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# Prevention of atypical accident scenarios through the use of resilience based early warning indicators

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ABSTRACT: An "atypical" accident scenario is a scenario deviating from normal expectations and, thus, not deemed credible by common processes of risk assessment. Past experience shows that non identified accident scenarios as such represent a latent risk for industry and society and sometimes their occurrence can lead to consequences of unexpected extent. An evident example of an atypical accident was the major accident occurred at Buncefield on 11th December 2005. A detailed analysis of this and other cases in literature has shed some light on the complexity of their causal factors, demonstrating that an atypical major accident is not the consequence of a single uncommon event, but rather the result of a series of failures at different levels of risk management. Thus, it has been a major challenge to foresee combinations of such failures and corresponding unidentified accident scenarios. Two complementary approaches to deal with this challenge are: i) improved identification of atypical scenarios, to reduce the occurrence of unforeseen events; ii) improved early detection, to reduce the possibility of remaining unforeseen events leading to an accident. For this reason the Resilience based Early Warning Indicator (REWI) method has been considered in this contribution. The main aim of this work is to show the preliminary results of the application of this method to the site at Buncefield, obtained by adapting the candidate set of REWI indicators to the oil depot characteristics and defining new indicators on the basis of the accident causes. In this way it has been also possible to understand the relevance of these resilience based indicators as early warnings of the atypical scenario and to demonstrate, by the correspondence of the defined indicators with the accident causes, that this major accident would have been likely prevented by the application of the REWI method.

## 1 INTRODUCTION

Within the EC project iNTeg-Risk, the issue of atypical accident scenarios has been tackled in order to outline a strategy to prevent major accidents not foreseen by common HAZard IDentification (HAZID) techniques (IR DoW, 2009). This study has produced detailed analyses of past atypical events (Atkinson et al., 2010, Paltrinieri & Wardman, 2010) and the development of a methodology to facilitate HAZID techniques in the challenging task of identifying atypical accident scenarios (Paltrinieri & Wardman, 2010).

Nevertheless, an improvement of HAZID process is a reactive approach that is unable to catch never experienced events about which there is no suitable information. There is then a need of a proactive technique acting on background conditions promoting atypical scenarios. Thus, the possibility of the remaining unforeseen events leading to an accident would be reduced. For this reason the Resilience based Early Warning Indicator (REWI) method has been considered in this contribution. In fact, the concept of resilience refers to the capability of recognizing, adapting to, and coping with the unexpected and one of its key characteristics is the interaction and interchange between different (organizational) system layers, levels, and focal points. The main aim of this work is to show the preliminary results of the application of this method to the site at Buncefield. A candidate set of resilience based early warning indicators are adapted taking into account characteristics of the oil depot. Then, the accident causes identified in the analysis are related to the indicators, in order to understand the relevance of these resilience based indicators as early warnings of the atypical accident scenario occurrence and to which extent this major accident could have been prevented.

## 2 THE MAJOR ACCIDENT AT BUNCEFIELD

### 2.1 *The atypical scenario occurring at Buncefield*

On 11th December 2005 an overfilling of unleaded petrol in one of the storage tanks at the Buncefield oil depot occurred. It was the result of a failure in both the automatic tank gauging system (ATG) and the independent high level switch (IHLS). It caused a release of over 250 000 litres of petrol that led to the formation of a flammable vapour cloud dispersing inside the plant and among the surrounding facilities. As soon as the vapour cloud came into contact with an ignition source (it is believed to have been in the fire pump house, in the generator cabin or from a car engine), a VCE (Vapour Cloud Explosion) of unexpected severity was generated. Fortunately there were no fatalities, but over 40 people were injured, large parts of the depot were destroyed, damage to surrounding property, and disruption to local communities were recorded (MIIB, 2008).

No scenario of this kind was foreseen by the compulsory Seveso II safety reports performed for the Buncefield site. In fact formation of a vapour cloud due to an overfilling and the consequent powerful VCE was not deemed possible, neither by the industry nor the competent authorities, to be taken into account. The worst credible scenario for this site was believed to be a major liquid fuel pool fire (MIIB, 2008).

According to EC project iNTeg-Risk, Paltrinieri et al. (2010) and Atkinson et al. (2010) the actual scenario occurring at Buncefield, can be defined as "atypical" because deviating from normal expectations of unwanted events or worst case reference scenarios and thus not captured by standard risk analysis processes and common HAZID techniques. As recent experience witnesses, atypical scenarios can have a large magnitude, but their low probability led to their neglection and minimisation because they were outside the model of possible realistic outcomes. (IR DoW, 2009). Thus, either they are new and never experienced issues or long standing issues never considered, there is a feature of emergence in them, such as there is, post-Buncefield, an emerging risk from apparently non-confined vapour cloud explosions at oil storage facilities.

Awareness is then a fundamental factor to properly manage the aspect of atypical events. The necessity of this factor can be easily described by Figure 1, which, applied to our case, shows that 4 different classes of events can be identified. The "Known Known" (we are aware we know) events, which can be generally assessed by current methodologies and on which there generally is a reasonable consensus. The "Known Unknown" (we are aware we do not know) events, which are events we do not know but recognize and to some extent define through the assumptions we make. Assessment based on these assumptions and/or precautionary actions can be performed for their prevention. The "Unknown Known" (we are not aware we know) events relate to how knowledge is disseminated and, in this case, how lessons from the past—own or other's experience—are not considered and learnt. To this end, Table 1 lists a series of VCEs in oil depots similar to Buncefield (MIIB, 2008) repeated since mid 1960, which demonstrate how a proper and complete knowledge management is hard to carry out. Finally the "Unknown Unknown" (we are not aware we do not know) events relate to the completely unexpected we currently ignore. These last 2 classes are characterized by a general lack of risk awareness and represent a dominant part of atypical events.

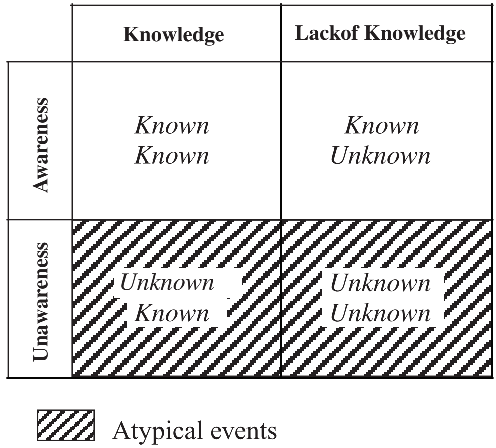


Figure 1. "Known/unknown" framework from the statement of Donald Rumsfeld relating to the absence of evidence linking the government of Iraq with the supply of weapons of mass destruction to terrorist groups (USDoD, 2002).

### 2.2 *Organizational aspects of the accident*

Paltrinieri et al. (2010), Atkinson et al. (2010) and COMAH CA (2011) in their analysis of the Buncefield accident have drawn a detailed picture of the accident and its direct and underlying causes. In fact, what emerges from those studies is that there were background conditions, which led to the occurrence of the atypical scenario, demonstrating that an atypical major accident is not the consequence of a single uncommon event, but rather the result of a series of failures at different levels of risk management.

Table 1. Main characteristics of the major accident occurred at Buncefield (MIIB, 2008).

| Major accident at the Buncefield oil storage depot | |
|---|---|
| Date | 11th December 2005 |
| Location | Buncefield oil storage and transfer depot<br>Hemel Hempstead, Hertfordshire, England |
| Major accident typology | Vapour Cloud Explosion and subsequent large multi-tank fire |
| Fatalities | None |
| Injured | 43 people |
| Damages | £1 billion |
| Worst scenario considered by Seveso II safety report | Large pool fire |
| Similar major accidents | Houston 1962<br>Baytown 1977<br>Newark 1983<br>Naples 1985<br>St Herblain 1991<br>Jacksonville 1993<br>Laem Chabang 1999<br>San Juan Bay 2009<br>Jaipur 2009 |

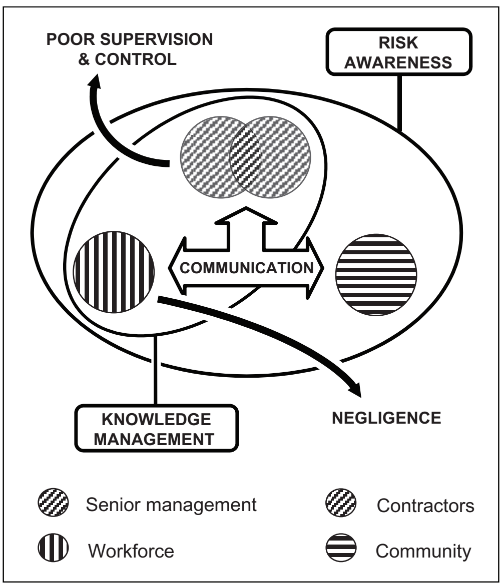


Figure 2. Scheme of organizational failures collected in the analysis of the accident at Buncefield (Paltrinieri et al., 2010, Atkinson et al., 2010, COMAH CA, 2011).

For instance, Figure 2 is a scheme of the main organizational causes identified within the accident analysis. There are four main actors in this scheme: senior management, contractors, workforce and the community surrounding the storage farm. All the actors are included in a set named "Risk Awareness", while only senior management, contractors and workforce are included in the "Knowledge Management" set.

Set borders can be defined as barriers of protection, whose lack (as registered in Paltrinieri et al., 2010, Atkinson et al., 2010) may lead the actors to general failures, such as poor supervision and control of senior management (Paltrinieri et al., 2010 and COMAH CA, 2011) or negligence at work of workforce (which was also affected by workload, as affirmed in COMAH CA, 2011).

Good communication would allow the actors to share information on the system and its related risks and, thus, to compensate lacks and strengthen the two protection barriers of the scheme (Fig. 2). Communication between senior management and contractors should be effective and constant, because the terminal considered is a joint venture between Total UK and Chevron Ltd. It is for this reason that senior management and contractors have been represented as overlapping.

However poor communication has been registered at different levels of the system between its main actors. Some clear examples are reported in COMAH CA (2011) as wider underlying causes. For instance, inappropriate communication between the oil supplier and the oil depot supervisors undermined their ability to plan and control the management of fuel. For historical reasons some lines of incoming fuel, such as that involved in the accident, were not controlled by the Buncefield supervisors, which had no access to the Supervisory Control and Data Acquisition (SCADA) system to tell them, independently of the ATG system, whether the lines were on or off line and, if online, the flow rate (often subject to changes). Needless to say, this lack of control was unpopular with the supervisors. Moreover, the Motherwell Control Systems 2003 Ltd, a contractor used to install and maintain the IHLS and ATG systems, did not fully know the IHLS characteristics due to a lack of communication with the manufacturer, and the day before the accident the IHLS had been left inoperable after a test. Thus, the operator had then a false sense of security and this affected also the risk communication within the site.

The issues connected to the interaction and organization of contractors played an important role in the development of background conditions that favoured the accident occurrence. This was also exacerbated by the increase in throughput of product at the tank farm, which caused a subsequent increase in the number of tanker drivers and contractors on site. At the time of the accident there where three operating companies at the deposit, two of which were joint ventures, and there were also subcontractors present onsite, such as Motherwell Control Systems. The organizational complexity was also demonstrated during the trials to determine the accident responsibility. Contracts were found to be unclear, including unclear responsibility. Eventually, after almost 5 years of trials, five different contractor companies were charged with offences based on the investigation of the Buncefield accident (COMAH CA, 2011).

## 3 METHODOLOGY

### 3.1 *Approach to atypical scenario risk management*

According to the known/unknown framework (Fig. 1), there may be two different but complementary approaches to manage the risk of atypical events: tackling respectively the risk of "Unknown Known" and "Unknown Unknown" events.

#### 3.1.1 *Tackling the risk of "Unknown Known" events*

This first, more technical and reactive approach aims to reduce the occurrence of unforeseen events using the improvement of HAZard IDentification (HAZID) processes. This improvement can be performed through the Dynamic Procedure for Atypical Scenarios identification (DyPASI), outlined within the EC project iNTeg-Risk (Paltrinieri & Wardman, 2010) in order to systematize information from past accidents or related studies and bring to light atypical scenarios otherwise not considered. This methodology has helped to identify and integrate the actual accident scenario occurring at Buncefield into a HAZID process carried out within the iNTeg-Risk project (Paltrinieri et al., 2010, Paltrinieri & Wardman, 2010) through a common and well-known methodology, such as the bow-tie analysis (ARAMIS, 2004).

With reference to the Cynefin framework (Fig. 3), this kind of approach is justified by the domain of "Knowable", which is the domain of methodology and looks for still unknown cause-effect relationship. In fact, the decision model suggested for this domain by Kurtz & Snowden (2003) states that incoming data (here represented by past events and related studies) should be sensed and analyzed through structured techniques and a response should be defined in accordance. In this way, a movement through the boundary between the "Knowable" and "Known" domains is promoted and atypical events analyzed can be properly assimilated and considered within the process of risk assessment.

#### 3.1.2 *Tackling the risk of "Unknown Unknown" events*

This approach aims to reduce the possibility of remaining unforeseen events ("Unknown Unknown") leading to an accident. This is a typology of events that has never been experienced or there has not been any information or knowledge in possession about (limits to conceive and image some scenarios). As stated in Lagadec (1994), we could prepare for crisis management in the case of inevitable occurrence of accidents and thus put into practice actions of precaution. Furthermore, we could make assumptions to the nature of risk and start assessing it, as suggested in Atkinson et al. (2010).

Anyway, if a glimpse of complex organizational systems are identified, a more proactive approach aiming to improve early detection, "destabilize less desirable patterns and stabilize more desirable ones

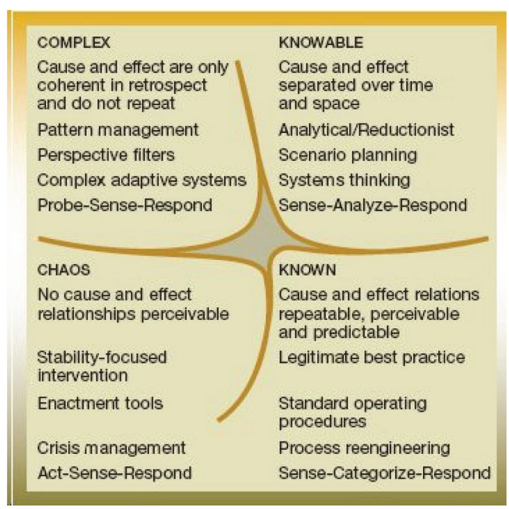


Figure 3. Cynefin framework (Kurtz & Snowden, 2003).

by seeding the space" (decision model suggested for the complex domain of Cynefin framework, Fig. 3, Kurtz & Snowden, 2003) should be performed for a more effective result. This does not mean that every organization should be faced as a complex system in order to prevent the occurrence of atypical scenarios, but rather that complex organizational issues can turn into a fertile ground for the occurrence of atypical scenarios. Thus, a verification to assess if the system considered can be defined as complex is needed. For this challenging purpose the International Risk Governance Council (IRGC) work on the recognition of complexity in emerging risks (IRGC, 2010), such as the risk of atypical events, can be of support. IRGC (2010) defines complex systems as "systems composed of many parts that interact with and adapt to each other, whose behaviour can not be adequately understood by only studying their component parts". Furthermore the following series of traits common to complex systems and relevant to emerging risks are outlined:

- Emergence
- Non-linearity
- Inertia
- Threshold behaviour
- Hysteresis and path dependency

As already affirmed, the case of Buncefield is characterized by the trait of emergence, which is an intrinsic feature of atypical events because they represent novel outcomes of the system at that moment not explained or predicted. Non-linearity understood as disproportional causation, as well as non linearity understood as circular causality are other important aspects describing the accident at Buncefield. The first one refers to the devastating outcome occurring due to rather common causal factors. Whereas the second one can properly describe deficient communication between two parts whose failures affects both undermining general knowledge management and risk perception. That degree of complexity, surprise and "wildness in wait" (as defined in Grøtan et al., 2011) characterizing the new work processes in the petroleum industry denoted as Integrated Operations (IO) general features (Grøtan et al., 2011) can be spotted to some extent also in the case of Buncefield. The constantly increasing throughput of product, the difficult collaboration between oil deliverers, pipeline controllers and storage farms, between numerous contractors and subcontractors and most of all their need of a more effective communication partially resemble the IO idea of increased exploration and production through closer collaboration offshore-onshore, collaboration across organizational borders and use of integrated contractors by means of new Information and Communication Technology (ICT) (Grøtan et al., 2010).

According to Le Coze (2005), organisational issues should not be studied through technical quantitative risk assessment for their intrinsic complex characteristics. Thus, as complementary approach to this aspect, the Resilience based Early Warning Indicators (REWI) methodology, which was initially developed for the petroleum exploration and production activities in the northern regions (SINTEF, 2010, Størseth et al., 2010) including use of IO processes, was taken into account, applied to the system of the Buncefield oil depot. Results obtained are shown in this contribution.

### 3.2 *Method of resilience based early warning indicators*

The method that has been established for the development of resilience based early warning indicators is based to some extent on a method developed by U.S. Electric Power Research Institute (EPRI) known as Leading Indicators of Organizational Health (LIOH) (EPRI, 2000, EPRI, 2001).

The main parts of the REWI method, also representing the different levels of the method, are listed here below:

- Resilience Attributes
- Contributing Success Factors
- General Issues
- Indicators

The REWI method consists of eight Contributing Success Factors (CSFs) being attributes of resilience. For each CSF there is a set of issues contributing to the fulfilment of the CSF goals accompanied with proposals for early warning indicators. The CSFs were developed based on a literature review and an empirical study on successful recovery of high-risk incidents (for this reason the term Contributing Success Factor) within the research project named "Building Safety in Petroleum Exploration and Production in the Northern Regions" (SINTEF, 2010, Størseth et al., 2010). The general issues and proposals for candidate indicators were developed based on a series of workshops with scientists with various background including engineering, psychology, organizational theory and human factors. These workshops were followed up by workshops with domain experts (Øien et al., 2010a).

Thus, the REWI method consists of a predefined set of general issues and also a set of candidate indicators for each general issue. However, it is still a contributory based method and new general issues may be added during the workshops for identification of indicators. The predefined set of general issues and sets of candidate indicators are first of all a foundation for triggering creation of suitable indicators, which may not be included already. At the

Table 2. The Resilience based Early Warning Indicators (REWI) method steps (Øien et al., 2010b).

| Step | REWI method part to consider | Task |
|---|---|---|
| 1 | Predefined list of general issues and candidate indicators | Review the general issues and add new issues if required |
| 2 | | Assess the importance of the general issues (three levels) |
| 3 | Selected list of important general issues | Review the candidate indicators and propose new indicators |
| 4 | | Select a manageable set of indicators |
| 5 | Selected set of indicators | Specify the selected indicators |
| 6 | | Implement and use the indicators |
| 7 | Implemented set of indicators | Review and update the indicator system regularly |

same time it forces users to assess the suggested general issues and indicators. In fact, the method steps shown in Table 2 include also a review first of the general issues (step 1) and then of indicators (step3). Moreover, step 7 explicitly points out a regular review and update of the whole indicator system.

Since the application of REWI to a Buncefield-like oil depot can not be carried out without being affected by past events, the analysis was developed in two distinct steps:

1. Definition of a first set of indicators only on the basis of the REWI candidate indicators
2. Comparison with the Buncefield accident failures collected and further integration of new indicators

The definition of these new indicators has been carried out also with reference to the quality characteristics for safety performance indicators outlined by the International Atomic Energy Agency (IAEA, 1999), mainly focusing on usefulness and convenience of indicators.

## 4 RESILIENCE BASED EARLY WARNING INDICATORS FOR A BUNCEFIELD-LIKE OIL DEPOT

According to the REWI method steps shown in Table 2, a selected list of important general issues has been generated for a Buncefield-like oil depot (Fig. 4). This list is the result of a review of the general issues suggested by the REWI method (step 1, Tab. 2) and a selection of the most important (step 2, Tab. 2). There was no need to integrate issues.

From the application of steps 3 and 4 of the REWI method (Table 2) a first set of indicators was selected from the REWI candidate indicators. Examples are shown in Table 3. Next, a comparison with direct and indirect causes identified within the analysis of the major accident occurring at Buncefield (MIIB, 2008, Paltrinieri et al., 2010, Atkinson et al., 2010) allowed a further integration of new suitable indicators, a part of which are shown in

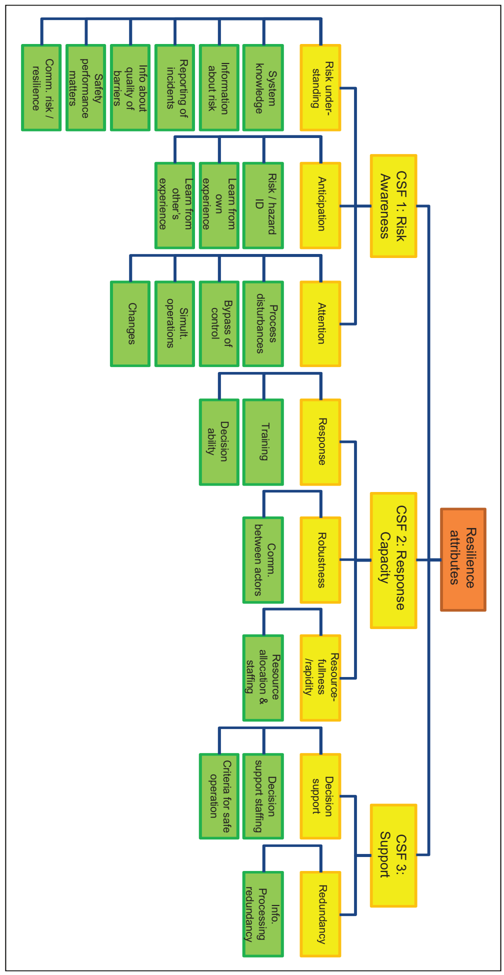


Figure 4. Selected list of important REWI general issues defined for a Buncefield-like oil depot.

*italic* in Table 3. Table 3 displays the preliminary results of the REWI application and in particular the indicators related to the CSF Risk Awareness,

Table 3. Selected set of resilience based early warning indicators for a Buncefield-like oil depot referring to the CSF "Risk Awareness". Indicators shown in *italic* have been added on the basis of the Buncefield accident failures collected.

| Risk Awareness—Indicators | |
|---|---|
| 1 | Average no. of years experience with such systems |
| 2 | Average no. of years experience with this particular system |
| 3 | Portion of operating personnel receiving system training last 3 months |
| 4 | Portion of operating personnel taking risk courses last 12 months |
| 5 | No. of violations to assumptions/limitations in the risk analysis (QRA) |
| 6 | *No. of accidents last 12 months* |
| 7 | *No. of incidents last 12 months* |
| 8 | *No. of near misses last 12 months* |
| 9 | No. of internal audits/inspections covering technical safety last 6 months |
| 10 | No. of internal audits/inspections covering operational safety last 6 months |
| 11 | No. of HSE initiatives taken by senior management |
| 12 | Portion of company actively using the risk register |
| 13 | Portion of operating personnel participated in HAZID |
| 14 | Fraction of operational procedures that have been risk assessed |
| 15 | *No. of reviews of safety reports in the last 5 years* |
| 16 | *Fraction of internal past events considered in safety report review* |
| 17 | *Fraction of external past events considered in safety report review* |
| 18 | No. of alarms disabled (without acknowledgment) during last month |
| 19 | *Fraction of sensible data related to a unique process line controlled by one supervisor* |
| 20 | No. of unauthorized bypasses/overrides during last 3 months |
| 21 | Maximum no. of simultaneous operations last month |
| 22 | No. of changes/modification of technical equipment last month |

which is a fundamental aspect for an effective and conscious prevention of atypical scenarios.

## 5 DISCUSSION OF INDICATORS OBTAINED

Considering Figure 4, which shows all the REWI general issues defined for the Buncefield-like case, a disproportion between the CSFs, in terms of number of related general issues, can be noticed at first sight. In fact it is evident that the application of REWI has been affected by the previous study on the atypical scenario. Risk Awareness, and most of all the Risk Understanding, has been a key factor in the accident at Buncefield, where the perception of risk was excessively low due to several different causes. The nine most representative general issues and their indicators are discussed and related to the causes that led to the Buncefield accident.

i. *System knowledge*
System knowledge both by the senior management and the workforce was lacking and a clear example is that the actual IHLS functioning was ignored within the tank farm (COMAH CA, 2011). For this general issue indicators 1, 2 and 3 (Tab. 3) have been defined, but indicator 2 should be specifically addressed to specialized workers (or contractor companies) assigned to a particular task, such as the Motherwell Control Systems company, which was in charge of the IHLS maintenance at Buncefield (COMAH CA, 2011).

ii. *Information about risk & communicating risk/resilience at all levels of the organization*
These are essential issues to cope with for a proper perception of risk in a company, which, as said, was lacking at Buncefield (Paltrinieri et al., 2010).

iii. *Reporting of accidents, incidents and near misses*
As Table 1 shows, there had been several other VCEs with similar characteristics prior to Buncefield and awareness about this kind of scenario by reporting these accidents would have helped its prevention. For this reason, indicators 6, 7 and 8 (Tab. 3) have been added to the set of candidate indicators. Accident is defined as a misfortune causing injury or death and damage as well. Incident is a relatively significant event where no serious injury nor death but some damage are involved. A near miss is an unplanned event that did not result in injury, illness or damage because a fortunate break in the chain of events prevented them.

iv. *Information about the quality of barriers*
The ATG system had been stuck 14 times between 31 August 2005 and 11 December 2005. Sometimes this was logged as a fault by the supervisors and other times it was not. Moreover, Motherwell staff never considered that the gauge should be investigated,

even if they had been frequently called to rectify the matter (COMAH CA, 2011). This demonstrates the importance of audit/inspections of both technical and operational safety and this is why indicators 9 and 10 (Tab. 3) have been selected.

v. *Risk/hazard identification (HAZID, …)*
The improvement of HAZID processes in order to identify atypical scenarios is the basic issue on which the DyPASI methodology is based (Paltrinieri & Wardman, 2010). The indicators 13, 14 and 15 (Tab. 3) in this case focus on a concerted HAZID process, on its completeness and on its updating, considered as effective ways of enhancing this fundamental aspect of risk management. Regarding the updating, the Seveso II Directive (Seveso II, 1996) imposes review and update of the mandatory safety reports, including hazard identification, every 5 years. For this reason indicator 15 (Tab. 3) refers to a period of 5 years. The DyPASI methodology has been specifically developed for the purpose of reiterated updating (Paltrinieri & Wardman, 2010).

vi. *Learn from own and other's experience*
Table 1 shows past events similar to the major accident at Buncefield from which lessons had not been learnt and thus which were not considered in the safety report reviews. In order to carry out effective safety report reviews, indicators 16 and 17 (Tab. 3) have been defined.

vii. *Process disturbances: control and safety system actuations*
Indicator 19 (Tab. 3) has been defined for this issue and addresses the capability of supervisors to have a good and nearly complete control of a single process line, in order to allow them a general overview of data. The indicator, in fact, refers to the impossibility of Buncefield supervisors to have access to certain information about some pipelines of the depot, such as the flow rate, forcing them to exclusively rely on ATG controls (COMAH CA, 2011).

viii. *Activity level/simultaneous operations*
Indicator 21 is selected for this issue (Tab. 3). It aims to identify situations of excessive workload, as had occurred at the Buncefield oil depot before the accident, as reported by COMAH CA (2011).

ix. *Changes: technical, process, organizational, external*
For this general issue the indicator 22 (Tab. 3) was selected among the candidate indicators. One of the reasons for this choice was the experience of what occurred in the major accident at Saint Herblain (1991) (Tab. 1), where a rubber joint guaranteed by the manufacturers to aromatic concentrations of a maximum of 30% ruptured the first day of an operational change to unleaded gasoline containing 55% of aromatics. This gave rise to a major leak and a subsequent VCE in the oil depot to some extent similar to Buncefield.

The other general issues related to CSF 2 (Capacity) and CSF 3 (Support) have as well a fundamental role in the prevention of major accidents, but not such a close and specific relation to atypical events. Hence they have been defined, but they are not further explained and discussed.

## 6 CONCLUSIONS

This study has demonstrated the effectiveness of a resilience based method (REWI) for early detection of events that can emerge from a complex system and lead to atypical accidents. The REWI method has been applied to a well-known case of an atypical major accident characterized by a series of organizational causal factors, basically linked to the coexistence of several contractor companies in a situation with gradual increase of production. The outcome has been a series of resilience based early warning indicators able to cover most of the failing organizational aspects highlighted by the previous analysis. This has been possible despite the REWI method was developed for another industrial field (petroleum exploration and production) due to its intrinsic flexibility. In fact the candidate general issues have been able to cope with most of the main organizational aspects of the accident and only a few new indicators have been added after a direct comparison with the causal factors of the accident.

This work has also pointed out complementarity and links between the two approaches, i.e. the DyPASI and the REWI methods. While the first is more technical and reactive, the second is more organizational and proactive. The REWI method aims to early identify poor knowledge management or deficient hazard identification and, thus, awake risk awareness in the company, which in turn could trigger the application of a tool to improve and update knowledge management and the HAZID process, such as DyPASI.

By means of this focus on risk awareness, which is a fundamental factor to prevent atypical scenarios, the REWI method would likely have prevented an atypical accident like Buncefield, as demonstrated by the correspondence of the defined REWI indicators with the causes of the Buncefield accident, such as, for instance, the indicators detecting poor system and risk knowledge or incomplete and outdated HAZID.

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