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DyPASI Methodology: from Information Retrieval to Integration of HAZID Process

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The availability of hazard identification methodologies based on early warnings is a crucial factor in the prevention of major accidents. Accidents like Seveso, Buncefield and Toulouse, where severe consequences occurred seemingly unexpected by the plant safety management, have made it clear that a comprehensive and complete identification and assessment of potential hazards in the process industry are of primary importance for the prevention and the mitigation of accident scenarios. The accident scenarios deviating from normal expectations of unwanted events or worst-case reference scenarios captured by common HAZard IDentification (HAZID) techniques are usually defined as “atypical”. The main issue posed by the prevention of atypical scenarios is the availability of techniques able to identify them within a routine HAZID process, capturing evidence of new hazards and learning from ‘early warnings’ as soon as they come to light. For this reason a specific method named Dynamic Procedure for Atypical Scenarios Identification (DyPASI) was developed. The method was conceived as a development of conventional bow-tie identification techniques. DyPASI is a method for the continuous systematization of information from early signals of risk related to past events. It dynamically integrates in the bow-ties the results of information retrieval activities. DyPASI features as a tool to support emerging risk management process, having the potentiality to contribute to an integrated approach aimed at breaking “vicious circles”, helping to trigger a gradual process of identification and assimilation of previously unrecognized atypical scenarios. The current contribution presents the technique and demonstrates the application by a selected case-study of practical application (Toulouse AZF accident, Buncefield oil depot accident, LNG regasification terminal, CCS plant).

1. Introduction

Comprehensive and complete identification and assessment of potential hazards in the process industry are of primary importance for the prevention and the mitigation of “atypical” accident scenarios, which are not captured by conventional HAZID techniques because deviating from normal expectations of unwanted events or worst-case reference scenarios (Paltrinieri and Wardman, 2010, Paltrinieri et al., 2012a). What remains unidentified cannot be prevented: a latent risk is probably more dangerous than a recognized one due to the relative lack of mitigation measures and emergency preparedness.

Several European Directives pressed industry towards the development and the extended use of structured HAZID techniques as e.g. hazard operability analysis (HazOp). In particular, the “Seveso” Directives and the following amendment (Directives 82/501/EEC, 96/82/EC, and 2003/105/EC) concerning the control of major-accident hazards involving dangerous substances, require issuing a comprehensive “safety report” for all installations falling under the obligations of the Directives. Within the safety report, the systematic identification and assessment of possible accident scenarios is required (Papadakis and Amendola, 1997). However, despite the measures taken, atypical accidents are still occurring, e.g. the

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Buncefield, Toulouse and Viareggio accidents (Dechy and Mouilleau, 2004, MIIB 2008, Landucci et al., 2011, Pontiggia et al., 2011). Several extensive reviews of available HAZID techniques are available in literature. For instance, the review carried out by Glossop, et al. (2005) describes more than 40 HAZID methods, but none of them seems to cover the issue of accident scenarios falling out of normal expectations of unwanted events and their dynamical integration into HAZID process.
The main issue posed by the prevention of atypical scenarios is the availability of methods able to identify the possibility of such events within a routine HAZID process, capturing evidence of new hazards and learning from early warnings as soon as they come to light. For this reason a specific method named Dynamic Procedure for Atypical Scenarios Identification (DyPASI) was developed.

2. Examples of atypical scenarios

Two significant examples of "atypical" accident scenarios occurred in the EU are those that took place at Toulouse and Buncefield, respectively in 2001 and 2005. The explosion at the "off-specifications" Ammonium Nitrate (AN) warehouse of the nitrogen fertiliser factory AZF (Grande Paroisse) at Toulouse caused 30 fatalities and €1.5 billion in damages. However, the worst scenario considered by the safety report of the site was an AN storage fire (Dechy and Mouilleau, 2004). At the oil depot of Buncefield a Vapour Cloud Explosion caused £1 billion of damage but fortunately no fatalities (MIIB 2008). In this case the worst scenario considered in the HAZID process was a low severity gasoline pool fire. Thus, in both cases, the accident scenarios that took place were not considered by the safety report of the site.
These two accidents had been anticipated by several similar past accidents: many severe AN explosions occurred between 90 to 60 years ago, and VCEs involving gasoline and light hydrocarbon fuels occurred in oil depots on average every 5 years since mid 1960 (Paltrinieri et al., 2012a, 2012b). Furthermore, after 2005 two other similar VCE explosions took place within a few days one from each other: in Bayamón (Puerto Rico) on October 23rd 2009 (US CSB 2009) and in Jaipur (India) on October 29th 2009 (MoPNG 2010). This highlights that early warnings are not always considered, and notions coming from past accidents may not be considered in daily activity concerning hazard identification.
A different type of latent risk can be represented by the accident scenarios related to new and emerging technologies. When new technologies are implemented, the potential for specific accident scenarios may still need to be properly identified, and may remain unidentified until an accident or a near miss takes place for the first time. Examples of new and emerging technologies can be found within the fields of Liquefied Natural Gas (LNG) regasification and Carbon Capture and Storage (Paltrinieri et al., 2011). New and alternative technologies are implemented for these processes, and the scale and extent of substance handling is set to increase dramatically worldwide. Thus, a lack of substantial operational experience may lead to difficulties in identifying accurately the hazards associated with the process. Hence, these new and emerging hazards may comply with the definition of "atypical" scenarios previously discussed.
The HAZID process is an important part of risk management, as no action can be made to avoid, or mitigate, the risk deriving from unidentified hazards. The HAZID process also has a large potential for human error, with little or no feedback pertaining to those errors. The aforementioned 'atypical accidents' are the severe feedback of such errors made. The availability of a HAZID methodology based on early warnings was recognized as a crucial factor in the identification of emerging risks.

3. Methodology

DyPASI is a HAZID method aiming at the systematization of information from early signals of risk related to past accident events, near misses and risk studies (Table 1). It supports the identification and the assessment of atypical potential accident scenarios related to the substances, the equipment and the industrial site considered. DyPASI is one of the results of the European Commission FP7 iNTeg-Risk project (Paltrinieri and Wardman, 2010), which addresses the management of emerging risks, identified as one of the major problems for the competitiveness of industry.
The application of DyPASI entails a systematic screening process that, based on early warnings and risk notions, should be able to identify possible Atypical Scenarios or Unknown Knowns available at the time of the analysis. The well-established approach of the bow-tie analysis, which aims at the identification of all the potential major accident scenarios occurring in a process industry, was taken as a basis to develop the methodology (step 0 - Table 1). Moreover, the method can be coupled with appropriate Key Performance Indicators (KPI), in order to monitor the quality of results (Paltrinieri et al., 2012c; Tugnoli et al., 2012).

Table 1: DyPASI steps (Paltrinieri et al. 2013)

Step	Description
0	DyPASI is a development of the bow-tie technique, which, by itself, is a qualitative hazard evaluation technique ideally suited for the initial analysis of an existing process or application during the intermediate stages of process design (CCPS 2008). Thus, as a preliminary activity (step 0) DyPASI requires the application of the conventional bow-tie technique to identify the relevant critical events. This can be performed following conventional guidelines as those outlined by the Centre for Chemical Process Safety (CCPS 2008) or the MIMAH tool (Methodology for the Identification of Major Accident Hazards) can be applied (Delvosalle et al., 2006).
1	In the first step of DyPASI application, a search for relevant information concerning undetected potential hazards and accident scenarios that may not have been considered in conventional bow-tie development is carried out. It can be summarized in 3 steps (Baeza-Yates and Ribeiro-Neto, 1999): - Definition of the information need and search systems to search on - Formulation of a query to send to the search system - Assessment of the relevance of results Search boundaries must be outlined and quoted in the formulation of the query, in the combination and number the analyst considers more appropriate. Examples of search boundaries used in queries are: the site, the process, the equipment, the substance, and the substance state.
2	Once the necessary information is gathered, a determination is made as to whether the data are significant enough to trigger further action and proceed with the process of risk assessment. As a support of this process of prioritization, a register collecting the risk notions obtained from the retrieval process and showing their relative relevance and impact can be obtained. Possible consequences can be determined on the basis of the risk notions and ranked by means of the following scale of severity levels: 1-near miss, 2-mishap, 3-incident, 4-accident, and 5-disaster.
3	In this step the potential scenarios are isolated from the early warnings gathered and a cause-consequence chain consistent with the bow-tie diagram is developed. This allows for the integration of the pattern of the atypical scenario the bow-tie of hazards previously identified at step 0. The process of integration of an atypical scenario in a bow-tie diagram may be obtained by a specific methodology based on set theory. The approach is able to ensure complete and concise results, without the need to re-develop a HAZID study from the beginning.
4	The definition of safety measures applied to the elements of bow-tie diagrams is the last step of the DyPASI procedure. Past experience concerning the effectiveness and performance of safety barriers may be encompassed in the analysis. The integrated bow-tie diagrams including the atypical scenarios should be completed considering safety barriers, classified by their effectiveness. Safety barriers properly acting at the moment of past accidents should be marked in green. Green colour is also applied to effective safety barriers in the case of near-misses. Safety barriers that showed deficiencies in at least one past accident are marked in orange. New potential, and hopefully more effective, safety barriers identified are represented using the red colour. This activity can also provide important elements for the risk mitigation process in the decision making phase of risk management.

4. Results and discussion

In order to allow a more comprehensive discussion of the methodology, some results obtained from the application of DyPASI to the examples of atypical scenarios described in section 2 are reported in Table 2. The past events reported in the table provide an example of application of step 1 of DyPASI (see Table 1). The following search systems were interrogated: MHIDAS, ARIA, Google Scholar and SciVerse Scopus. Specific search boundaries were defined according to the specific case. For example in the study of the Buncefield oil depot, the search boundaries included: oil depot, atmospheric storage, tank, gasoline, and liquid. A number of studies and past events were found, some of which are reported in the table. The risk notions found for LNG regasification and CCS technologies demonstrate the potential of DyPASI to support the emerging risk management process.

An example of outcome of the prioritization step (step 2 of Table 1), is reported in Table 3. In the example, DyPASI was applied to a generic case gasoline storage tank in an oil depot falling under the Seveso II regulation (Directive 96/82/EC), which is a critic case for several reasons. The prioritization was performed on the basis of the relevance and impact of the data collected. Each item was compared with the characteristics of the case of interest in order to assess its relevance and was given a severity level in order to identify its impact. In this specific case prioritization was carried out mainly on the basis of impact, since no important difference in relevance could be identified among the results of the search. In fact the technology analyzed is well-know and can be effectively described by the few words used as search boundaries. However, in the case of new technologies the aspect of relevance assumes more importance and must be carefully taken into account. High priority was given to the past events and the studies about VCEs in oil depots (for this reason such items are shown first in Table 2), because they caused and can still potentially cause disasters until are considered in HAZID process and effectively prevented. High priority was given also to natural events, which can range from lightning and flooding to earthquake and tsunami. In this case the severity level is defined on the basis of the earthquake and the subsequent tsunami that destroyed the storage facility of the Sendai refinery (Japan) on 11th March 2011 (ARIA 2012). A previous earthquake (21st June 1978) had already damaged the tanks of that oil depot (ARIA 2012) and such a combination of earthquake and tsunami had been recorded at least twice in that area in history (NOAA 2012). Also flooding proved effective in damaging or buckling atmospheric storage tanks, leading to multiple releases, which may be are particularly critical in environmentally sensitive areas (Landucci et al., 2012). This highlights the importance of early warnings relevant to the specific site analyzed. This is demonstrated also by the events related to malicious interference: most of them occurred in hot areas for terrorism, such as Corinto (Nicaragua, Sandinista rebel attack against an oil depot in 1983), Chechnya (bomb in an oil depot in 1994) and Aden (South Yemen, terrorist attack in 1994) (MHIDAS, 2003). Thus, considering that sites handling dangerous sites, such as Seveso sites, were identified as potential targets of terrorist attacks after the 9/11 events (Reniers, 2012), the category of malicious interference was considered of high priority. Finally, fires, tank fires, generic explosions, catastrophic ruptures, leaks, spills and overfillings are the most frequent events, even if in general relatively less severe.

The prioritization in the table is not intended to replace consequence analysis: in fact, it is simplified and deliberately not exhaustive because the impact should be primary inferred on the basis of the notions collected. It is well known as operative conditions, together with equipment and layout design pay also a major role in the definition of severity of accident consequences (Tugnoli et al., 2008).

The example reported in Figure 1 refers to an ammonium nitrate storage warehouse, similar to the one involved in the Toulouse AZF accident. In particular, the fault tree part shows as possible design, procedural and human errors may lead to detonation of the stored material. These branches are not present in conventional bow-ties concerning fertilizer storage, as those obtained by MIMAH (Delvosalle et al., 2006). Other diagrams, not reported for the sake of brevity, focus on different modalities of external interference (such as natural events, terrorist attack) that were found to be relevant.

Table 2: Examples of DyPASI results from risk notion retrieval (Paltrinieri et al., 2013)

	Toulouse AZF	**Buncefield oil depot**	**LNG regasification**	**CCS technologies**
Risk notions	*Similar events:* - Oppau, Germany 1921. - Texas City, Texas, USA 1947. - Brest, France 1947. - Red Sea, on the Italian cargo ship Tirrenia 1954.	*Similar events:* - Houston TX, USA 1962. - Baytown TX, USA 1977. - Newark NJ, USA 1983. - Naples, Italy 1985. - St Herblain, France 1991. - Jacksonville FL, USA 1993. - Laem Chabang, Thailand 1999. - Jaipur, India 2009. - San Juan Bay, Puerto Rico 2009.	*Events of RPT:* - LNG Import Terminal, UK 1965. - LNG Import Terminal, UK 197. - LNG export facility, Algeria 1977. - LNG export facility Indonesia 1993. - LNG Import Terminal France 1995. *Event of cryogenic burn:* - Arzew, Algeria 1977. *LNG asphyxiation is treated in SNL, 2004.*	*CO_2 events (as fire suppressant)*: - 62 incidents, worldwide, before 2000 *Pipeline events:* - 39 incidents, USA, 1986 – 2008 *Natural CO_2 releases:* - Dieng Volcano, Indonesia 1979 - Lake Monoun, Cameroon, 1984 - Lake Nyos, Cameroon, 1986

Table 3: Examples of prioritization of risk notions: gasoline storage tanks in oil depots. For the sake of brevity the pieces of information collected are grouped on the basis of the event typology. The following search systems were used: MHIDAS, ARIA, Google Scholar, SciVerse Scopus (Paltrinieri, et al., 2013)

	Event typology	No. of records found	Severity
1	Vapour Cloud Explosion	10	Disaster
2	Natural events	6	Disaster
3	Malicious intervention	6	Accident
4	Fire, tank fire, explosion	30	Incident
5	Catastrophic rupture, leak, spill, overfilling	27	Mishap

Finally step 4 allowed defining safety barriers for the atypical scenarios identified. Figure 1 shows some examples of the safety barriers that failed in the past events considered for the study (in orange), such as poor training, failing level control and lack of inspection, security and emergency preparedness. Safety barriers identified as successful in past events would have been reported in green. Finally, new safety barriers that may effectively mitigate the related risk, which were suggested by the studies collected as risk notions, are highlighted in red. This specific step of DyPASI provides a further chance to include past experience in the prevention of atypical scenarios.

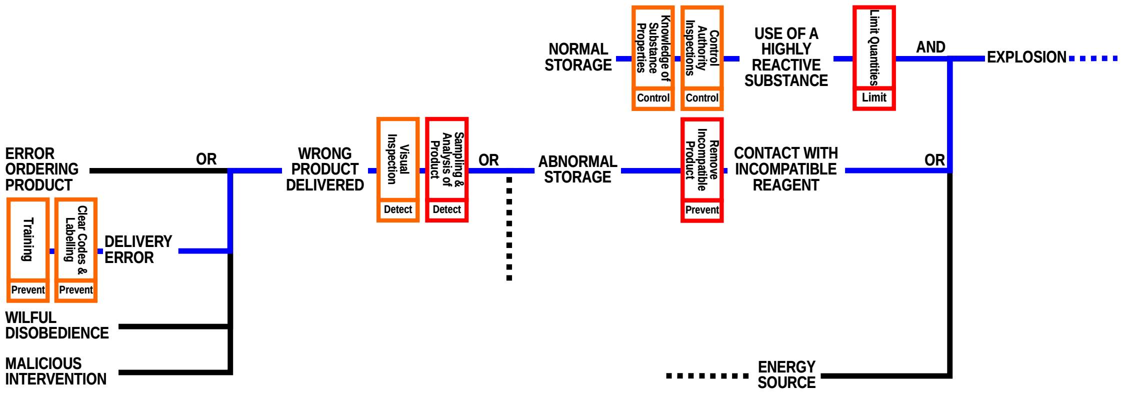

Figure 1: Bow-tie diagram referring to ammonium nitrate explosion in a warehouse (a similar scenario occurred in the Toulouse AZF accident).

5. Conclusions

The availability of hazard identification methodologies based on early warnings is a crucial factor in the prevention of major accidents. The DyPASI method was conceived as a method for the continuous systematization of information from early signals of risk related to past events. It dynamically integrates in the bow-ties the results of information retrieval activities. The DyPASI methodology was built in the effort of mitigating deficiencies of the current HAZID techniques in the identification of unexpected potential hazards related to atypical scenarios and integration of the recommendations from past atypical accidents. The main aim of the methodology is to provide an easier but comprehensive hazard identification of the industrial process analysed. The principal features of DyPASI are its dynamic and systematic nature and the enhancement of the knowledge management. DyPASI features as a tool to support emerging risk management process, having the potentiality to contribute to an integrated approach aimed at breaking “vicious circles”, helping to trigger a gradual process of identification and assimilation of previously unrecognized atypical scenarios. The application of DyPASI in the presented case studies (Toulouse AZF accident, Buncefield oil depot accident, LNG regasification terminal, CCS plant) provided a practical demonstration of these features.

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