A three-dimensional visualization tool to support HSE management of chemical facilities

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Chemical and process facilities may feature complex procedures to manage health, safety, and environmental (HSE) related documentation in real time. These procedures may sometimes have negative implications on plant management and on inspections/audits. Therefore, the aim of this work is to show the benefits in developing and applying an innovative software framework to support the integrated management of HSE aspects of industrial installations. The tool is a three-dimensional technology designed to monitor and control the activities in industrial facilities by collecting process and environmental data in real time. The software is aimed to collect, monitor, and manage general process variables, status of maintenance and reliability of equipment, and many other aspects related to HSE aspects. A consequence assessment module, based on literature integral models, is also implemented in the software to perform real-time consequences analysis, and to display the evolution of the credible events resulting in case of accident. Either prefixed conditions or real-time input data (e.g. meteorological conditions, information on release features, etc.) may be implemented in the software. Real time three-dimensional consequence assessment may be carried out to support emergency response, training, and also risk based inspection and maintenance activities. The potentialities of the developed tool are tested though the application to an industrial case study.

Keywords: risk and hazard assessment, consequence assessment and modelling, HSE management

1. Introduction

In the framework of facilities under the obligations of Seveso Directive (EU 2012), communication towards competent authority and population is of utmost importance: access to risk information, effective emergency response, either in the industrial site or in the external residential areas, are critical aspects. However, health, safety, and environmental (HSE) management systems for this kind of facilities may feature relevant complexity (Tanabe & Turco 2016). Procedures for the obtainment and utilization of HSE internal documentation and, more in general, communication may face difficulties, with negative impact on the risk profile of a facility (Paltrinieri et al. 2012).

Therefore, the need of safety improvement for Seveso installations asks for more advanced tools for risk estimation, evaluation and communication. In fact, besides considering technical aspects, such as malfunctions and process upsets, external events may contribute to failures (Reniers and Cozzani, 2013) as well as operational errors (Pitblado et al. 1990, Vinnem et al. 2012). Moreover, even at the organizational level, lack of attention and motivation to safety culture may lead to risk increment, in terms of likelihood of undesired failure (Ale et al. 2014, Attwood et al. 2006, Griffin et al. 2014).

All those aspects may not be easily investigated with conventional quantitative risk assessment (QRA) techniques and tools, which are known to be static, thus unable to estimate the variation of risks due to operation or changes during the lifecycle of a production plant (Kalantarnia et al. 2009). Thus, integrating the common methodology for risk evaluation adopting real-time plant data (from process operations and from the external environmental) in an innovative software framework, may result in a major step forward both for management and HSE aspects. Moreover, automatization of procedures, real time data acquisition and simulation are elements which are consistent with the current European trend of automation and digitalization of the industrial sector is the framework of Industry 4.0 (Kagermann et al. 2011, 2012)

In the last decade, Chemical Controls has collaborated with several Italian Port Authorities, with the aim to build an information system to support the rapid and efficient management of emergencies related to hazardous materials handling, storage and transport in port areas and to share the necessary information through an easy-to-use interface supported by 3-dimensional (3D) graphics. From the experience gained in the support to port facilities, the software tool was extended to fixed industrial facilities with the primary aim to manage and monitor in real time and on a single 3D platform the documentation, administration and logistics.

The present works deals with the presentation of the 3D tool with relevant upgrades related to the development of specific HSE tools. In particular, the software was improved by introducing operational and maintenance management aspects, and a specific functionality to support real time hazard assessment and evaluation of major accidents consequences adopting real time data.

A sample application is presented to highlight the benefit and potentialities of the tool, discussing potential future developments.

2. Methodology

2.1 Overview

The aim of the work is to provide a quick and easy 3D tool to support HSE management of chemical and process facilities; the software is named “DATACH IMPIANTI 3D”, in the following DI3D. The software creates a 3D map of the facility and collects all the available information about the equipment, in real-time and in a single interface.

As mentioned in Section 1, the former version of the tool, namely HACKPACK PTS, was developed to manage port activities involved in the handling, storage and transport of hazardous materials. HACKPACK PTS allows to constantly monitor every port operation providing real time detailed information and reports about the monitored activities, in a 3D harbour visualization (Chemical Controls, 2017).

In the present work, the idea was to extend and improve the capabilities of the software HACKPACK PTS into DI3D for its use in fixed industrial facilities, implementing a real-time, flexible, and quick module for evaluation of hazard and risk. The main features of the 3D interactive mapping technologies are:

1. Plant inspection, performed by a laser scanner fitted on a drone;
2. Three-dimensional reconstruction of the plant on a graphic interface;
3. Association of real-time and / or static data and documentation, to each mapped element;
4. Real-time evaluation of consequences following an accidental release, to support to emergency planning.

Drone inspection allows for the plant reproduction on a 3D interactive map, through which all the information can be made available: building, piping system and equipment features (maintenance status, operating conditions, stored substances, etc.) can be displayed by clicking on mapped elements. Management systems are constantly monitored and easily available. These features were already implemented in the port software HACKPACK PTS. Hence, the core element of innovation of the industrial tool DI3D is point 4, namely the real-time hazard evaluation and assessment. For this purpose, accidental releases of hazardous substances, evaluation of physical effects following the release and the elaboration of real-time meteorological data are implemented in the software. The evaluation of flammable and toxic gas dispersion is shown in the following as example of potential physical effects analysis through DI3D.

2.2 Procedure for hazard evaluation in the software

The procedure is aimed at providing a straightforward quantitative hazard assessment through real-time prediction of the evolution of a hazardous material release over time and space. The approach is shown in Figure 1; on the left side of the figure, the necessary input data and information are shown, while the tasks of the procedure are on the right side of the flowchart. The approach starts with the characterization of the process and the identification of the equipment in a given industrial facility. Then, in the second phase, the consequence analysis is carried out identifying the credible scenarios and damage distances linked to accidental scenarios. In order to provide a simplified but effective hazard assessment, the approach developed by (Tugnoli et al. 2007) for consequence-based inherent safety assessment is considered as explained in the following sections.

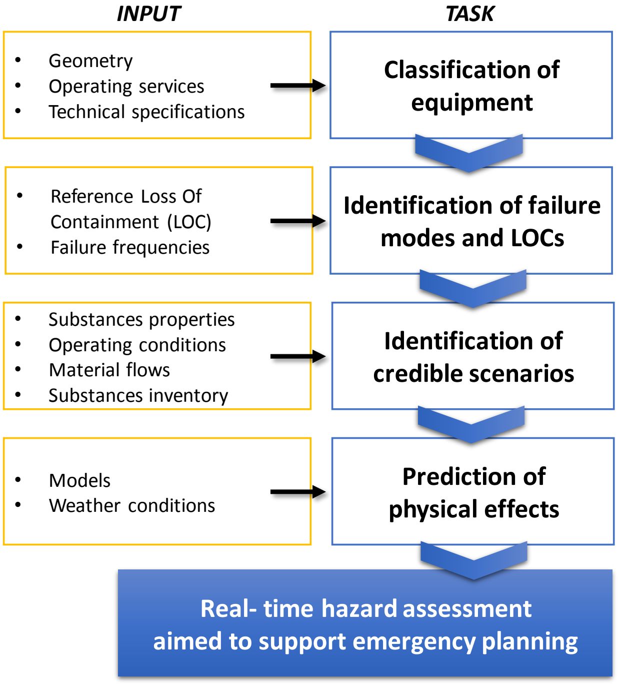


Figure 1. Flowchart of the methodology for the development of DI3D.

2.2.1 Input data and classification of equipment

As defined in Figure 1, the first step of the procedure is to obtain the input data needed for the process characterization. These data are usually obtained from the process flow diagram (PFD), where information on the operating conditions of the equipment are available. The requested preliminary data for each piece of equipment are:

- Characterization of substances handled;
- Operating conditions (temperature, pressure, physical state of substances);
- Piping system specifications and material flows in process lines;
- Technical specifications of equipment;
- Estimation of substances inventory in each equipment.

In order to provide a simplified evaluation of failure modes of equipment, relevant units in process plants were sorted by a specifically defined taxonomy, that was based on the geometrical structure of the units. Table 1 reports the main general unit categories defined for process equipment. For each unit category, sub-categories featuring the specific characteristics of the units related to their function/operative condition were also defined. The characterization of equipment, according to geometrical and operational criteria, was based on previous literature studies (Uijt de Haag & Ale 1999, Delvosalle et al. 2006).

Table 1. Example of classification criteria for process units.

Category	Sub-Category
Vessel	Atmospheric
	Pressurized
	Portable (road tankers, rail tankers, etc.)
Tube bundle equipment	Heat exchangers, reactors, etc.
Piping system	Pipeline, manifold, etc.
Fluid transfer systems	Pumps
	Compressors
Warehouse	Packed materials
	Spare materials
Special equipment	Solid handling
	Other

2.2.2 Failure modes and LOCs

Once the process units are classified, it possible to identify the modes of failure which can lead to a loss of containment (LOC), related to each class of equipment. Loss of containment events are defined for various systems in an establishment; generally, each category of equipment (see Table 1) has a limited number of associated failure modes. The reference LOCs and their failure frequencies implemented in this study are taken from technical literature, namely the TNO Purple Book (Uijt de Haag & Ale, 1999) and the API publications (API, 2000), depending on the data availability.

2.2.3 Characterization of accidental scenarios

The credible scenario following the loss of containment events are identified through a standard Events Tree Analysis (ETA) (Less 1996). The ETA allows both the identification of the scenarios and the quantification of the credibility of each scenario following the accidental release. Each LOCs has a conventional event tree to which it can be associated.

Combining the appropriate event tree with the LOC event depends on three main factors (Lees 1996): the type of release (continuous or instantaneous), the characteristics of the released substance (inflammable, toxic), and the physical properties of the substances leaked (phase, temperature, pressure, etc.). Thus, the event tree final outcomes are different for each loss of containment and they may involve fire (e.g. fireball, jet fire, etc.), explosions (e.g. vapor cloud explosion), or dispersions. Probability of occurrence of each scenario is then quantified introducing standard literature data for the quantification of event trees (Uijt de Haag & Ale 1999).

In this step of procedure, the source term of the release is characterized and quantitively determined. Modelling source terms depend on the released phase (vapour/gas or liquid) and on its released conditions (temperature, pressure, hold up). In this work, the implemented models are based on standard integral approaches (Lees 1996, Uijt de Haag & Ale 1999).

2.2.4 Weather data

Weather data treatment is of fundamental importance to provide real-time consequence assessment results. Data may be provided by the user to verify the status of the plant in predetermined conditions or may be directly acquired from a local meteorological station. In the latter case, data are processed to evaluate atmospheric stability features supporting, for example, dispersion studies.

Atmospheric stability indicates the degree of turbulence of air in the atmosphere (unstable, neutral or stable atmosphere) and therefore its ability to generate mixing phenomena. Turbulence depends on the incident solar radiation (which defines the vertical temperature gradient) and on the pressure gradient. Monin and Obukhov (Golder 1972) provide a method for calculating stability through the evaluation of the vertical temperature gradient. This may be calculated in different ways depending on the available data.

The model selected in this work is based on the iterative procedure recommended in "Yellow Book" (Van DenBosh & Weterings 2005), which needs the following initial data from the meteorological station: i) wind speed; ii) solar radiation. Besides, considering appropriate surface roughness data, information is processed to determine the stability classes suitable for the assessment of toxic or flammable gas dispersion. More information on Monin and Obukhov model and other tools needed to process meteorological data are reported elsewhere (Van DenBosh & Weterings 2005).

2.2.5 Physical effects modelling

Physical effects of accidental scenarios are modelled through the software based on the elaboration of source terms following a LOC and weather data. The aim of this part is to determine the release evolution over time allowing for the quantification of the scenario severity. An example is shown in the following for flammable and toxic gas dispersion scenarios.

Models for the simulation of gas dispersion feature different levels of complexity:

1. Advanced approaches, based on distributed parameters models in computational fluid dynamics (CFD) codes, provide a local numerical solution of Navier-Stokes equations, expressing the conservation of mass, momentum and energy (Ferziger & Peric 2002). CFD modelling provides accurate results; however, CFD induce relevant costs associated with model set up, computational time and graphic representation (Schmidt, 2012);

2. Commonly applied physical effects models in quantitative risk assessment studies are based on integral models (Van DenBosh & Weterings 2005) which are implemented in software packages (e.g., DNV GL Phast, TNO Effects, US EPA Aloha, etc.). These tools provide results with low computational demand and are useful to assess physical effects in the far field, i.e. at relevant distance from the risk source. However, they need skilled people for their set up and do not account for complicating phenomena, such as the presence of obstacles or absence of wind;

3. Semi-empirical models, such as simplified correlations, adopt simple relationships to reproduce experimental observations. These models are less accurate but feature higher computational speed, flexibility and easiness of set up;

4. A simplified estimation of physical effects can be based on short-cut methods, such as the one adopted for emergency response planning (see more details in (ISPRA-APAT 2006)).

The correlations for the physical effects evaluation implemented in DI3D are either semi-empirical or integral models. Semi-empirical models for gas dispersion adopt simple exponential functions and/or Gaussian trends to reproduce data obtained from field experiments or from studies of the gaseous effluents of the plants. Instead, more details on integral models for gas dispersion are reported by (Van DenBosh & Weterings 2005). The models selected for developing DI3D tool are briefly described in the following.

The free-jet model by (Chen & Rodi, 1980) is adopted to describe gas releases in a uniform quiescent atmosphere, either considering buoyant or non-buoyant jets, with full preliminary characterization of the source term; in this case, weather conditions charachterization is not necessary.

If the free-jet model is not applicable, model selection depends on meteorological data and on whether the release will lead to a cloud denser than the ambient air, as described below:

- For clouds heavier than ambient air the SLAB model (Ermark, 1990) is applied in this work for instantaneous releases and releases of finite duration. For continuous releases, in case of vertical jet and this jet be ignored, the HMP-model (Hoot et al., 1973) is implemented to determine maximum plume rise and concentration. Thereafter, results are coupled with the SLAB-model. Otherwise, the SLAB-model is used.

- For clouds with lighter or with equal density than ambient air (positively buoyant or non-buoyant, respectively), the Gaussian Plume Model (GMP) (Hanna et al., 1982) is used for modelling passive dispersion of instantaneous and continuous releases. The rise of positively buoyant plumes is evaluated through the simplified Briggs e Davidson model (Briggs, 1969; Davidson, 1989).

All the mentioned models were already verified against available experimental data sets (Haugen 1959, Koopman et al. 1982, Bouet 2015) and a specific verification procedure allowed confirming the validation results, so testing the reliability of the numerical implementation of these models into DI3D (Picconi et al. 2016).

2.2.6 Damage distances

The last step of the procedure is the estimation of the severity of each possible accidental scenario. Starting from the results of physical effects modelling for dispersions, e.g. concentration profiles, it is possible evaluate damage distances adopting a threshold-based approach. For gas dispersion scenarios, the refence events are toxic contamination for toxic gases; flash-fire for flammable gases; clearly enough, both scenarios for flammable and toxic gases. Two hazard levels were considered, respectively for high and low severity effects limit. The threshold values are summarized in Table 2 and were derived from the Italian legislation for land use planning; those values are adopted for the simulation of a demonstration case study.

Table 2. Threshold values adopted in the present study.

Scenario	High severity (lethality level)	Low severity (incipient lethality)
Flash-fire	LFL	LFL/2
Toxic dispersion	LC_{50} 30 min*	IDLH*

* IDLH = Immediately Dangerous to Life and Health concentration, 30 minutes exposure; LC50 30 min = lethal concentration for 50% of exposed population given 30 minutes of exposure (value for humans).

2.3 Managerial and communication support

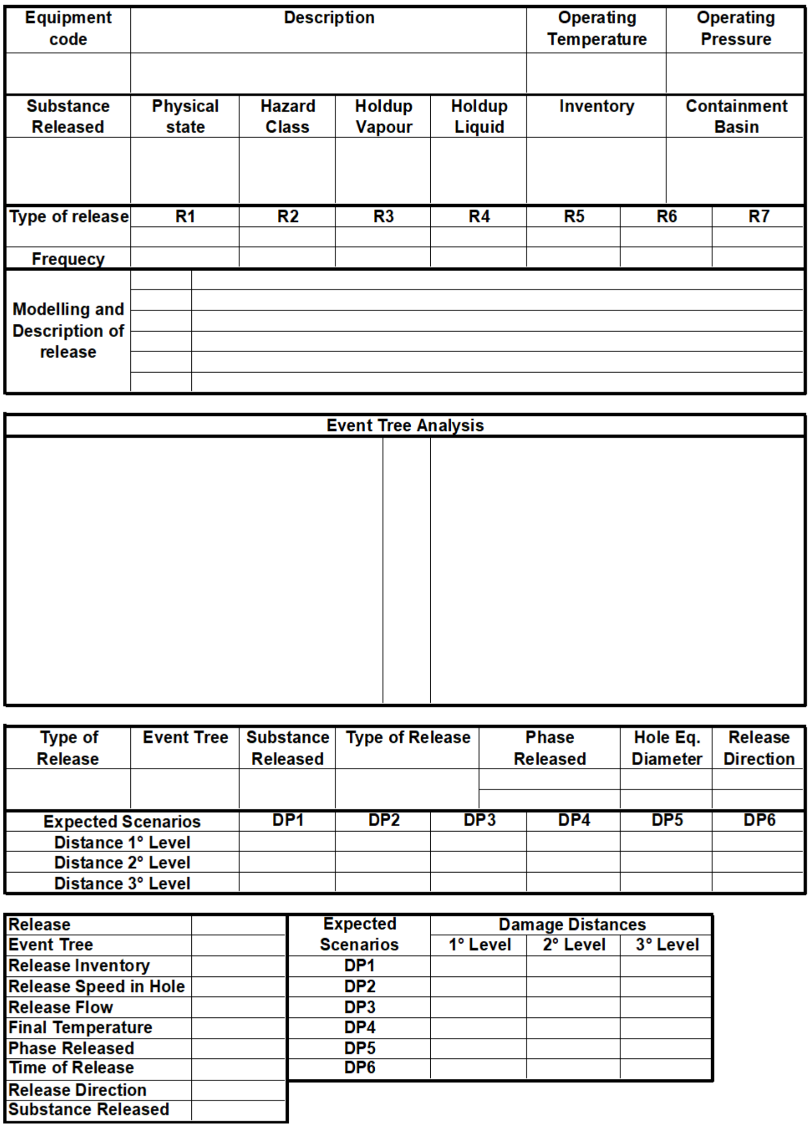
2.3.1 Equipment datasheet

In order to support data gathering and communication of either managerial or technical data associated with each piece of equipment, DI3D collects all the available data from the field and the results of hazard assessment creating a summary equipment sheet. The latter represents the fingerprint of the piece of equipment under consideration and is displayed in the tool graphical interface by clicking on the process units in the 3D interactive map of the plant.

Information reported in the sheet are a summary of:

- Type of equipment and operation performed;
- Characteristics of the substances involved (physical state, hold-up and hazard class)
- Release types and associated frequencies;
- Expected scenarios and related damage distances.

In Figure 2 the typical equipment summary sheet is shown, as displayed in the DI3D software.



Equipment code	Description	Operating Temperature	Operating Pressure

Substance Released	Physical state	Hazard Class	Holdup Vapour	Holdup Liquid	Inventory	Containment Basin

Type of release	R1	R2	R3	R4	R5	R6	R7
Frequecy							

Modelling and Description of release		

Event Tree Analysis		

Type of Release	Event Tree	Substance Released	Type of Release	Phase Released	Hole Eq. Diameter	Release Direction

Expected Scenarios	DP1	DP2	DP3	DP4	DP5	DP6
Distance 1° Level						
Distance 2° Level						
Distance 3° Level						

Release	
Event Tree	
Release Inventory	
Release Speed in Hole	
Release Flow	
Final Temperature	
Phase Released	
Time of Release	
Release Direction	
Substance Released	

Expected Scenarios	Damage Distances		
	1° Level	2° Level	3° Level
DP1			
DP2			
DP3			
DP4			
DP5			
DP6			

Figure 2. Example of the summary equipment sheet displayed in the graphical interface of DI3D.

2.3.2 Real- time hazard assessment module

The main innovation introduced by the software is the capability to perform real-time hazard assessment. This can be done adopted the simplified standard LOC assessment described in Section 2.2 or even imposing predetermined failure conditions. In fact, in Seveso installation, the safety report including the results of QRA is normally available (EU 2012). Thus, in this case, all the equipment in which dangerous substances are present in quantities more than the threshold quantities listed by the directive have been already identified and analysed, so it is possible to implement in DI3D all credible scenarios related to the process units of concern. However, studying all the possible scenarios in all the weather and operating conditions is normally not shown in the safety report, picturing a static representation of accident scenarios, typically adopting worst case or average conditions.

The aim of DI3D, instead, is to provide real-time monitoring of accidental scenarios evolution of consequences over time and space. The core of this feature is linked to plant data acquisition and elaboration. In this framework, the main input data processed by the software are:

- Real-time operating condition of process unit (temperature, pressure, hold up)
- Identification of credible scenarios;
- Real-time wind speed and solar radiation evaluating atmospheric stability and, thus, physical effects;
- Real-time wind direction predicting consequences and, thus, damage distances evolution over space.

It should be considered that there are some limitations in this approach, due to the adoption of simple models, either semi-empirical or integral, for the estimation of physical effects. Since they are lumped models, accuracy limits are present in the far field making the 3D evolution of consequences consistent in a limited distance range. Moreover, it is not possible to model the presence of obstacles which can modify the physical effects following a loss of containment.

3. Definition of case studies

In order to evaluate the software capabilities, the new features implemented in DI3D are tested through the application to industrial case studies located in an Italian industrial plant.

3.1 Input data

The reference substances identified for the industrial case studies are: ammonia (flammable and toxic substance), methane (flammable substance), and chlorine (toxic substance). For the case studies, common storage conditions of the reference substance are considered, in particular: methane is in cryogenic conditions (saturated liquid at 1.01 bar); ammonia and chlorine are liquefied pressurized gases at 20°C storage temperature.

The same reference equipment is considered for the three substances, in particular a horizontal vessel with diameter and height equal to 2 m and 4.5 m, respectively. It is assumed that around the tank there is a containment basin of 5 m in length and 2.4 m wide. The failure of the tank is assumed to occur in the top space, thus leading to the release of a vapor phase in the atmosphere.

3.2 Failure modes and LOCs

Following the approach shown in Section 2, the piece of equipment considered is classified according to the taxonomy shown in Table 1. Thus, the tank is classified as “vessel” for all the case studies and the sub-category is “atmospheric” for the methane cryogenic storage, and “pressurized” for all the other cases.

The standard literature failure modes and LOCs are considered for “vessel”-type units (Uijt de Haag & Ale, 1999), namely:

- R1: Instantaneous release of the complete inventory;
- R2: Continuous release of the complete inventory in 10 min at a constant rate of release;
- R3: Continuous release from a hole with an effective diameter of 10 mm.

Then, the following credible scenarios are considered for the event tree analysis:

- Fireball (instantaneous release only);
- Jet- Fire (continuous release only);
- Vapour Cloud Explosion, VCE;
- Flash Fire;
- Toxic dispersion.

The two latter scenarios were analysed in detail in the case study.

3.3 Physical effects and summary of simulations

The physical effects modelled for the case studies are the dispersion events. Physical effects of dispersion are linked to hazardous properties of substances. Methodology sets the reference thresholds for the evaluation of physical effects equal to those reported in Table 2. Table 3 shows a summary of the case studies simulated through DI3D in this analysis.

Table 3. Summary of the case studies and related dispersion models. Model details are reported (Uijt de Haag & Ale 1999, Lees 1996). Meteorological and environmental data integrated in the case studies are also reported, assuming fixed conditions.

ID	Substance	Release scenario	Dispersion Model	Meteorological & Environmental Input
1	Methane - gaseous	Continuous release	Free-Jet	Unrelated
2	Ammonia	Continuous release + Passive dispersion	Briggs + GPM	Wind speed = 5 m/s Stability class = D
3	Chlorine	Continuous release + Passive dispersion	HMP + Slab	Wind speed = 1 m/s Stability class = D
4	Methane - cryogenic	Instantaneous release + Pool evaporation + Passive dispersion	HMP + Slab	Wind speed = 1.92 m/s Monin & Obukhov length = 0.0665 1/m Soil roughness = 0.0002 m

4. Results of case studies

In this section, examples of results obtained through the application of the tool to case studies are reported. Frequency and credible scenarios evaluation, together with captions of the 3D interactive map implemented in the software, are reported in the following.

4.1 Results of credible scenarios evaluation

Figure 3 shows an example of results derived from the procedure for the identification of the expected scenarios. The latter are referred to the accidental releases identified in Section 3. In particular, the analysis of R1 release event is shown graphically through the related event tree, and the final frequency calculated for each scenario are also reported. Figure 3 provides the typical representation associated with the equipment datasheet taken from the software.

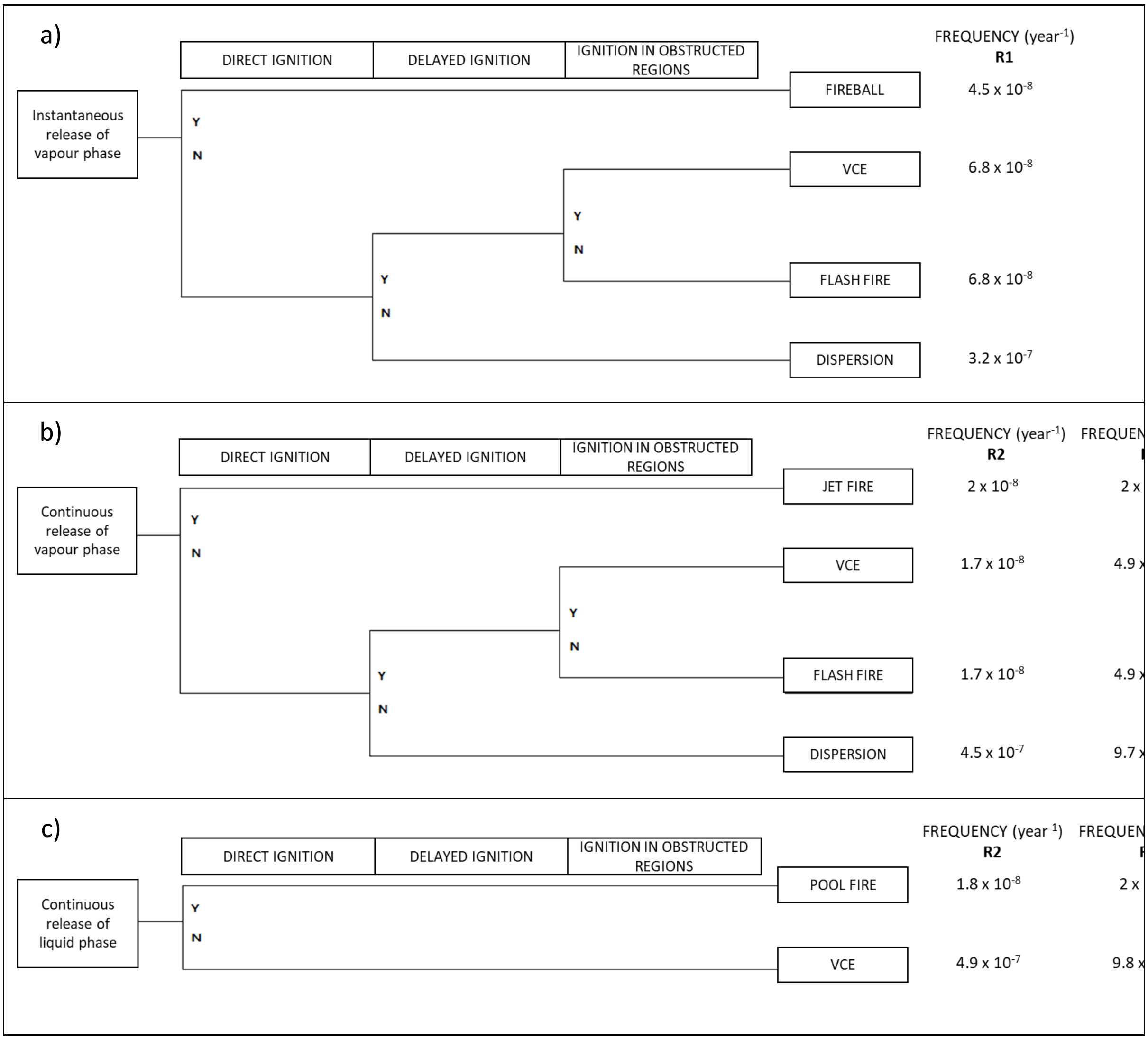


Figure 3. Example of event tree analysis for the a) instantaneous release of vapour phase, and the continuous release of b) vapour phase, and c) liquid phase; R1, R2, and R2 in the LOCs definition, respectively. Frequencies of each scenario are reported on the right side of figures.

4.2 Results of graphical implementation

The 3D map of the plant implemented in the software for the case studies and the results of the risk assessment module are reported in the Figure 4 for the case studies identified in Table 3.

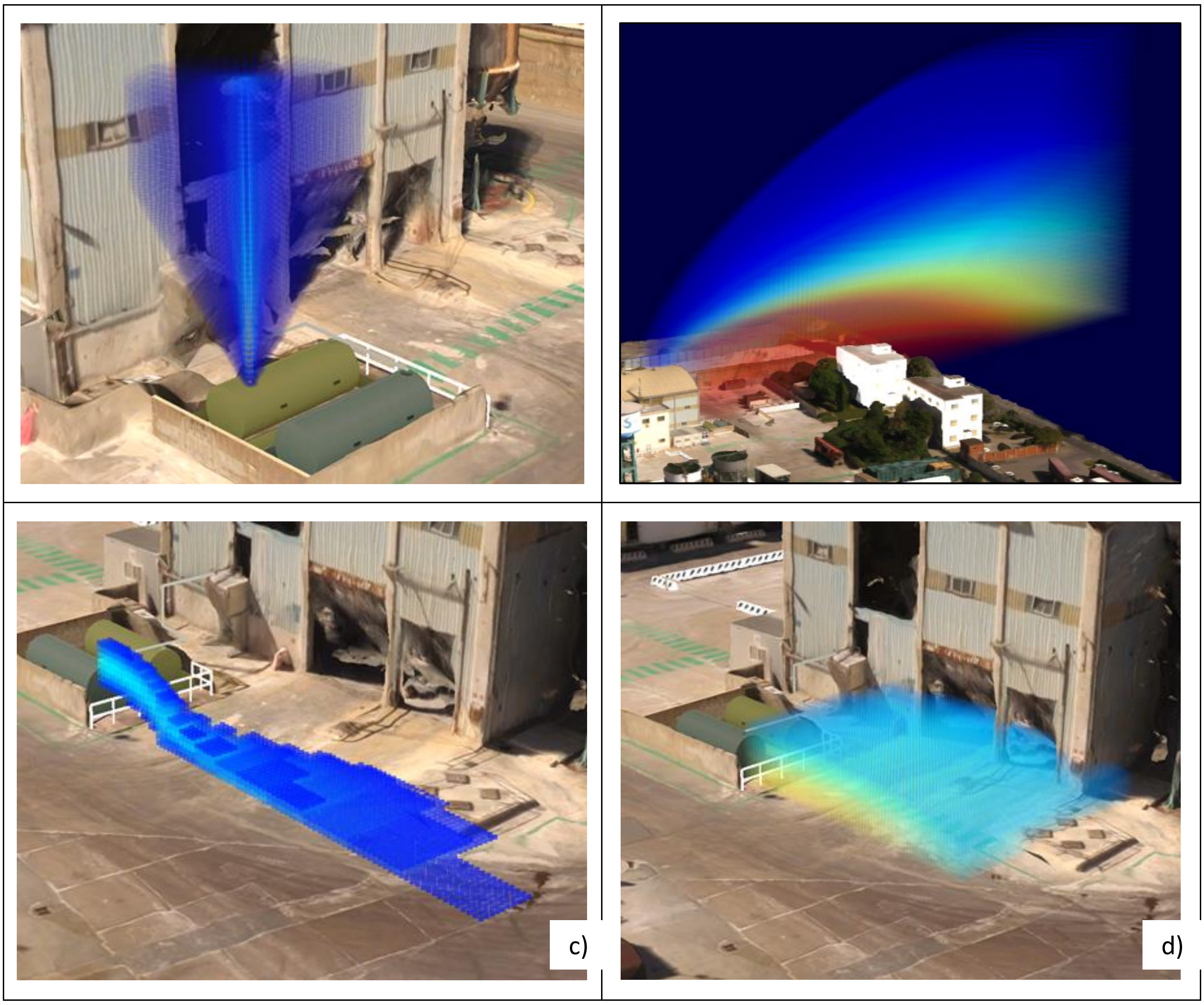


Figure 4. Graphical results of the risk assessment module implemented in the DI3D for the case studies identified in Table 3. The panels show the outcomes of continuous release of a) methane in gaseous state, b) ammonia, c) chlorine; and d) the pool evaporation of methane in cryogenic state. Value of concentration: a) UFL@4 m; LFL@12 m; max_width@LFL = 0.8 m max_width@UFL = 0.2 m; b) IDLH@1m = 125 m; c) IDLH@1m = 2360 m; d) puff_width@LFL = 22.5 m

5. Discussion

The aim of the work was to enhance the capabilities of an existing tool for the management of industrial facilities. Software improvement was carried out implementing a module for hazard assessment able to collect and elaborate both equipment and meteorological data in real-time. The main innovation introduced in the tool is thus related to the support of HSE management, through the 3D interactive interface and the real-time simulation of accidental events. This feature aims to support active emergency planning, concerning also real-time virtual emergency training. Furthermore, in case of authorities' inspection, the evolution of all expected scenarios can be displayed in the interactive map enabling for risk and hazard awareness.

However, limitations can be found in software modelling. In general, the software is based on simplified models for calculations of physical effects, which are less accurate than more complex models, such as those implemented in the CFD and, more in general, in distributed parameters tools. Therefore, results are not accurate in the near field and are on the safe side, without accounting for the presence of obstacles in congested plant situations. The advantages of the simplified models are in the reduced computational costs with reliable results in the far-field. Moreover, modelling loss of containments through standard failure data and other assumptions (such as release direction, hole diameter, etc.) introduces additional uncertain in the simulations. Besides, the physical effects currently implemented in the tool are limited to dispersions events. Thus, the risk assessment module needs to be extended to all accidental scenarios involving fire and / or explosions.

Another limiting point is related to the potential receptiveness of Companies, which is linked to economical and sharing issues of the tool. Firstly, costs related to drone inspection and to software installation have to be taken into account for the DI3D implementation in a given facility. Then, Companies have to interface with the tool's manufacturer providing process flow diagrams, connections to control systems, documentations, technical information, etc. It is not uncommon for Companies to have uncomplete or partial data, thus, the software may not have all the requested information and supplementary approximations should be done to cover the gaps.

Finally, it is worth mentioning that the tool has the advantage of being open to any customer implementations, making the above listed benefit only a part of the software's potential.

6. Conclusions

The present work shows an innovative three-dimensional tool aimed at supporting the management of HSE issues in major accident installation. The software tool, namely DI3D, is provided with a hazard assessment module able to calculate in real time consequences of accidental releases and to plot the evolution of the event over time and space on a 3D interactive map of the considered industrial facility. Results of validation and case studies showed the ability of the software to constantly monitor the atmospheric stability and to simulate in real-time the accidental event evolution. All this information can be useful both for the management of internal evacuation procedures, and for communication to public authorities, especially in cases of emergency where the promptness of information collection is essential.

7. References

Ale, B., van Gulijk, C., Hanea, A., Hanea, D., Hudson, P., Lin, P.-H., Sillem, S., 2014. Towards BBN based risk modelling of process plants. Saf. Sci. 69, 48–56. doi:10.1016/j.ssci.2013.12.007

API - American Petroleum Institute, 2000, Risk-bases inspection base resource document. 1st ed. API publication 581.

Attwood, D., Khan, F., Veitch, B., 2006. Occupational accident models-Where have we been and where are we going? J. Loss Prev. Process Ind. 19, 664–682. doi:10.1016/j.jlp.2006.02.001

Bouet R., 2015, Ammonia - Large-scale atmospheric dispersion tests, INERIS - Accident Risks Division, Work study 20/12/2005 N° 10072.

Briggs, G.A, 1969, "Plume rise", U.S. Atomic Energy Commission Report TID-25075.

Chemical Controls SRL, 2017. Available online at: http://www.datachtechnologies.it/prodotti-software/hacpack-pts-work-3d/?lang=en.

Chen, C.J. and Rodi, W., 1980, "Vertical turbulent buoyant jets", Pergamon Press, Oxford.

Davidson, G.A., 1989, "Simultaneous trajectory and dilution predictions from a simple integral plume model", Atmospheric Environment 23, 341.

Delvosalle C., Fievez C., Pipart A., Debray B., 2006, ARAMIS project: A comprehensive methodology for the identification of reference accident scenarios in process industries. J of Hazardous Materials 130, 200–219.

Ermark, D.L.,1990, "SLAB User's Guide", U.S. ENVIRONMENTAL PROTECTION AGENCY Office of Air and Radiation Office of Air Quality Planning and Standards Research Triangle Park, NC 27711

EU (European Union). 2012. Council Directive 18/2012/EU of 4 of July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC. OJ L 197/1.

Ferziger JH, Peric M. Computational methods for fluid dynamics. Berlin, Germany: Springer-Verlag; 2002.

Golder, D., 1972, Relations among stability parameters in the surface layer. Boundary-Layer Met. n. 3, 47-58.

Griffin, M.A., Hodkiewicz, M.R., Dunster, J., Kanse, L., Parkes, K.R., Finnerty, D., Cordery, J.L., Unsworth, K.L., 2014. A conceptual framework and practical guide for assessing fitness-to-operate in the offshore oil and gas industry. Accid. Anal. Prev. 68, 156–171. doi:10.1016/j.aap.2013.12.005

Hanna S.R., Briggs G.A. en Hosker Jr. R.P., 1982, "Handbook of Atmospheric Diffusion", DOE/TIC-11223 (DE 82002045).

Haugen D. A., 1959, Project Prairie Grass, A field program in diffusion. Air Force Cambridge Research Center, Geophysical Research Paper n. 59 AFCTLC-TR-58-235.

Hoot, T.G., Meroney, R.N. and Peterka, J.A., 1973, "Wind tunnel tests of negatively buoyant plumes", NTIS Report PB-231-590.

ISPRA-APAT 2006 Handbooks and guidelines 35/2006 ISBN: 88-448-0159-0 Shortcut Method to assess incidental consequenceshttp://www.isprambiente.gov.it/en/publications/handbooks-and-guidelines/shortcut-method-to-assess-incidental-consequences

Kagermann H., Lukas W.D., Wahlster W., 2011, Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution. Ausgabe Nr. 13/2011.

Kagermann H., Wahlster W., Helbig J., 2012, Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0 Abschlussbericht des Arbeitskreises Industrie 4.0, Vorabversion Forschungsunion Wirtschaft und Wissenschaft. Deutschlands Zukunft als Produktionsstandort sichern.

Kalantarnia, M., Khan, F., Hawboldt, K., 2009. Dynamic risk assessment using failure assessment and Bayesian theory. J. Loss Prev. Process Ind. 22, 600–606.

Koopman R.P., Cederwall R.T., Ermak D.L., Goldwire H.C.Jr., Hogan W.J., McClure J.W., McCrae T.G., Morgan D.L., Rodean H.C., Shinn J.H., 1982. Analysis of Burro series 40 m3 LNG spill experiments. J Haz Mats. 6, pp 43 – 83.

Lees F.P., 1996, Loss Prevention in the Process Industries. 2nd ed. Oxford, UK: Butterworth-Heinemann.

Paltrinieri, N., Oien, K., Cozzani, V., 2012. Assessment and comparison of two early warning indicator methods in the perspective of prevention of atypical accident scenarios. Reliab. Eng. Syst. Saf. 108, 21–31. doi:10.1016/j.ress.2012.06.017

Picconi L., Landucci G., Chiavistelli T. 2016. Chemical-controls internal report CC1701-threedimensional consequence assessment (in Italian).

Pitblado, R.M., Williams, J.C., Slater, D.H., 1990. Quantitative assessment of process safety programs. Plant/Operations Prog. 9, 169–175.

Reniers, G., Cozzani, V., 2013. Features of Escalation Scenarios, in: Domino Effects in the Process Industries: Modelling, Prevention and Managing. Elsevier B.V., Amsterdam, The Netherlands, pp. 30–42.

Schmidt J. 2012. Process and Plant Safety: Applying Computational Fluid Dynamics. Berlin, Germany: WILEY-VCH Verlag.

Tanabe M., Turco C., 2016, Technical-HSE management system in the design phase of an LNG plant project, Chemical Engineering Transactions, 48, 541-546 DOI:10.3303/CET1648091

Tugnoli A., Cozzani V., Landucci G., 2007, A Consequence Based Approach to the Quantitative Assessment of Inherent Safety. Wiley InterScience, AIChE Journal Vol. 53, No. 12, 3171-3182.

Uijt de Haag P.A.M., Ale B.J.M., 1999, Guidelines for Quantitative Risk Assessment (Purple Book). The Hague, The Netherlands: Committee for the Prevention of Disasters.

Van Den Bosh, C.J.H. & Weterings, R.A.P.M. 2005. Methods for the calculation of physical effects (Yellow Book), 3rd ed. The Hague (The Netherlands): Committee for the Prevention of Disasters.

Vinnem, J.E., Bye, R., Gran, B. a., Kongsvik, T., Nyheim, O.M., Okstad, E.H., Seljelid, J., Vatn, J., 2012. Risk modelling of maintenance work on major process equipment on offshore petroleum installations. J. Loss Prev. Process Ind. 25, 274–292. doi:10.1016/j.jlp.2011.11.001