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Analysing Accidents and Lessons Learned: You Can't Improve What You Don't Measure

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For a long time now, accident analysis theory has evolved from a study of mechanical and emergency response failure to the study of the wider influences that may have made the accident more likely, particularly safety management systems. This trend is very positive, but there is still considerable room for improvement especially since frameworks to drive analysis of these causal factors are not widely available for routine accident analyses. Indeed, there is growing evidence that incident reporting remains insufficient for yielding feedback on many topics that are at the centre of process safety discussions today, such as systemic risk and emerging risks associated with new technologies. It can be argued that safety experts have limited tools for capturing warning signs of complex or new causal factors, such as ageing of sites, process automation, management of organizational change, and safety culture. Given increasing consensus on the value of safety performance monitoring, and the role of incident analysis in this process, it would seem that there should be greater attention to this limitation. To a large extent, complex and new causal factors belong to a third dimension of causality, beyond safety management systems and technical factors, that may require development of a third generation of user-friendly tools or frameworks to identify them. This paper describes the findings from a study that aimed to confirm the hypothesis that the practice of lessons learned analysis is not sufficiently capturing new and complex risk factors. To do so, the European Commission's Joint Research Centre (JRC) conducted a study of lessons learned reported for 108 accidents occurring between 2010 – 2017. The study aimed to understand to what extent safety experts were actively seeking evidence of systemic and emerging risks in their analyses. This paper describes the findings from that study, presenting the state of practice with the eMARS database in regard to analysis of underlying causes and identification of precursors. The outcomes also suggest that many practitioners are already trying to apply a third level of analysis and in some cases point towards possible solutions.

1. Introduction

Two areas of ongoing discussion in chemical process safety are the concern about emerging risks that may not be fully recognised or understood, and the question of whether and how we can continue to reduce risk in high risk industries. While there has been significant progress in understanding and managing risks associated with technical and management system failures, there is a concern that new technologies and market conditions are undermining this progress with an increased risk of complex causality from changing physical, economic and social forces affecting site risk. Whether we are even measuring risk correctly to measure progress in risk reduction has also come into question, given the limited scope of data on impact severity that is statistically available for this purpose.

Several serious accidents in the last two decades have highlighted the failure to recognise new risks associated with various changes in conditions, processes, and organizational factors leading up to the occurrence of a serious, and in some cases catastrophic, incident. It can be concluded that a lack of attention to warning signs of elevated risk associated with this factors was a contributor in varying degrees to BP Texas City (USA, 2005) (Baker Report, 2007) , Buncefield (United Kingdom, 2005) (UK COMAH Competent Authority, 2007), and West, Texas (USA, 2013) (US Chemical Safety Board, 2015). There are numerous lesser known incidents for complex causality has also been suggested as an underlying factor, for example, the incident at Shell Moerdijk (Dutch Safety Board, 2015) and a series of Statoil incidents in 2016 (New in English.no, 2016). The OECD Working Group of Chemical Accidents published a report highlighting the

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process safety risks associated with change over time (ageing) (OECD, 2017) and most recently published a guidance on ownership change in hazardous facilities (OECD, 2018).

This paper proposes that advancements in causal theory associated with industrial accidents are not yet fully reflected in the way accidents are analysed and monitored.The question of future risk reduction quickly becomes a discussion about how can anyone know if current safety challenges are being addressed and that risk are being reduced if there are no data available to answer those questions. As indicated in the Sendai Framework, developing mechanisms for a more precise and complete understanding of disaster risks is an obligation of all sectors involved (public, private and civil society) at every level (local, national, international). (UNISDR, 2015). The study used data from the European Union with the view that similar challenges likely exist in many other industrialised regions.

2 Systemic risk and organizational factors in accident analysis practice

In the past several years, there has been considerable discussion in the process safety field about risk factors that are not associated with just one site, but that can potentially affect a wide range of industries. They are all, to varying degrees, variations of common cause risks, of which many (but not all) might also be classified as systemic risks. They are by and large new or increased exposure to risks associated with changing industrial conditions, e.g., ageing sites and technologies, new technologies (e.g., increased process automation) and changes in market supply and demand. They also include risks associated with organisational structures and policies, for example, site ownership and staff changes, changes in the decision-making process, and safety culture on individual sites or across an organisation. Table 1 includes a non-exhaustive list of safety topics that are widely discussed among chemical process safety experts today, and as evidenced by recent initiatives highlighting challenges in technological disasters, such as the Chemical Accident Risks Seminar (Wood, 2017) and in the chemical accident risks chapter of the European Commission study on the State of the Science of disasters (Wood et al., 2017). These trends are generally applicable across all hazardous industries although sites with greater complexity (e.g., multiple installations and operations) may be more vulnerable to common cause risks, such as ageing and increased automation.

Table 1. Examples of trending topics surrounding new and complex risk factors in process safety today

Trending topics	Description
Ageing of capital and human resources	Ageing of equipment, people, procedures, and technologies
System complexity	An unanticipated interaction of multiple failures in a complex system
Increase in outsourcing of personnel	Increasing engagement of third party personnel to work in critical functions such as maintenance and operations functions
Increased automation of process controls	Expanded use of computer technology and software engineering to control processes
New products, processes and market demands	Renewable energies, biofuels, and liquefied natural gas (LNG) industries are all examples of sectors in a growth phase where experience on some risk aspects are limited
Organisational management, including organisational change	Change affecting the entire site or company, e.g., change of ownership, re-organisation, and downsizing of staff
Risk governance	The government's performance in implementing and enforcing relevant laws
Corporate leadership	The ability of the upper management to establish and enforce robust process safety management company-wide
Safety culture	The attitude, beliefs, perceptions and values that employees share in relation to safety in the workplace.
The Internet of Things	The network of physical devices, vehicles, appliances and other items that can connect across a local Internet and exchange data

Typically, these causal trends have been explored, elaborated and confirmed in the chemical processing industries through the study of major chemical disasters, such as Esso Longford (Australia, 1998) [(Hopkins, 2014) , BP Texas City (Baker report, 2017) Buncefield (UK COMAH Competent Authority, 2007), Macondo (United States, 2010) (Deepwater Horizon Study Group, 2011), and most recently, Tianjin (China, 2015) (State Administration of Work Safety of China, 2016). In addition, a number of analytical models have been developed by researchers in the last two decades to assist analysts and investigators in identifying underlying root causes of technological accidents, and in particular, systemic risks. Some well-known models and theories include AcciMap (Rasmussen, 1997) Functional Resonance Analysis Method (FRAM) (Hollnagel, 2012), Systems Theoretic Accident Modelling and Processes model (STAMP (Levenson, 2004), Normal Accident Theory (Perrow, 1984) and Drift into Failure (Dekker, 2011). However, as Leveson (Leveson, 2011) and others have acknowledged (Underwood et al., 2013) these theoretical models, that have gained wide acceptance and continue to be validated by recent accidents, are having less effect on preventing serious accidents than might have been expected.

Given that these trending topics have already been identified, it can be difficult to understand why analytical tools to diagnose the presence of such risk contributors are not widely available. Part of the answer may be that the precursors for many of these systemic and common cause failures are not routinely identified, or at least recognised as such, in performance monitoring practices on many sites, in corporations, and in competent authorities with oversight responsibilities. Ideally, elements of the performance monitoring system, such as, incident tracking and analysis, safety performance indicators, and safety and management system audits, are designed to identify these signals before they manifest into serious incidents. In particular, prevention eventually comes down to identifying where specific risk factors may be elevated on a specific site. Hence, preventing accidents that could result from certain precursors requires systematic identification of signals that one or more precursors is, or could be, present. The accident investigation models mentioned previously are normally reserved for major disasters, since they require considerable expertise and resources to apply. However, risk management generally aims to avoid major incidents that require in-depth post-incident investigations and by the time these incidents happen, it is, of course, too late. Rather, risk management requires user-friendly tools for the safety practitioner whose job is to analyse accidents and near-misses as part of good practice in routine performance monitoring.

2. Study of lessons learned dimension of recent accident reports in eMARS

The hypothesis is, therefore, that tools for analysing third dimension causality are not readily available and this is a serious limitation to preventing some types of accidents going forward. To explore this hypothesis, the Major Accident Hazards Bureau of the European Commission's Joint Research Centre (JRC) decided to seek evidence in the EU eMARS database of chemical accidents. To do so, it reviewed lessons learned of 108 reports of major accidents and near misses submitted by EU and European Economic Area (EEA) Member State authorities and occurring from 2011-2017 in the eMARS database. This period was chosen because the JRC implemented a new quality control system in 2011 such that no reports are published without lessons learned findings included. The study had two main objectives. The first aim was to understand the depth of analyses, that is, whether lessons learned from more recent incidents remained rooted in classic "technical failure" analysis (e.g., "There was a hole in the tank"), or if there was evidence of a more complex analysis to identify underlying causes. The second objective was to ascertain whether signals (or precursors) of complex and new causality were present in the descriptions, regardless of the level of analysis. Notably, the study could not distinguish between practices of industry vs. government experts because it is not evident whether the site operators, the inspector or a combined effort of the two was responsible for the final analysis.

2.1 Study design and execution

The study design was fairly straight-forward using taxonomy and contextual criteria to classify different cases and simple descriptive statistics to characterise outcomes. For the analysis, four dimensions of analysis were created as listed in Table 2 on the next page. Each level was progressively more advanced than the one before it, such that it is assumed that an SMS failure analysis (Level 3) includes a technical failure analysis (Level 2), and that an organizational factor analysis (Level 4) includes and SMS failure analysis (Level 3). A Level 1 analysis indicates no analysis at all. A Level 2 analysis consisted of a lessons learned description covering purely technical elements (e.g., related to equipment and procedure failures). Level 3 and Level 4 classifications were based on identification of key words, phrases and concepts that were associated with SMS (as defined in Annex III of the Seveso III Directive) and organizational factors respectively.

In the second part of the study, the JRC developed its list of precursor categories loosely based on the topics listed in Table 1. The topics themselves could not be used directly for this exercise because, with some exceptions, 1) the analysts were not seeking the specific evidence needed and 2) the details were only enough to signal a specific type of deficiency of the new or complex variety without specifying precisely which type (e.g., were the organisation's problems due to organisational change or corporate leadership?).

Table 2 Categorisation used by the study to assess level of analysis in lessons learned descriptions

Level	Dimension of analysis
Level 1	No lessons learned provided
Level 2	Technical elements only
Level 3	Safety management systems elements
Level 4	Organisational elements

2.2 Findings and observations on analytical complexity

As shown in Figure 1, the results were overall positive in that nearly 60% of the reports included at least a Level 3, if not a Level 4, analysis. From this finding, it can be concluded that analysis of management systems has become a routine part of the accident review for many operators and inspectors of hazardous sites. The SMS, especially as it is defined in Seveso Directive legislation and guidance, has become an accepted and well-known model for assessing the robustness of safety management.

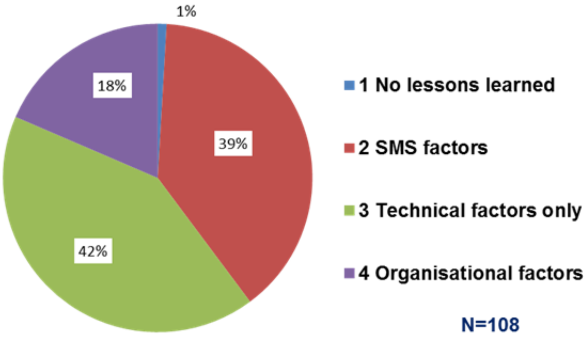

Figure 1: Level of analysis of 109 eMARS reports of chemical accidents between 2011 – 2017

The study identified 18 reports (17%) that achieved a Level 4 analysis. On the downside, Figure 1 also shows that 42% of the accidents indicated lessons learned of a Level 2 (of a technical nature only). While it is theoretical possible that some incidents can occur due to a simple one-off technical mistake, it seems unlikely that this is true for the majority of accidents clearly identified as "major accidents" or "near misses". Hence, these results confirmed that the study's hypothesis was true for this group of accidents, that is, the majority of cases did not aim to identify signs of elevated risk from the new and complex causes that are high concerns for process safety experts today.

2.3 Presence of precursors for complex and systemic weaknesses

The study identified 34 accidents where there was a weak signal associated that could be with the trending topics identified earlier in Table 1. As noted in Figure 2, allusions to aspects of safety culture appeared in 16 reports. As one report concluded:

> "All parties need to ensure that they have adequate processes and procedures in place related to the handling, storage, transportation and disposal of emulsion explosives. They also need to ensure that these methods are properly implemented. In major hazard installations everyone is responsible for safety and following instructions."

Issues associated with organisation management were mainly associated with personnel management, including requirements for minimum supervision of tasks, minimum staff levels, etc. were indicated in 7 cases. There were also reports that made clear recommendations associated with corporate leadership. One case recommended investigation of common cause failure (involving drainage of rain water), and another cited the involvement of a range of organizational and system factors suggesting a complex causality. There were also some notable Level 3 (SMS) analysis that alluded to potential systemic issues even though the lessons learned analysis was clearly based on an SMS framework. One description concluded the analysis with a statement that recognised an issue of complexity:

> "[The] company has not been able to identify one significant contributing factor leading to failure. They consider that the Swiss Cheese Model of multiple contributing failure modes maybe the most credible/likely scenario. They state that they have learned valuable lessons around maintenance and reviewing the integrity of their tanks."

Of all the countries, Finland stands out as identifying the most precursors in its analyses. Finland clearly used a template for capturing organisational factors in at least three reports. The strength of all its lessons learned descriptions suggests that this template drove all, or most, of its other analyses, too. This observation has great significance because it highlights again the power of using a reference framework in identifying underlying causes of a particular nature.

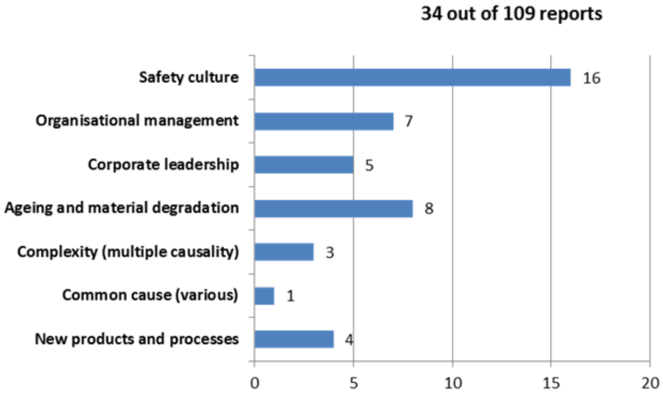

Figure 2: Precursors of potential complex and systemic weakness identified in eMARS reports of chemical accidents 2011 – 2017

3. Conclusions and Recommendations

The findings regarding depth of analysis provided an interesting overview of the state of accident lesson learning since 2010 with some promising results in terms of SMS analysis, but less promising results in terms of analysis of new and complex causes. In contrast, the precursor analysis showed that analysis of weak signals is still being narrowly applied. The findings also pointed to opportunities for improving the ability of safety experts to produce more robust analyses. They also suggest that routine accident analysis is in large part not identifying potential deficiencies associated with new and complex causes of major concern in process safety today. This situation most probably exists because there are almost no tools for safety experts, who have limited resources and are not necessarily trained investigators, to probe findings for accident lessons learned for this purpose. If this situation continues, the routine analyses of all near misses and accidents on hazardous sites, recommended as standard good practice for several years now, will continue to miss obvious signs of horizontal causality if not examined systematically for this purpose.

The Level 3 SMS analyses in these reports clearly show that analyses are greatly aided by having a reference model (i.e., the safety management system) as a guide. Moreover, it is notable that some actors are indeed using frameworks to identify precursors to identify potential elevated risks from new and complex causes. However, as long as this practice is not widespread, it will be difficult for sites, companies and regulators to track and anticipate vulnerabilities of this nature. This finding suggests that more effort should be invested to develop conceptual frameworks, possibly accompanied by descriptive criteria, to identify precursors that can both help in identifying potential areas of weakness and also quantify the strength and breadth of the vulnerability. It is worth exploring some existing models and guidance as a basis for developing solutions. For example, Accimap might be adapted as a tool for identifying weaknesses in corporate management systems. Themes developed within the OECD Corporate Leadership Guidance and theOECD Site Ownership guides could also be incorporated into existing accident analysis methods. Similarly, there may also be an opportunity at some point to update the EC-JRC eMARS database to use keywords or other simple tools to signal and track specific risk factors not captured within the technical and SMS framework.

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