tank	Chlorine	Liquid	-10	5.5	1000		
	A-TK3	Atmospheric tank	2-ethylhexanol	Gas	25	1.03	5000	18	19.6
Plant B	B-TK1	Atmospheric tank	Ammonia	Liquid	-40	0.069	15000	30	21.2
Plant C	C-TK1	Atmospheric tank	Kerosene	Liquid	25	1.03	62000	60	21.9
	C-TK2	Atmospheric tank	Benzene	Liquid	25	1.03	60000	60	21.2
	C-TK3	Atmospheric tank	Methanol	Liquid	25	1.5	50000	50	25.5

3.2 Results and discussions

The application of the methodology (described in section 2), determines the credible accident scenarios for major installations at Plants A, B and C. Table 9 exemplifies the accident scenarios for Plant B for a range of hole sizes and possible outcomes thereof. Each scenario can be identified based on a reference code (Plant Name - Eq. ID - Release event No. - Expected outcome), for example: B-TK1-3-c. In order to evaluate the emergency situation within the cluster, two different outcomes from Table 9 are considered for a minor leakage event in B-TK1: Scenarios B-TK1-1-a and B-TK1-1-c. It should also be taken into account that the toxic dispersion scenario (B-TK1-1-a) may lead to a flash fire scenario (B-TK1-1-d) as well. Table 10 shows the result of the consequence analysis of these selected scenarios in the form of downwind distances based on the levels of concern (from Table 3) by using the ALOHA software (2016).

Table 9-Credible accident scenarios for Plant B and the possible outcomes

Eq. ID	Release event	Expected outcomes
B -TK1	1-Minor leak -300 mm	a. Toxic dispersion, b. Fire ball, c. Pool fire, d. Flash fire
	2-Major leak -1000 mm	a. Toxic dispersion, b. Fire Ball, c. Pool fire, d. Flash fire
	3-Instantaneous release	a. Toxic dispersion, c. Pool fire, d. Flash fire,

Table 10- Consequence analysis for the Ammonia Storage Tank in Plant B

Accident Scenario ID	Distance to heat radiation levels (m)			Distance to LFL % (m)		Protective action zones (m)		
	4 (kW/m^2)	12.5 (kW/m^2)	37.5 (kW/m^2)	10%	60%	AEGL-1	AEGL-2	AEGL-3
B-TK1-1-a	-	-	-	-	-	> 10000	3100	452
B-TK1-1-c	187	144	105	-	-	-	-	-
B-TK1-1-d	-	-	-	147	58	-	-	-

The first emergency situation, the flammable chemical escapes from the storage tank and forms a burning puddle (B-TK1-1-c). Figure 6 shows the pool fire footprint and the affected companies within the cluster. All three companies are within the radiation impact zones. Some parts of Plant A receive a 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 the on-site workers, while other installations within Plant B are affected by fire (internal domino effect may happen). Plant C is located within the radiation hot zone, so there could be serious injuries towards on-site personnel. Some units in plant C such as C-TK2 (atmospheric tank) are exposed to high radiation levels (more than the threshold values reported in Table 4) and there is a possibility that escalation occurs (external domino effect). The results in Table 11 indicate the damage probability in the affected plants for their selected installations.

Table 11- Calculated damage probability for the affected equipment by the pool fire at B-TK1

Primary Scenario ID	Escalation Vector	Threshold value kW/m^2	Target Equipment	Volume (m^3)	Radiation Level (I) kW/m^2	Domino Probability (P)
TK1-1-C	Radiation	15	B-TK 2	15000	63.5	0.094
		15	C-TK 2	62000	37.5	0.426
		15	C-TK 4	18000	29.1	0,003
		15	A-TK 3	5000	12.3	1.023E-07

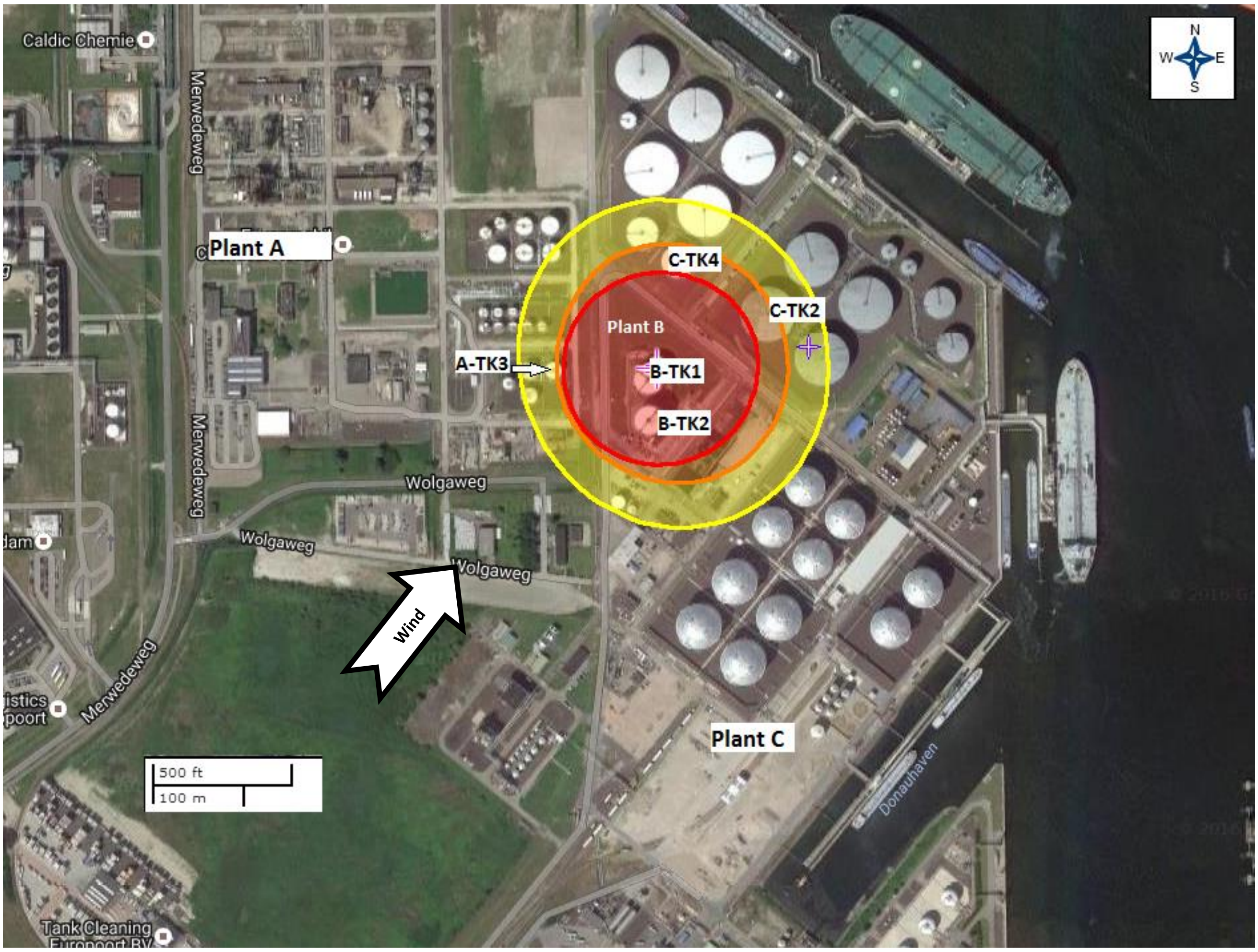

Figure 6- Accident scenario B-TK1-1-c, the pool fire footprint affected zones at the chemical cluster

The second emergency situation, the flammable chemical (not burning) escapes from the storage tank and forms an evaporating puddle (B-TK1-1-a). The result of consequence analysis reported from Table 10 indicates the Ammonia dispersion plume footprint downwind distances, which is shown in Figure 7. Per O’Mahony et.al. (2008) definition, the hot, warm and cold emergency zones can be determined based on AEGL levels (10 min exposure). The Ammonia plume affects both the companies within the cluster and some parts of the river and the nearby rural area. As indicated in Figure 8, Plants B and C are within the hot zone and it is predicted that on-site personnel could experience life threatening health effects or even death. The personnel of passing ships or boats in the nearby river may be exposed to high amounts of the toxic gas (within the warm zone) and would experience serious or irreversible adverse health effects. Also the gas cloud (cold zone) is likely to reach the rural area outside the cluster, and the general population. They may experience notable discomfort, irritation and reversible effects.

Besides the adverse health effects of Ammonia, this chemical is a highly flammable and explosive material and there is chance that a flash fire within the 10% of LFL area (scenario B-TK1-1-d) may happen. Figure 9 shows the downwind concentration profile for 10% LFL.

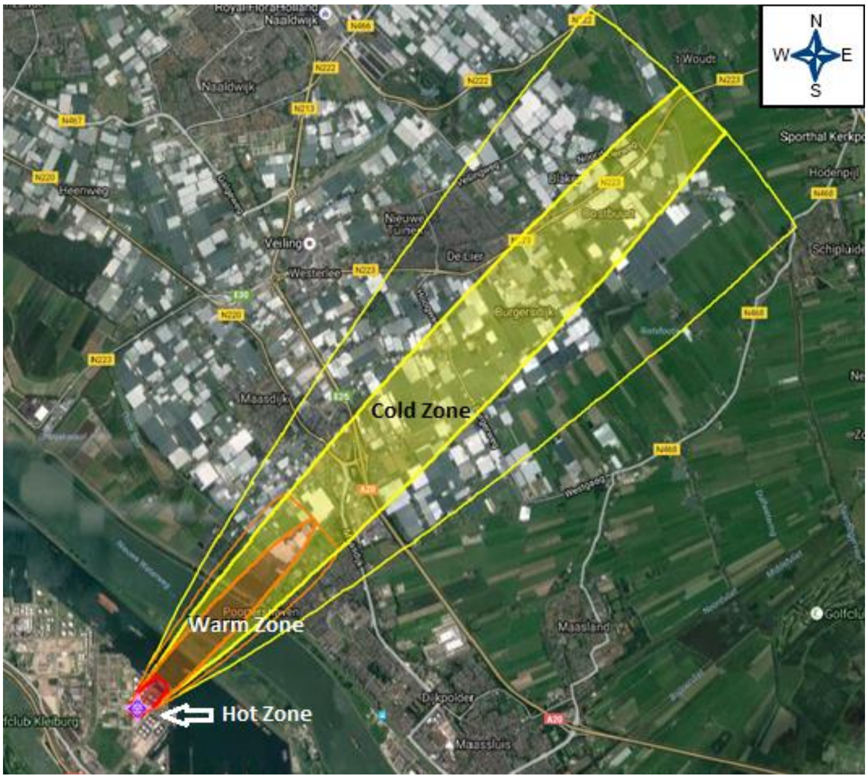

Figure 7-Accident scenario B-TK1-1-a: Ammonia gas plume dispersion footprint hot (red contour), warm (orange contour), and cold (yellow contour) zones

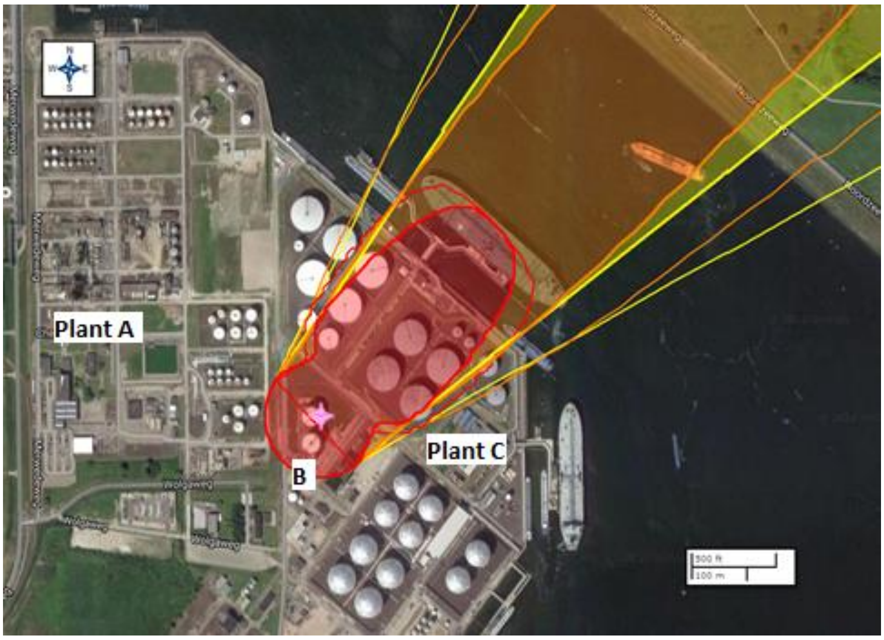

Figure 8-Accident scenario B-TK1-1-a: Ammonia gas plume dispersion footprint in the chemical cluster

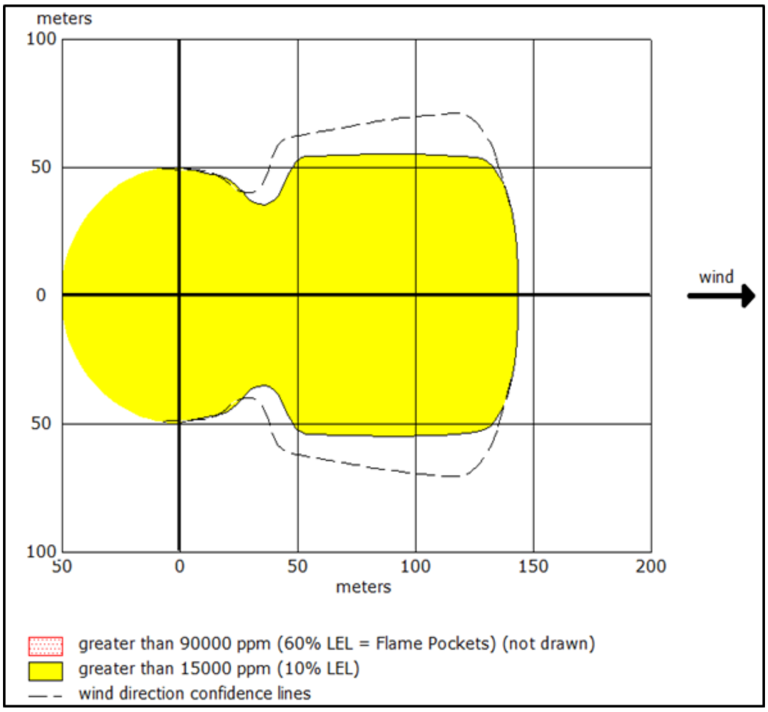

Figure 9-10 % LFL concentration downwind profile for Ammonia minor release scenario

By evaluating the consequence severity and the damage probability of each plant for the first scenario, and the dispersion distances of the second scenario from Table 6 and using the proposed decision matrix (Figure 1), the emergency level for each company for both scenarios can be predicted. The results are illustrated in Table 12.

Table 12- Multi-plant emergency levels for the selected scenarios

Scenario ID	Plan A	Plant B	Plant C
B-TK1-1-c	Level 1	Level 3	Level 3
B-TK-1-a	Level 1	Level 4	Level 3

Since the emergency levels for each chemical company are identified, the response strategies can also be established and scenario specific detailed action plans can be set for the selected scenarios. Tables 13 and 14 report the role of on-site and offsite responders in managing the emergency situation and the needed resources.

Table 13-Scenario specific detailed action plan for scenario B-TK1-1-c

Task	Action party	Equipment / Resources
On-Site Responders @ Plant B **Emergency Level 3**		
1-Confirm the pool fire incident	CCTV, On-site personnel,	Detection system(s) and/or visual observation
2-Trigger the fire alarm	On-site personnel, Operator	
3-Call emergency services	Operator	
4- Evaluate the situation	Incident Commander, HSE officer	- ESD systems
5- Raise Emergency response alarm for nearby plants	Incident Commander/ Emergency Deputy	- Water spray system/ Sprinkles
6-Notify the off-site emergency community services	Incident Commander	
		- Fire water supplies
7-Activate the ESD system for the entire site	Operator/ Emergency Deputy	
8-Raise evacuation alarm for site personnel	Emergency Deputy	-Portable extinguishers
9-Manage the site evacuation procedure	Security personnel	-First aid kit -Fire water pump/ trucks
10- Dispatch the fire brigades and start the firefighting procedure	Emergency Deputy / Fire brigades	-Backup power -Proper PPE to prevent burns
11-cool nearby equipment,	Fire brigades	
12-monitoring of wind/ weather conditions	HSE Coordinator	
13-Prepare to receive off-site emergency services	Incident Commander	
14-Continually assess incident conditions for ongoing safety. Advise if any further evacuation requirements necessary.	Incident Commander	
15-Be prepared for fire at adjacent storage tanks	Fire fighters	
Off-Site Responders		
1-Confirm the incident with port authorities	Mayor	-Forward control point (FCP) located upwind of incident
2- Dispatch Emergency services (local police, Fire brigades, Ambulances)	Mayor / Regional operation manager	-Fire water pump/trucks complete
		-Mobile water monitors
3- Cordon off incident area and evacuate surrounding area lying in path	Local Police	-Mobile water screens
4-Restrict or control navigation traffic around incident area	Cluster security with local police	-(high resolution) thermal image camera
		-Rescue boat
5-Provide additional fire personnel, if needed	Regional operation team	-Ambulances

6- Continually assess incident conditions, Advise if any further evacuation requirements necessary.	Regional operation manager with Cluster emergency manager	-Proper PPE to prevent burns
On-Site Responders @ Plant C **Emergency Level 3**		
1-Confirm the received alarm	Incident Commander / Operator	Detection system(s) and/or visual observation - Water spray system/ Sprinkles - Fire water supplies -Portable extinguishers -First aid kit -Fire water pump/ trucks -Backup power -Proper PPE to prevent burns
2-Make contact with Incident commander in Plant B, Cluster Emergency Manager	Incident Commander	
3-Trigger the site evacuation alarm,	Emergency Deputy	
4- Evaluate the accident situation and affected installations	HSE Coordinator	
5- Notify the site emergency services	Emergency Deputy	
6-Manage the site evacuation procedure	Site Security	
7-Activate the emergency discharge procedure for most affected storage tanks	Process Operator/ Emergency deputy	
8-Startup firefighting procedure on affected areas and cool exposed equipment	Fire brigades	
9-monitoring of wind/ weather conditions	HSE Coordinator	
10-Continually assess incident conditions for ongoing safety of emergency personnel	Incident Commander / Emergency deputy	
11-Request additional emergency services, if needed.	Incident Commander	

On-Site Responders @ Plant A **Emergency Level 1**		
1-Confirm the received alarm	Incident Commander / Operator	Detection system(s) and/or visual observation - Water spray system/ Sprinkles - Fire water supplies -Portable extinguishers -First aid kit -Fire water pump/ trucks - Backup power -Proper PPE to prevent burns
2-Make contact with Incident commander in neighbor companies, Cluster Emergency Manager	Incident Commander	
3-Trigger the notification alarm,	Emergency Deputy	
4- Evaluate the situation and affected installations	HSE Coordinator	
5- Notify the site emergency services	Emergency Deputy	
6-Avoid the personnel to come near the affected area	Site Security	
7-Activate the emergency discharge procedure for most affected storage tanks	Process Operator/ Emergency deputy	
8- Cool exposed equipment	Fire brigades	
9-monitoring of wind/ weather conditions	HSE Coordinator	
11-Request additional emergency services, if needed.	Incident Commander	

Table 14-Scenario specific detailed action plan for scenario B-TK1-1-a

Task	Action party	Equipment / Resources
On-Site Responders @ Plant B **Emergency Level 4**		
1- Confirm the release event	On-field personnel, CCTC, Leak detector	- Detection system(s) and/or visual observation
2- Trigger the evacuation alarm	Operator	- ESD systems
3- Refer to Installation Manager or shift supervisor	Operator	- Water spray system
Use Meteorological Data to predict toxic gas dispersion pattern	Incident Commander/ HSE Coordinator	- First aid - Proper PPE
5-Notify the affected neighboring companies (Raise Evacuation Alarm)	Operator/ Incident Commander	- Ventilation system - Fire water pump/ trucks
6-Notify the emergency services,	Incident Commander	- Gas detectors
8- Evaluate emergency response zones (hot, warm, cold)	HSE Coordinator	
9- Evacuate personnel in upwind direction out of the hot zone	Site Security	
10-Eliminate the ignition sources in the path of gas migration	Incident Commander/Emergency Deputy	
11-Dispatch site fire brigades to the incident location	Emergency Deputy	
12-Be prepared for fire	Emergency Deputy/ Fire brigades	
13- Use of water spray in the form of water screens/curtains that may minimize gas migration	Fire brigades	
14- Refer to receive off-site emergency services	Emergency Deputy	
On-Site Responders @Plant C **Emergency Level 3**		
1-Make contact with the Cluster Emergency Commander/ Plant B Incident Commander	Incident Commander	- Detection system(s) - Fire water pump/ trucks
2-Raise evacuation alarm for site personnel	Incident Commander/ Operator	- Proper PPE - Water spray system
3- Evacuate personnel in the upwind direction	Security	- ESD systems - Gas detectors - First Aid
3- Determine the affected area and Emergency response zones (hot, warm zone)	HSE Coordinator	
4-Eliminate the ignition sources in the path of gas migration	Incident Commander/ Emergency Deputy	
5-Avoid entering the gas hazard area (hot &warm zone)	Security	
6- Control for ‘gas pocketing’ in all buildings in and enclosed spaces in vicinity of vapor cloud area (hot zone)	Fire brigades	
On-site Responders@ Plant A **Emergency Level 1**		
1- Make contact with the Cluster Emergency Commander/ Plant B Incident Commander	Incident Commander	- Detection system(s) - ESD systems - ESD systems

2-Raise 'Notification Alarm'	Operator/ Incident Commander	- Water spray system - Gas detectors
3- Avoid personnel to be near the hazard area	Security	
4-Dispatch emergency responders/ fire brigades if needed.	Emergency Deputy	
Off-Site Responders		
1-Confirm the incident with port authorities	Mayor	-Forward control point (FCP) located upwind of incident - Fire water pump/trucks complete - Mobile water monitors - Gas detectors - (high resolution) thermal image camera - Rescue boats -Ambulances
2- Dispatch Emergency services (local police, Fire brigades, Ambulances)	Regional Operational Manager	
3- Assess the gas dispersion path, determine the affected area outside the cluster	Regional Operational Team with cluster emergency incident commander	
4- Arrangements for meeting incoming external response groups at forward control point (FCP)	Regional Operational Manager	
5- Advise people to stay at their building and close windows and stop ventilation systems (warm zone)	Local Police	
6- Navigational traffic waterways	Port authorities	
6- Restrict or stop traffic to prevent people coming into hazard area(warm & cold zone)	Local Police/ port authorities	
7- Use of portable gas monitoring equipment to monitor gas cloud extent	Regional Operational Team	
8- Assess incident conditions for ongoing health and safety for public	Regional Operational Manager with cluster emergency manager	
9-Search and rescue for possible casualty	Emergency medical services/ Fire brigades	
10- Continual monitoring of wind/weather conditions	Regional Operational Manager with cluster emergency manager	

4 CONCLUSIONS

Managing a single chemical company's and a chemical cluster's emergency situations is not identical. Dealing with single company incidents mostly requires the involvement of company emergency response personnel (e.g., fire brigade, safety and security officers, medical team) of a single plant. In some situations, however, emergency community services would be needed too. However, major accidents with cross-plant consequences (crisis situations) need the involvement of emergency response management (incident commanders, technical safety experts, fire brigades, etc.) from different plants, thus the organization and implementation of such emergency planning needs a different emergency response strategy for major accidents. In the present study, we have proposed an emergency response decision making tool in order to prioritize the credible accident scenarios, identify emergency levels, and determine emergency action plans accordingly. This has been carried out based on the consequence, damage probability and toxic dispersion distance of credible major accidents.

AKNOWLEDGEMENT

The authors appreciate the financial support provided by the Leiden- Delft- Erasmus (LDE) Centre for Safety and Security, The Netherlands.

APPENDIX A

Emergency response organizational chart

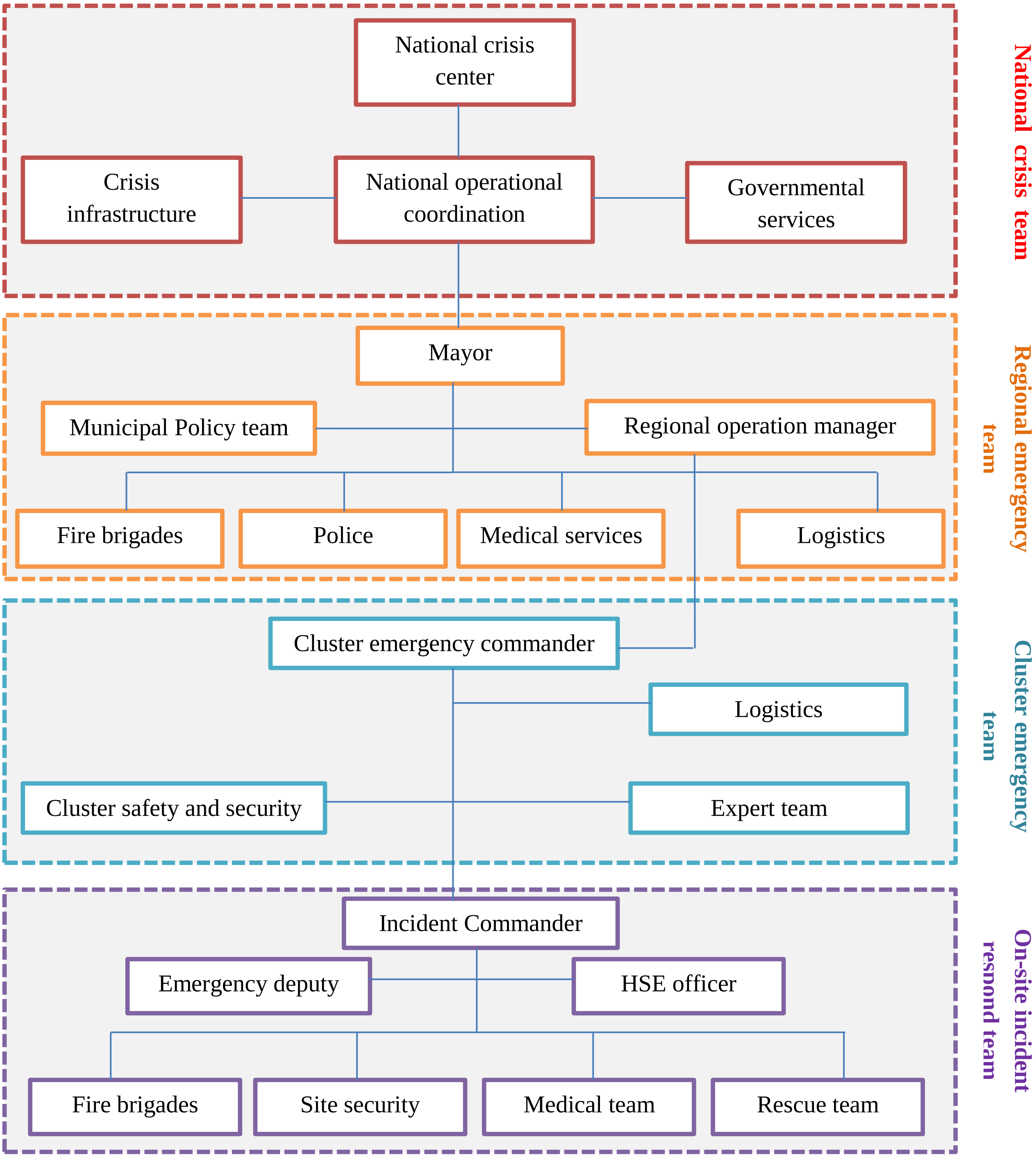

Table A- Emergency levels general requirements

Responses		Level 0 Alert	Level 1 Emergency	Level 2 Emergency	Level 3 Emergency	Level 4 Emergency
Communication	Internal	Notification of " Informative Alert" for neighbor companies	Notification of "Pre-alarm" affected companies in cluster	Notification of "Alarm" for affected neighbor companies in cluster	Notification of " Alarm" for Affected companies in cluster	Notification of "Alarm" for affected companies in cluster
	External National	Reactive, as required.	Mandatory for individuals who have requested notifications,	Planned and instructive in accordance with the specific ERP team.	Planned and instructive in accordance with the specific ERP team.	Planned and instructive in accordance with the specific ERP team.eg, municipalities, safety regions
	Media	Reactive, as required.	Reactive, as required.	Reactive, as required.	Notify Local Government crisis center (safety regions.)	Notify National Crisis Center (NCC).
		Reactive, as required.	Reactive, as required.	Proactive media management for local interest.	Proactive media management for local or regional interest	Proactive media management for regional or national interest.
Actions	Internal	No action required by neighboring companies.	On site and as required by emergency response team.	Need for multidisciplinary coordination at the incident scene. cluster crisis management team alerted .	Need for multidisciplinary and safety regions coordination and cluster crisis management engaged to support on-scene responders.	Need for management By central government in situations where national security is or may be at Risk.
	External	None.	On site, as required by emergency response team.	Potential for multiagency (operator, municipal, provincial, or regional) response.	safety regions heads take decisions together for multiagency (operator, municipal, provincial, or regional) response.	National crisis center take decision for Immediate multiagency (operator, municipal, provincial, or federal) response.
Resources	Internal	None.	Immediate and local. If needed, personnel from nearby companies should be alerted.	Establish what resources would be required and may be appropriately engaged to support on-scene responders.	Cluster supplemental resources or personnel required and have to engage on scene response.	Significant incremental resources from several companies within cluster is required.
	External	None.	None.	Begin to establish resources that may be required from responsible community of emergency services.	Possible assistance from regional operational teams and if need external support services by national operational coordination center.	Assistant from national operational coordination team and regional operational team in each concerned region.

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