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Handbook for Learning Lessons from Chemical Incidents

A technical guide to analyzing and investigating incidents for learning

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The authors of this document were privileged to write this handbook, derived from the long experience of the JRC's Major Accident Hazards Bureau (MAHB) in chemical accident analysis, with considerable support from the diversity of expertise represented by the AABE. Maureen Heraty Wood is a staff member of the JRC in charge of the MAHB project and the AABE team leader. Lee Allford is an independent advisor with twenty five years experience in major accident safety who provided technical support to the Joint Research Centre in the leadership of the AABE team.

Abstract

Effective risk management and oversight of technological risks require the judicious application of lessons learned to prevent future technological incidents and control their impacts. In this respect, the number and diversity of industries, substances, equipment, and processes, make learning lessons from chemical accidents particularly challenging. Throughout the risk management cycle, it is critical to have competences involved that are able to use past accidents to identify and apply relevant lessons learned to a wider range of scenarios involving different substances, equipment, processes, establishments and industries. Auditors and inspectors also need to know what constitutes a useful accident report and good lessons learned practice. There should also be competence in lessons learning available to help management and authorities use accident information to change their risk management practices and requirements, and conduct learning investigations of their incidents.

Despite this need, techniques for analyzing lessons learned, and conducting learning investigations, are not widely taught as part of the engineering disciplines that underpin the industrial economy. Learning and analysis for learning are traditionally disciplines of the social sciences and there is not always sufficient cross-fertilization between the disciplines.

Therefore, this handbook is written to try to fill that gap. It is mainly intended for the engineers that work daily with the processes and systems where lessons learning should be applied. It is specifically aimed to build competence in lessons learning in the chemical accident stakeholder community, in particular, inspectors of hazardous sites, but also is just as relevant for operators of these sites. Moreover, the concepts and techniques are equally effective in extracting lessons learned from other types of technological risks.

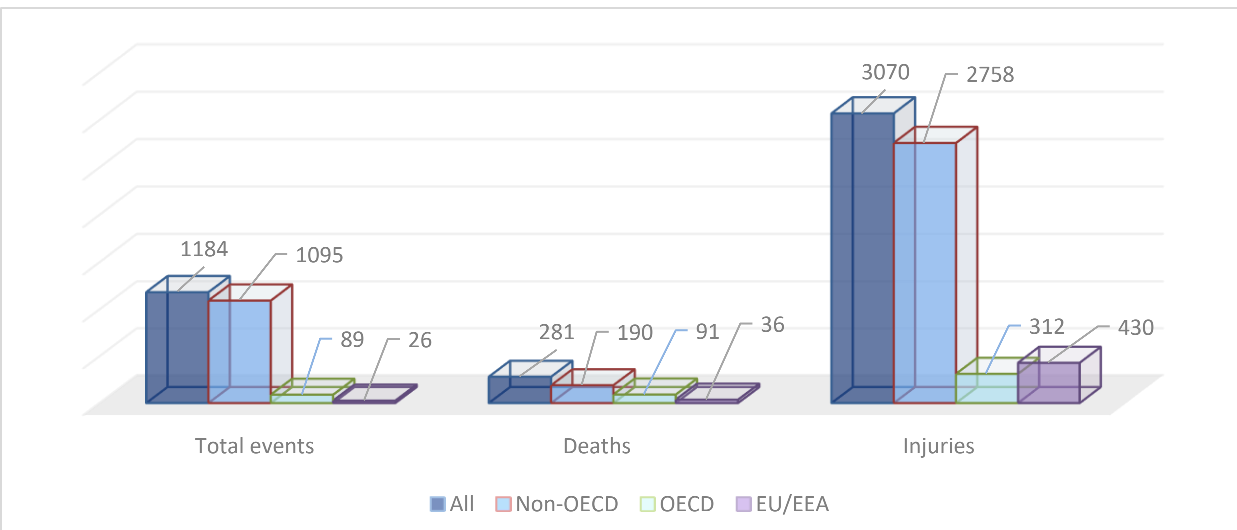
Preface

In the hazardous industries, lessons learning is held as one of the most important contributors to prevention of chemical incidents[1] and mitigation of their consequences. Many countries, such as those in the European Union (EU) and in the Organization for Economic Cooperation and Development (OECD), have legislation that encourages, or even requires, that hazardous industries engage in lessons learning. There are several open source databases of chemical incidents for that purpose.

Nonetheless, there is evidence that there is not enough learning taking place. For example, in highly industrialized countries that also have strong regulatory regimes to reduce chemical accident risk, the following can be noted:

- Chemical accidents are still a regular occurrence, although most of them are fortunately not serious. For example, **Figure 1** shows that the EU was responsible for nearly 1/3 of the over 1,000 chemical incidents worldwide in 2023 but suffered only 36 deaths as a result compared to 1,095 fatalities from chemical incidents worldwide in that same year. [2]
- Serious accidents, e.g., with one or more deaths or injuries, often seem to occur as a result of a well-known failure types, for example, in maintenance and in loading and unloading activities. Such failures occur both in companies with high hazard awareness as well as companies in industries that are not considered high hazard, although they deal routinely with hazardous substances.

Figure 1. Analysis of serious chemical accidents as reported in the global media in 2023



Source: JRC GMI-CHEM database of chemical accidents reported in the global media. For more information, see the [JRC CAPRI Chemical Accident Information Portal]

Further evidence can be found of a survey of EU hazardous site inspectors as part of a workshop on lessons learning for inspectors in 2013. According to the survey, many inspectors across the EU routinely assess operator investigation reports. Their survey responses indicated that operator reports frequently

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[1] A chemical incident is an umbrella category of events occurring in a work environment involving the release of a hazardous substance.

[2] From the European Commission's GMI-CHEM database of chemical incidents reported in the global media, collected by the Joint Research Centre's Major Accident Hazards Bureau. (For more information, the JRC's CAPRI portal provides a snapshot of data from serious incidents collected from the media annually as well as data on worldwide and historic disasters.)

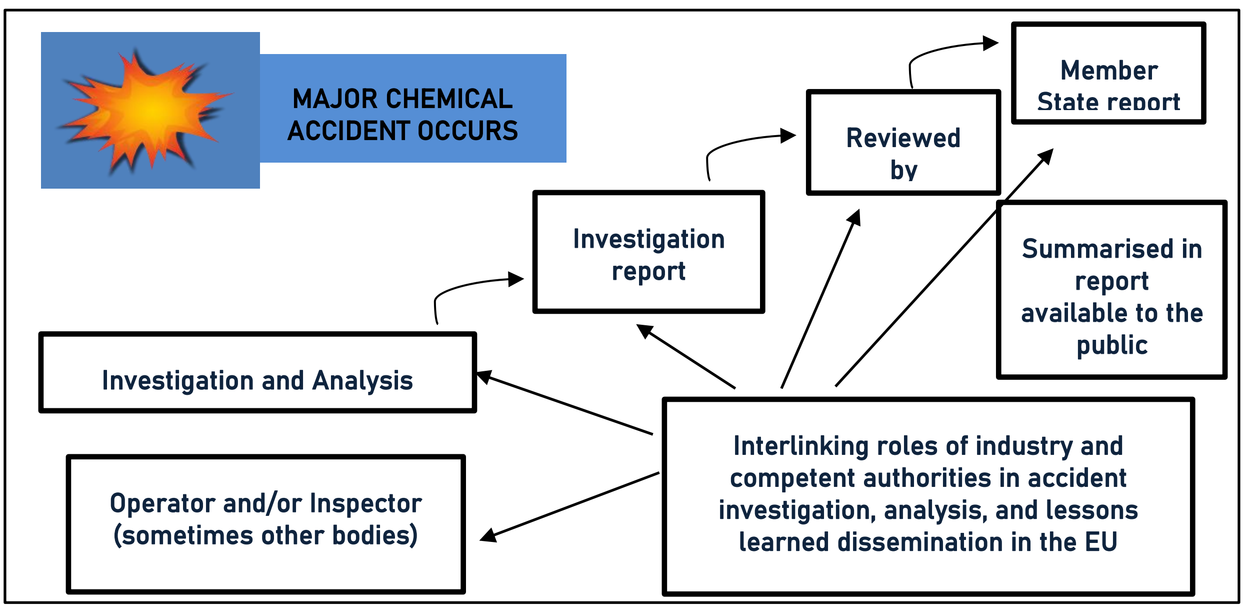
exhibit the following common deficiencies (Weibull et al., 2020).The search for root causes is not deep or broad enough.

- Organizational, management and human factor issues are overlooked in favour of technical and engineering factors.
- Lessons learned are missing or not specific enough.
- Corrective actions are often limited to the relevant plant or equipment only and not applied on similar facilities or equipment.
- Investigations are carried out to fulfil formal requirements or in an attempt to prevent legal or civil claims.

In the last few decades, there has been considerable effort by many hazardous industries as well as government organizations to promote lessons learning through reporting and investigation mechanisms. As a result of a broader movement in other hazardous areas, such as nuclear power and transportation, one can find quite a lot of guidance and various methodologies for performing accident investigations to identify root causes and contributing factors. Yet, despite the wealth of information on investigation, and a plethora of chemical accident reports available in the public domain, there is actually very little information on what lessons learning should look like and the many ways that lessons learned information can be useful for preventing chemical accidents and their consequences

Notably, a requirement for chemical accident reporting and investigation is built into many corporate risk management policies and into government programs and legislation governing chemical risk management. Indeed, there are a number of industry and government open source databases where information resulting from chemical accident investigations can be found. A typical approach followed by many governments around the world is illustrated in **Figure 2**.

Figure 2 . Steps in reporting following a chemical incident



Source: Flowchart by Allford and Wood

Reporting incidents is not enough, however. There are more steps in this learning process following an investigation, including dissemination and instigation (or implementation) of the learnings. More often than not the process of learning is stopped after reporting. (Hailwood, 2016). Learning does not occur if accident reports are only filed into a computer database.

This handbook argues that processing information to identify lessons learned is also a distinct step in the learning process. Processing usually occurs at least once after the investigation by the investigation team, but it also can occur many times after dissemination by other actors involved in the dissemination or application of the lessons learned. There are particular skills that these actors need to derive useful lessons learned from accident reports that are relevant for their target audience.

As one example, at the workshop for EU hazardous site inspectors in 2013, a common frustration for inspectors was that there was not very much available on effective ways of using the information from investigations. Comments and workshop discussion indicated that the competence was largely developed within the inspectorate from experience and academic sources. Moreover, in a survey of workshop participants, only 36% of inspectors reported having confidence in their ability to extract lessons learned and use other data from open source databases of chemical incidents (Weibull et al., 2020)

The handbook also places emphasis on the many actors that can stand to learn from an incident or groups of incidents. Investigation(s) following an incident will generally only bring the perspective of the target audience that they are serving to interpret the incident findings as learnings. For example, a company will look for insights for improving its operations. Government safety boards may look at the failures of both the company and government oversight organizations. Due to their specific missions, there may be lessons learned that these investigations ignore. For instance, the company will not generally look for lessons learned that could be useful their government inspectors and government safety board may not be particularly interested in delving too far into human factor causality. Yet even if they did not note them, the lessons may be there.

In essence, knowing how to spot lessons and patterns from chemical incidents can benefit many stakeholders. While knowing the lessons is not the same as implementing the lessons, it is the first step in that direction. The authors believe that if lessons learning is more widely appreciated and taken up as a skill by the community of stakeholders engaged in chemical accident risk management, then there will be more learning.. With more stakeholders engaged in learning, there will be more opportunity to learn lessons early and apply them in a timely fashion before another chemical accident occurs.

1 Introduction

This chapter aims to help users understand the purpose of the document and the intended audience. It explains the necessity of learning from chemical incidents that can occur in any business handling acutely dangerous substances in volumes sufficient to cause serious accidents. Furthermore, each chapter is identified as contributing to the document's overall objective of teaching how to master the art of lessons learning for reducing chemical accident risk.

1.1 What is the purpose of this document?

This handbook is intended to be a resource in oversight and risk management responsibilities associated with any activity where the chemical accident risk has been determined as high enough to merit focused risk management measures. The diversity of factors that can influence a chemical accident is very broad (e.g., substances, industrial sectors). Therefore, lessons learning sometimes requires a certain level of confidence and expertise to sift through a mountain of data to derive robust and important findings. It is hoped that this handbook might contribute to elevating and spreading competence among those who are charged with the important responsibility of overseeing or managing chemical process safety.

1.2 Why is this publication necessary?

There is strong evidence that competence in lessons learned is not widely available. While lessons learning is not only about the analysis, the analysis is the first step in learning. A paucity of competence in analysis within hazardous industries, and even academia (as may also be the case), can lead to limited understanding to anticipate and predict future potential failures one's own operations as emerging risks in the industry as a whole.

In particular, in industrialized countries that have strong process safety cultures and regulatory regimes, the following is observed:

- Without a doubt many industry actors place a high value on lessons learning. However, it is not evident that the art of data analysis, as it applies to chemical incidents, is systematically taught or prioritized as a training objective for safety staff on many sites dealing routinely with hazardous substances.

- The analysis of lessons learned is not taught as part of process safety studies, including analytical techniques for trend analysis, as evidenced by a very low number of high quality studies of failure trends associated with chemical incidents in the scientific literature. Such training would include recording incident information in a systematic way (e.g., common nomenclature) to facilitate filtering and quantitative analysis of groups of accidents. It would cover the basic principles of statistical analysis, and how to use information effectively to draw meaningful conclusions.

- There are several open source databases of chemical incidents created by both government and industry and yet none use the same nomenclature or format for presenting chemical incidents. Only two databases are available for download in an Excel file, the EU eMARS database and the IOGP incident database (see **Annex 3**). It is hard to find evidence that analysis of lessons learned from incidents outside one's own operations is a common practice.

- These observations suggest that competence in maximizing lessons learning potential from chemical accidents is not easy to obtain. There are few if any courses for process safety engineers that would help the industries develop specialists in this area.

In teaching the art of analysis through this publication, it is hoped that the entire field of process safety will make a higher commitment to learning from failure from accidents. With greater attention on cultivating this competence in industry and government, it could be expected that more failure trends will be spotted earlier by industry and government. Also, there may be higher priority assigned to monitoring chemical incidents as they occur over time across geographic areas and industry, providing advance notice of emerging trends and existing vulnerabilities.

1.3 What does this document cover?

This handbook provides guidance on the art of extracting lessons learned from investigations of chemical incidents occurring on industrial sites. The process of learning lessons from chemical incidents is derived from lessons learning across all technological risks, especially nuclear, aviation and transportation fields. The recommendations in this document can be easily applied in other technological areas. The authors have focused on chemical accident risk because it is their expertise, but also because there is often insufficient training in lessons learning in government and industry that have responsibilities related to chemical risk management.

Lessons learned from chemical incidents supports the overarching objective of protecting workers, people and the environment from the consequences of chemical accidents. For this purpose, this document cites the many different audiences that can benefit from learning how to derive lessons from chemical accidents. It also gives some examples of what learnings such audiences can specifically obtain through studying chemical accidents.

The document is divided into chapters that move from the theoretical concepts to practical application.

- Chapter 1 describes the purpose of the document and why it is needed, and identifies the target audience and ways in which the content may be applied.
- Chapter 2 document gives a general overview of the fundamental principles that underpin lessons learning from incidents.
- Chapter 3 gives an overview of common conceptual frameworks used to structure investigation and analysis of chemical accidents.
- Chapter 4 provides insights into how components of the investigation process can be designed to help drive lessons learning objectives.
- Chapters 5 describes techniques for extracting lessons learned from individual chemical incident narratives.
- Chapter 6 explains the systematic procedure that can be followed to derive lessons learned from analyzing groups of incidents.
- Chapter 7 offers a perspective on what kinds of decisions may be involved in achieving effective implementation.
- Chapter 8 Conclusion

How to achieve successful implementation of lessons learned is outside scope of the document. Implementing lessons learned is a whole topic unto itself bound with corporate leadership, safety culture and performance management. Several organizations have worked, and continue to work, on making implementing lessons learned a practice that is common to hazardous sites. Many of these organizations are those mentioned in the references and in **Annexes 3 and 4** in association with chemical incident databases and investigation reports.

1.4 Who is the audience for this document?

This document aims to support any stakeholder in government, industry or research engaged in learning lessons from chemical accidents, whether in association with a specific incident investigation or in analyzing of findings from incident investigation reports or summarized in chemical incident databases.

The document is of particular relevance for process safety in the chemical and petroleum industries, and also operators in other sectors, that are identified in legislation as "high hazard". [3]

However, any operator in any domain that is aware of its activities having a chemical hazard component may find this document useful. Chemical accident risk management is a multi-disciplinary field, requiring the involvement of many different actors with different roles and specialties. Hence, the use of this document is expected to reach a diverse range of experts and functions that play a role in reducing chemical accident risk in society. These experts and functions include, but are not limited to, safety managers; environment, health and safety managers; designers of equipment and chemical processes; government inspectors and regulators with related environment, safety and health competences; emergency responders; industry associations; high level operations managers; corporate and government policymaking units; and researchers in process safety, human factors and many other related fields.

The document is intended to support various roles associated with lessons learning from chemical incidents, such as,

- analyzing and generating lessons learned as part of an accident investigation team
- reviewing findings and lessons learned from an investigation as part of corporate or government oversight
- analyzing accidents to extract lessons learned from an existing report or from an incidents database, for any number of purposes, such as:
    - Design of equipment or production processes
    - Improvement of procedures or risk management strategy
    - Preparing for an audit or inspection of a hazardous operation
    - Sharing lessons learned as part of training and awareness of staff
    - Identifying evidence of impacts of government or corporate policy or to identify areas for improvement
    - Creating or updating technical and safety standards

1.5 What this document is expected to achieve

In sum, the authors hope that this document will equip a wide range of actors with the technical competence to extract lessons learned from incidents. Moreover, incidents that create opportunities for learning are not limited to those involving hazardous substances. Learning from incidents is universally applicable to a wide range of fields, from finance to civil engineering to medicine and many, many other complex operations and technologies. The more learning from adverse events is an accessible skill, the more information is available to protect the well-being of our loved ones, our communities and environment.

[3] For example, the EU Seveso Directive 2012/18/EU for controlling major accident hazards in the European Union covers a wide range of industries using type and volume of acutely hazardous substances as criteria (rather than industry sector).

Chapter 1 Summary

- **Purpose of the Document –** The handbook is designed to support the extraction of lessons learned from chemical incident investigations to enhance safety and prevent major accidents in industrial settings. It aims to assist stakeholders in government, industry, and research in systematically analysing findings from incident reports and databases.
- **Necessity of Lessons Learning –** Despite numerous chemical accident reports and public databases, there is little guidance on how to effectively extract and apply lessons. The handbook builds on prior research, including insights from process safety pioneer Trevor Kletz and regulatory experiences, to provide practical guidance.
- **Applicability Across Sectors –** While the focus is on chemical accident risks, the principles outlined can be applied to other technological risk areas such as nuclear, aviation, and transportation. The document aims to address the lack of structured training in lessons learning related to chemical risk management.
- **Intended Audience –** The handbook is particularly useful for professionals involved in process safety, including safety managers, inspectors, policymakers, emergency responders, industry associations, and researchers. It is relevant for any industry dealing with hazardous substances.
- **Structured Approach to Lessons Learning –** The document provides methodologies for deriving lessons from chemical accidents through investigation, analysis, and review processes. It covers frameworks for structuring investigations, analyzing incidents systematically, and deriving meaningful insights.

2 Fundamentals of lessons learning in the context of chemical accident risk

This chapter defines lessons learning as a critical part of chemical accident risk management, detailing how it reveals breaches in safety boundaries and the need for continuous updates to practices as technology, management, and personnel evolve. It distinguishes between different types of chemical incidents—such as accidents, near misses, and potential accidents—and explains how extracting lessons goes beyond identifying causal factors by focusing on actionable insights without casting blame. Furthermore, it outlines the essential competencies—like process safety expertise, deductive reasoning, and data analysis—needed to systematically study incident patterns and inform improvements in hazard identification, risk assessment, and overall safety management.

2.1 Lessons learning key concepts and definitions

Lessons learning is an essential component of chemical accident risk management. It has been proven over and over again that safe operations depend on respecting boundary conditions. The boundary conditions are all the elements that assure the safe operation, rules and procedures, process and equipment controls, equipment integrity, utilities and infrastructure, management, standard and regulations, etc. Lessons learning from chemical accidents exposes all the ways that such boundaries can be violated. As technology, management, and employees change, the lessons need to be continually renewed and passed on.

The ongoing dissemination of lessons learned achieves a number of objectives.

- It is necessary for **avoiding repetition of mistakes** of the past. It is also
- It is essential **to updating practices, frameworks and standards** that guide management of these risks remain as more is known about specific risks
- it allows understanding of risk to keep pace with technological and social change and emerging changes in vulnerability and exposure

The guiding principle behind lessons learning is that no one can know it all. Even if eventually our computers store all the lessons learned that have ever been generated, the information still has to be extracted and provided to the humans that need it.

In particular, incidents confirm or provide evidence of vulnerabilities before the vulnerabilities become sources of incidents. In complex systems, the human brain is not necessarily always able to envision all that could go wrong. Nature, technology and social interactions are far more complex than is imaginable. Even artificial intelligence (AI) can only be useful if, in the first instance, humans identify all the types of lessons that can be learned in a given situation.

Therefore, it is crucial that lessons learned from chemical incidents provide input into the risk analysis process. It follows then that lessons learning competence is needed for more than just the investigation. The risk management processes, that is, hazard identification, risk assessment and risk treatment, are a manifestation of conscious efforts to address potential weaknesses in safety management. Failure to identify hazards in process design, and recognize potential risk from even the smallest deviation from established standards and procedural norms may have serious and sometimes even fatal impacts.

Moreover, operators in complex systems must maximize opportunities for learning by not only systematically incorporating lessons learning from their own failures, but also from the failures experienced by others. Achieving this objective requires knowledge of how to find chemical accident data in the public domain and how to analyze accident reports to find patterns of failure.

2.2 What is meant by a chemical incident, accident, and near miss?

A chemical incident is an umbrella term for events that involve, or could potentially have caused, the release of a dangerous substance that is acutely hazardous, that is, the substance is able to cause harm immediately after it is released.[4] Theoretically, any type of chemical incident can generate interesting lessons learned. However, the purpose of studying chemical incidents is to prevent serious chemical accidents.[5]

This document takes the view that not all chemical incidents are accidents, even if a release occurred. The following classification, borrowed from Cowley (Cowley, 2020), classifies chemical incidents involving unplanned releases of hazardous substances in this way:

- A **chemical accident refers to an actual accident,** that is, a real incident that happened (energy or hazardous material was released) and had significant actual consequences, that have a measurable impact on human heath, company operations, the environment, the community, or society at large. Such accidents may also be referred to as **serious accidents.**

  In this context, significant consequences may also be further elaborated. **Table 1** shows one way to assess the severity of consequences. The European Gravity Scale for Industrial Accidents also uses a similar approach, dividing impacts into four category impacts including volume of substance released, human and social consequences, environmental consequences, and economic consequences.

- A **near miss** in this document refers to a real incident that happened (energy or hazardous material was released) without significant consequences but did not have a serious impact but might have had under different circumstances, that is, if the sequence of events had not been interrupted by a planned control measure or by happenstance.

- A **potential accident** is an unsafe act or condition that could have led to an incident but was stopped from developing into a real incident, without release of energy or hazardous material.

Another subset of chemical incident that is not an "accident" is an event that results from an intentional release of an acutely hazardous substance, e.g., as the result of a malicious or terrorist act. Such an incident would not qualify as an accident, but would clearly have important lessons learned for security. Intentional incidents also often have lessons also for process safety generally, such as providing information to improve emergency response, or to enhance knowledge about potential consequences from releasing a particular substance

Notably, chemical incidents are distinct from chronic releases of dangerous substances in that the system surrounding the production, use, handing and delivery of the chemical is designed for zero exposure to acutely hazardous substances. Therefore, a chemical incident or accident are often described as a "loss of containment".

[4] Acutely hazardous substances are those whose flammable, explosive or toxic properties have potential to cause serious harm or damage to humans or the environment upon release from containment. Acutely hazardous substances are classified in many countries around the world in alignment with the UN Globally Harmonized System of Classification and Labelling of Chemicals (GHS). The GHS or similar classification is also the leading criterion for determining whether particular regulations and risk management practices apply in a workplace.

[5] This document predominantly uses the term "chemical incident" and "chemical accident" interchangeably, although by default, "chemical incident" is the preferred term, as is also the practice in the field of chemical process safety. However, it is not always clear which term is better, chemical incident or chemical accident, in some contexts. The aim of process safety management is to prevent serious chemical *accidents* but the preferred strategy for preventing serious chemical accidents is to prevent all chemical *incidents* (or potential chemical incidents). For example, the objective of safety management is usually identified as the management of "chemical accident risk" (or sometimes even "chemical disaster risk") not "chemical incident risk". For this reason, the two terms, chemical incident and chemical accident, are often used interchangeably partly because "chemical accident" is the norm in some contexts, even if not strictly correct, and also because it is not always possible to determine whether "incident" or "accident" fits better.

Table 1. Consequence Severity Scale Reference (Summers et al., 2011)

	People	Environmental Damage	Asset loss/Operation impact
5	Multiple fatalities	Catastrophic off-site damage	>$10M and substantial offsite damage
4	1 or more fatalities	Significant off-site damage	$1M - $10M and severe impact
3	Hospitalization injury	Onsite or offsite release without damage	$100K - $1M and significant impact
2	Lost workday injury	Onsite or offsite release without damage	$10 - $100K and some impact
1	Recordable injury	Onsite release	<$10K and minor impact

This document primarily targets lessons learned from chemical incidents in industrial settings, although the information is equally valid for commercial settings, hospitals and other sectors where dangerous chemicals are part of normal operations.

Some experts will say that there is also a category of chemical incidents where little harm is caused and the lessons learned are so basic that they do not really achieve new learnings, e.g., it was caused by a fluke event or willful disregard of a known rule. However, the default assumption is that such events are rare and there is value in understanding the factors that caused the unplanned releases that occur. For example, the analysis of groups of incidents in similar contexts may sometimes reveal a pattern of vulnerability that could not be identified in the individual case.

2.3 What are lessons learned?

As a concept, lessons learning from incidents (sometimes abbreviated as LFI) has its roots in organizational learning theory. A lessons learned from a chemical incident is an insight that identifies a potential vulnerability in the circumstances surrounding the storage, handling or use of a dangerous substance that could initiate release of the substance from its containment.

A lesson does not have to be new as in the sense of something that was previously unknown. If a person or organization is unaware of a particular lesson, then it is still a lesson for them. There are many instances where a lesson has been learned from an accident but the lesson is not applied elsewhere because other sites fail to recognize that the lesson applies to them. For example, one might ask why are there so many chemical incidents associated with loading the wrong substance into a container. If, despite all the warnings from similar incidents, such an incident occurs on a site, the lesson for the site is that they have a vulnerability that they failed to identify.

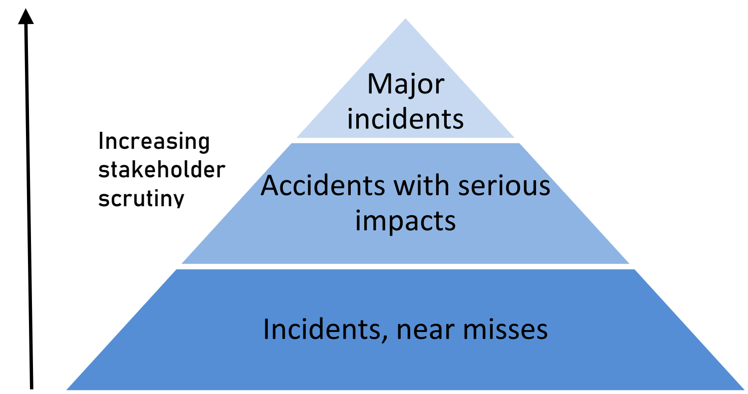
There are many lessons in hazardous industries that have been "learned" many times but are somehow repeated. If a known principle is ignored or violated, the lesson lies in the reason why the principle was known or violated. Moreover, there is also a lesson in repetition. Sometimes a repetition of the error is a signal that there is something deeper that needs fixing.

2.4 What can cause a minor accident can cause a major accident

What can cause a minor accident can cause a major accident. **Figure 3** is a representation of the accident triangle, first proposed by Heinrich in which he suggests there is a quantitative relationship between the number of catastrophic, serious accidents, and minor accidents and near misses. The theory is useful for conceptualizing the value of investigating and learning lessons from near misses.[6] While Heinrich's and others' claim about a universal ratio between the different accident severity types is not credible, the triangle itself is an elegant way to illustrate that minor incidents and major accidents are related.

Good risk management requires tracking all incidents, including "potential incidents" and "near misses". The incident register can then be periodically analyzed as a kind of vulnerability check and to identify potentially recurring threats to safety. When an incident occurs, it normally would be registered but also investigated for lessons learned if it meets criteria established by the operator. For example, one criterion may be that the accident had the potential to cause far more serious harm under other conditions. This practice allows learning lessons from minor events so that major events can be prevented.

Figure 3. The accident triangle



Source: Heinrich, 1931

2.5 Deriving lessons learned vs. determining causality

Causality and lessons learning analysis are two separate activities along the continuum of accident investigation and analysis. First, causal factors are identified and then the analyst will review the causes and extract lessons learned. As indicated in **Figure 4**, there is an inherent logic in this sequence when one considers that different contributing factors may be attributed to a similar underlying condition, e.g., the lack of a training program, failure to adhere to maintenance standards, etc. In many cases, there is no one-to-one relationship between the causes identified and the lessons learned derived from them. Sometimes, many causal factors point to one lessons learned and also, vice versa, one cause can generate more than one lessons learned.

Analytical methods are often distinctive in terms of how they define causality and the conceptual framework they use to link causes to the chain of events. In fact, sometimes investigators and analysts themselves will apply more than one methodology to the same incident in order to obtain more insights about the lessons that could be learned. For example, methods applying barrier analysis seek to identify potential missing barriers between the victims (people or objects) and the harm, that is measures that block from reaching them, or that mitigate its severity. In contrast, system analysis aims to describe the outcome as dependent on prior events and their influence on a system, in particular, looking at the degree to which the system becomes vulnerable to a breach when parts of the system behave in different ways.

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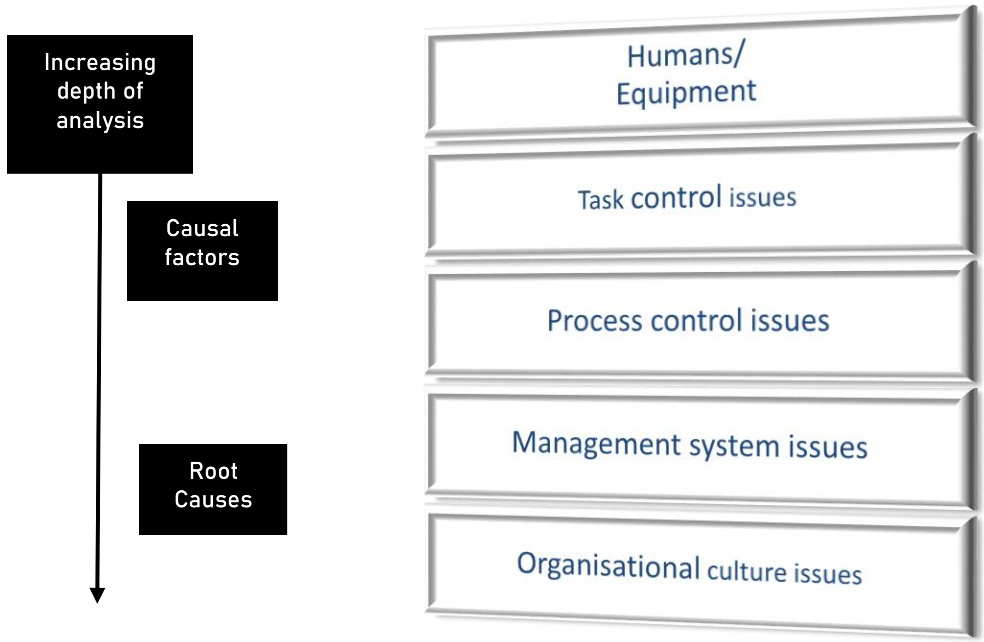
6 . Many factors, including resources, awareness and risk tolerance, can influence whether a site has many or fewer catastrophic and serious incidents in comparison to near misses and minor incidents.

Figure 4. Incident investigation: Levels of analysis



Source: Flowchart by Wood and Allford

Each of these approaches can generate slightly different theories about what contributed to the incident and its severity, and in turn, the causal theory will help to shape views on what are the lessons learned.

The findings of the Accident Analysis Benchmarking Exercise (AABE) (Allford and Wood, 2021) a project conducted by the JRC from 2015 to 2018, provides insights on how a number of commonly used accident investigation/analysis models approach causality. The participating teams evaluated each method used against a number of different factors and also performed a Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis. The team evaluations from the JRC AABE project can be found in **Annex 1** of this document.

2.6 Deriving causality vs. finding blame

Identifying causality is also not about casting blame. Some investigations are inevitably targeted at finding blame, especially criminal and compliance investigations. However, even objectively focused fact-finding investigations will inevitably point towards certain actors that may have failed in their responsibilities or that simply made mistakes, due to lack of information, contradictory information, or other motivation. However, the fear of being punished is a great motivator for hiding the truth. The failure to uncover the truth may risk future lives because without the truth, the learnings that should have been generated are not identified.

Ideally, investigations for finding out what happened and learn from it should be separated from investigations aimed to establish who was responsible. For this reason, it is accepted protocol that accident reports shared for the purposes of lessons learning are devoid of any blame on specific individuals for the incident. However, the no-fault rule does not necessarily exempt organizations from being assigned blame to a certain extent, partly because organizations are already assumed to be at fault if an accident happens and the blame is shared, that is, not exclusive to one person.

2.7 Expertise needed to achieve lessons learning competence

Lessons learning analysis is a discipline. It requires certain competences and an aptitude for analysis and logical thinking. Competence in lessons learned analysis is essential to both industry and government, though in different ways and for different purposes. Auditors and inspectors also need to know what constitutes a useful accident report and good lessons learned practice. There should also be competence in lessons learning available to help management and authorities use accident information to change their risk management practices, and requirements.

In essence, the practice of lessons learning requires the following combination of skills and expertise:

- **Knowledge and experience in process safety**. The analyst should have a firm understanding of the foundational principles of process safety, a systematic approach to risk management, whereby good design principles, engineering, and operating practices are judiciously applied to ensure the integrity of all operations involved in handling and processing of hazardous substances in order to prevent chemical accidents and mitigate their effects.
- **Multidisciplinary skillset.** Process safety is not only a matter of engineering competence, but also often involves knowledge of other disciplines, especially human factors, organizational factors, specialist areas of chemistry and physics, e.g., thermodynamics, energetic substances, etc. Expertise, per se, in all areas is not required. Rather, the analyst should have the ability to navigate less familiar disciplines and acquire knowledge of them as necessary for the analysis at hand.
- **Training and experience in deductive reasoning.** Critical thinking is necessary for evaluating evidence, the circumstances, and relevant knowledge in order to reach reasonable and useful conclusions. Critical thinking is a skill that many disciplines practice regularly, especially since it is often taught as part of mathematics and statistics, but also in the study of philosophy and the law.
- **An open attitude and a commitment to objectivity**. An ability to look at evidence from different perspectives helps to foster creative thinking especially when there is complex causality. Consciously refraining from making biased judgments is a necessary condition for critical thinking.
- **Training in data analysis, if studying groups of incidents.** If the aim is to study groups of incidents for trend analysis from groups of incidents, then a minimum of basic training in data analysis, and descriptive and inferential statistics is necessary. For many thematic analyses, descriptive statistics are the only statistics that can be applied because of the size of the database and heterogeneity of variables (contributing factors. However, inferential statistics knowledge can be useful for data mining and when the incident database under study is sufficiently large and homogeneous. In this respect, it is also helpful to understand inferential statistics enough to know when not to use them.

Chapter 2 Summary

- **Lessons Learned Role in Risk Management -** It identifies how safety boundaries—such as operational procedures, equipment controls, and management practices—can be violated. This ongoing process helps prevent repeating past mistakes, update risk management frameworks, and adapt to technological and social changes.
- **Key Definitions -** The text defines a chemical incident as an unplanned release of a hazardous substance, distinguishing between accidents (events with significant consequences), near misses (incidents with potential for harm that were mitigated), and potential accidents (unsafe conditions halted before escalation). Severity scales, like the European Gravity Scale, further classify the impact of these events.
- **Connection between Minor and Major Incidents -** By illustrating the accident triangle, the chapter emphasizes that minor incidents and near misses are directly linked to major accidents. Tracking and analyzing all types of events, including potential incidents, is essential for early vulnerability detection and proactive risk management.
- **Lessons learned vs. Causality and Blame -** The process of deriving lessons learned is distinct from identifying causality. While causal factors are first determined, the focus shifts to extracting actionable insights to prevent future occurrences, rather than assigning blame. This separation encourages a no-fault approach, fostering an environment where critical learning is prioritized over punishment.
- **The Necessity of Having Lessons Learned Competence -** Effective lessons learning requires specialized expertise, including process safety knowledge, deductive reasoning, data analysis skills, and an objective mindset. Maintaining and enhancing these competencies is crucial for both industry and government, enabling the systematic study of incident patterns and driving long-term improvements in safety practices.

3 What can be learned from chemical accidents

This chapter explains that lessons learned are essential for identifying hidden vulnerabilities in chemical accident risk management and for preventing future incidents by compensating for the limits of human foresight. It details various methodologies—from root cause analysis and loop learning theories to systems and nonlinear approaches—that enable the extraction of actionable safety insights from both individual events and recurring incident patterns. By incorporating real-world examples and systemic analysis models, the chapter demonstrates how understanding and addressing these lessons can drive significant improvements in safety practices, regulatory oversight, and overall risk preparedness.

3.1 Potential for learning from chemical accidents

To a large extent, lessons learned exist as a discipline to awaken the human consciousness to those hidden elements that work, alone or together, to keep the plant safe. Lessons learning compensates for the inability of the human imagination to conceive everything that could go wrong, or to envision an event caused by several things going wrong at once. In particular, many of the components that work towards achieving safety are routine and taken for granted because they are passive, or at least, they require no tangible effort when they are in place. Some examples include a pipe composed with the proper material and structure for the job it is supposed to do. Or one can imagine the experienced employee who instinctively knows how to recognize signs of equipment malfunction or process anomalies that need to be addressed.

Hence, by itself, one individual incident may seem to be of little or no interest, if the technical causality is easy to identify. However, a proficiency in looking beyond the immediate cause to understand why the incident it happened can often yield important lessons learned. This section describes some of the main ways that lessons learning can benefit chemical accident risk reduction.

3.1.1 New safety information and reinforcement of known principles

There is a wide range of information that can be obtained by studying individual chemical incidents or groups of incidents. The information provided can be as simple as a correction to a piece of equipment, a process or a practice. However, the analysis can also show weaknesses in more than one part of the safety management system, as is typically illustrated using James Reason's Swiss cheese model (see **Figure 5**) or alternatively, the layers of protection analysis (LOPA) model (see **Figure 6**).

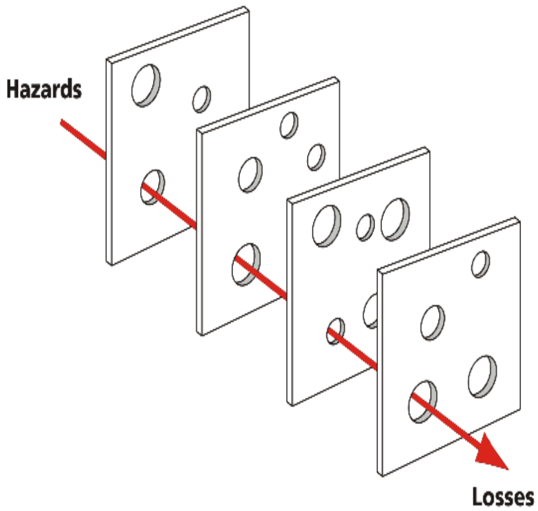
Table 2. Examples of types of the wide range of learning that are possible from chemical incidents

Examples of learnings from chemical incidents	
• Process design vulnerabilities • Equipment design vulnerabilities Substance behavior and rates of degradation under certain conditions • Weaknesses in the maintenance program • Weaknesses in purchasing spare parts and equipment • Failure in inventory management • Gaps in the hazard assessment process • Failure in the risk evaluation process • Lack of resources	• Impacts of a decline in business profit margins • Good practice that prevented a worse incident Ageing infrastructure • Error in process operation • Failure in management of change • Poor safety culture • Unforeseen sequence of events • New information on potential scenarios • New information on potential impacts • New information to improve emergency response

Table 2 lists some examples of what can be learned from an incident. It is often the case that there are several failures that contribute to a chemical incident occurrence. Hence, it is conceivable that all of the items on the list could even be generated from one single event, especially if it has serious consequences. What lessons learned are possible is partly, but not completely, dependent on decisions made in the

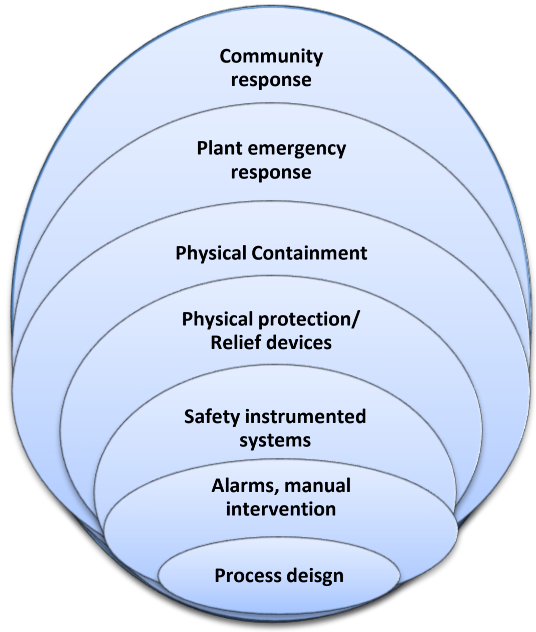
investigation and investigation report. However, with some knowledge of the technology and safety practices, a good lessons learned analyst may also identify more lessons learned than the investigation, by using the technical knowledge in combination with common sense.

Figure 5. James Reason's Swiss Cheese Model



Source: Reason, 1990

Figure 6. Layer of Protection Analysis (LOPA)



Source: AICHE, 2001

3.1.2 Identification of systemic weakness

Figure 7 contains the social-technical model proposed by Rasmussen (Rasmussen, 1997) for identifying the potential actors that may have had some role in causing a technological incident. In applying this construct to chemical accidents, it becomes evident that chemical incidents are not just relevant for the site operators and their workers. Corporate leadership and even the industry sector may bear some responsibility. There also may be findings that implicate contractors and suppliers, whose products or services may have been involved in the incident.

Likewise, an incident may implicate a failure in regulation or oversight, or in the knowledge available to the government that could have played a role in preventing the incident. There are often implications for the emergency responders, but there can be even more far-reaching conclusions whose impact goes beyond the environmental health and safety authorities, for example, affecting equipment regulations or chemical classification and labelling.

There are a number of incident analysis methods, including Accimap, but also FRAM, STAMP, DISC, MTO, the EsREDA Cube, and several others, that specifically aim at learning lessons about systemic relationships from technological incidents. The JRC accident analysis benchmarking exercise (see **Annex 1)** applied many of these methods to explore the potential of these methodologies for chemical accident analysis. A summary of the cases studied and methods used can be found in the project report (Allford and Wood, 2021).[7]

[77] The information is also reproduced within the chemical accident analysis section of the JRC Minerva website.

Text Box 1. Examples of accidents with learnings involving systemic failure

Example of a disaster with lessons learning for government regulators

Tianjin, China, port warehouse explosion, 2015. The disastrous fire and explosion event in the port of Tianjin, China, in 2015, is mainly attributed to lax safety procedures and a deliberate lack of government oversight. The owners of the storage and distribution company at the source of the accident somehow managed to persuade numerous authorities to look the other way in regard to permitting, inspections and hazard control measures. The site began operations in 2014 handling and storing a variety of dangerous substances many in volumes much higher than would be considered safe. According to the official investigation report, there was neither evidence that recognized safety standards were applied nor that workers had been trained for handling hazardous goods. In addition, to causing 165 deaths people and injury to nearly 800 people, 30,000 people in the surrounding community were evacuated.

(State Council of China, 2016)

Example of a disaster with lessons learning for the organization – BP Texas City and BP Macondo

BP Texas City (USA, 2005). On March 23, 2005, a series of explosions occurred at the BP Texas City refinery during the restarting of a hydrocarbon isomerization unit. Fifteen workers were killed and 180 others were injured.

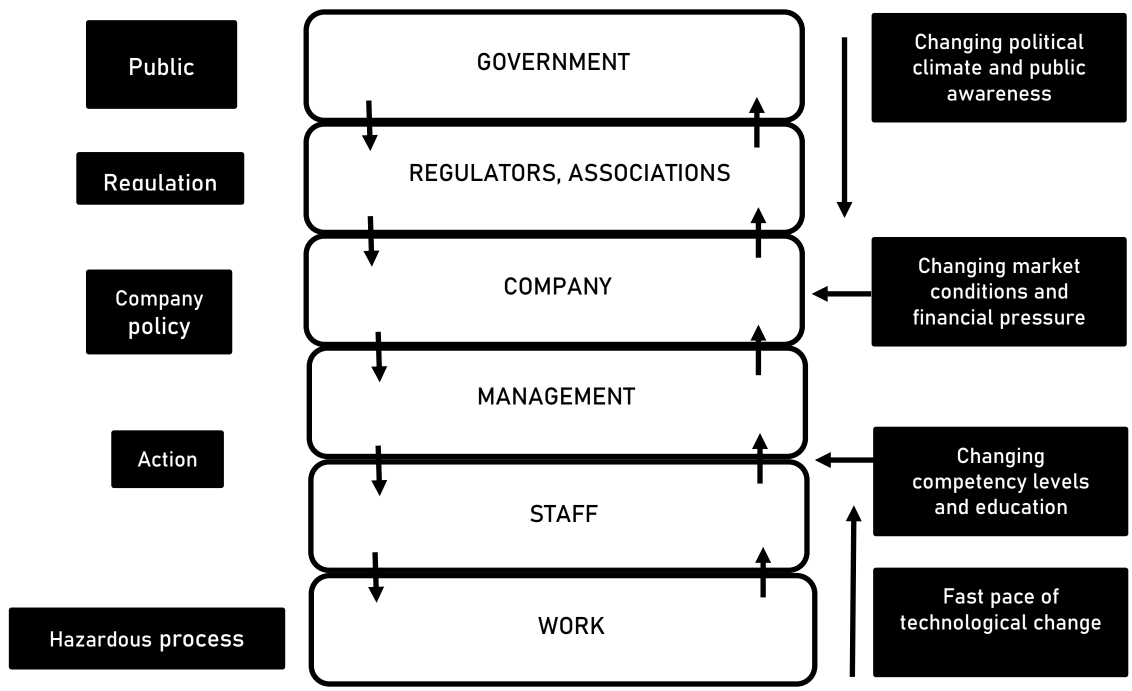
Macondo Oil Drilling Platform (Gulf of Mexico, 2010) The Macondo disaster of April 20,2010, in the Gulf of Mexico, stemmed from the loss of control of an oil well, resulting in a blowout and the uncontrolled release of oil and gas (hydrocarbons) from the well. The accident resulted in the deaths of 11 workers and caused a massive, ongoing oil spill into the Gulf of Mexico.

These two accidents were stupendous organizational failures with remarkably similar causality, including:

- Multiple system operator malfunctions during a critical period in operations
- Not following required or accepted operations guidelines ("casual compliance")
- Neglected maintenance
- Instrumentation that either did not work properly or whose data interpretation gave false positives
- Inappropriate assessment and management of operations risks
- Multiple operations conducted at critical times with unanticipated interactions
- Inadequate communications between members of the operations groups
- lack of risk awareness
- Diversion of attention at critical times
- A culture with incentives that provided increases in productivity without commensurate increases in protection
- Inappropriate cost and corner cutting
- Lack of appropriate selection and training of personnel, and m) improper management of change.

(BP Refineries Independent Safety Review Panel, 2007 and U.S. Chemical Safety Boar, 2016)

Figure 7. Socio-technical model of system operations



Source: Svedung and Rasmussen, 2002

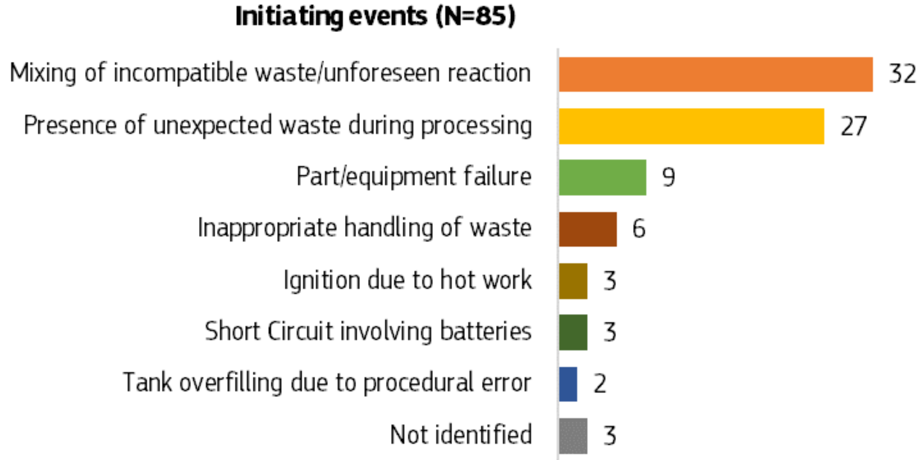
Tianjin and BP Texas City, featured in **Text Box 1**, are two well-known incidents that in many ways were caused by the failure to notice or address a number of parts of the system that were undermining safety. These events also appeared to ignore lessons learned from long experience in managing risk in other operations within the same company and industry. The factors contributing to these disasters have been well documented and notably, many of these factors have also been contributors to many other past disasters. In fact, the investigation report of the Tianjin port disaster indicated that the incident that triggered the sequence of events had already occurred months before (but without significant impacts). The operator failed to make any effort to learn from this initial incident, a decision that resulted in a failure to prevent the loss of 165 lives.

3.1.3 Recognition of failure trends across similar incidents

It is true that a single chemical incident may have rich learning possibilities that could potentially help to prevent a future accident. However, a lot more can often be gained from studying groups of incidents with similar features, for example, involving the same type of site, the same process, the same substance, the same type of equipment, the same type of job, etc. Thematic studies of groups of incidents can have even deeper implications than the single incident study, potentially generating changes that improve safety across industries and influence future government policy. One incident may indicate a site failure, but a repeat of the same incident on many sites may indicate a systemic vulnerability associated with a process, equipment, a practice, or even a particular industry.

Figure 8 shows a clear pattern involving the initiating event from a study of 85 incidents at hazardous waste management facilities. The analysis found that nearly 38% of the incidents (32 out of 85) resulted from a reaction in the waste processing operations. An additional 32% of the incidents (27 out of 85) began with a reaction due to the presence of contaminants in the waste stream. From the study, there is a clear lessons learned that the waste management industry should make improvements in pre-processing waste identification.

Figure 8. Results of a study of chemical incidents at waste management sites



Source: Koutelos and Wood, 2024

3.2 Learnings for targeted audiences

The lessons learned potential from chemical incident analysis also depends on the nature of the learning and how much the lesson learned explores underlying causality. Some incidents have lessons only for the immediate operation, and other incidents have much broader lessons, e.g., for the company at large, standards organizations, regulators, etc. Moreover, as indicated in Chapter 4, the depth and focus of findings from incident investigation determine the extent to which learnings are available. Studies for patterns from groups of incidents may have an even wider range of learnings because the collective findings from all the incidents may have many dimensions.

Table 3 contains a list of potential actors who might benefit from lessons learned studies with potential learnings for these actors indicated as follows:

- The "**All cases**" column refers to what one can learn from any individual incident case.
- The **"Thematic studies"** column refers to what might be additionally obtained by studying groups of incident cases that can give information on a particular theme (e.g., corrosion in refineries, management of contractors, incidents involving ammonium nitrate, etc.).

Thinking about these possible beneficiaries, and their roles in risk management, may serve to stimulate the analyst, to identify additional lessons learned opportunities. This kind of list of potential outputs from incident analysis can guide the analyst, in considering the depth and breadth of the lessons learned that can be considered for any one incident or incident trend study.

The table includes a long list of industrial and commercial and other sectors, such as health care, that use hazardous substances and that could also learn from certain incidents, for example, about dangers associated with improper chemical storage and on training and response to a chemical incident. They need to be kept informed about lessons that pertain to the safe handling substances so that they too implement the relevant practices for preventing accidents and mitigating consequences.

3.3 Analytical frameworks for learning

The investigator, and by extension, the analyst can produce much richer results by having different frameworks for reviewing and presenting information already in mind at the start of the activity. As indicated in **Text Box 2**, different phases of the investigation and analysis may require more than one methodology. This section provides a brief overview of typical approaches to lessons learning, some of

Table 3. How chemical incident lessons learned can benefit various actors within the risk management system (p. 1)

Actor	All cases	Thematic studies
Operator and site managers **(Plant manager, business manager, safety manager, etc.)**	• Identification of vulnerabilities in infrastructure, systems and processes before they cause a serious chemical incident • Essential source of information for hazard identification and risk assessment • Development of reference accident scenarios • Confirmation of good risk management decisions that prevented or reduced impacts	• Identification of systemic vulnerabilities across similar types of substances, equipment, processes, and practices, and development of new recommended practices • Source of information for design and construction of equipment and processes • Inputs to probabilistic risk assessment • Insight on how to set priorities for allocation of resources, e.g., for maintenance, training, hiring, etc.
Employees **(Site and company staff, contract staff, unions)**	• Identification of bad practices to avoid and good practices to follow for specific jobs	• Improved ability to recognize safe and unsafe situations • Knowledge for responding safely to unsafe situations
Company leadership **(Corporate management, owners or shareholders)**	• Insight into vulnerabilities in the safety management system of a specific site, business unit, or the entire organization that requires management attention. • Insight into good practices that helped prevent or reduce impacts and that could be applied site/company-wide • Identification to reinforce good practice with dissemination of lessons learned	• Foresight on potential risk exposure associated with current and future businesses • Opportunities to reduce risk exposure in current and future businesses
Emergency responders **(On site responders, local police and fire fighters)**	• Development of reference accident scenarios • Confirmation of good emergency planning and response decisions that prevented or reduced impacts • Identification of elements of the authority's emergency response that may require heightened attention or improvement	• Identification of systemic vulnerabilities in emergency planning and response across similar types of substances, equipment, processes, and development of new recommended practices
Suppliers **(e.g.,, equipment, substance, software, infrastructure, etc.)**	• Identification of improvements needed in the product, or in associated handling procedures, documentation, training,, maintenance, etc., as relevant	• Opportunities for innovation to reduce incidents involving equipment

Table 3. How chemical incident lessons learned can benefit various actors within the risk management system (p. 2)

Actor	All cases	Thematic studies
Industry sector and their insurers	• Identification of vulnerabilities in processes and practices that could be reduced with a common industry approach • Opportunity to reinforce good practice with dissemination of lessons learned • Potential addition to or modification of widely used industry reference scenarios	• Foresight on potential risk exposure associated with changing market dynamics and new technologies • Promotion of strategic approaches to reduce systemic risks associated with specific processes, equipment and practices
Inspection, licensing and land-use planning authorities	• Identification of vulnerabilities, and associated improvements that may be needed, relating to site risk management • Identification of elements that may require heightened attention across all similar sites	• Identification of systemic vulnerabilities across similar types of substances, equipment, processes, and practices to improve performance expectations, practices and checklists • Development of new requirements and criteria for certain types of sites
Government policymakers **(Environment, labor, civil protection, transportation, chemical classification and labelling, etc.)**	• Insight into vulnerabilities in the regulatory framework, or on products and substances, that may require re-evaluation • Evidence that policy decisions that may have influenced a positive incident outcome • Identification of weaknesses in the implementation of obligations of the authorities	• Foresight on potential risk exposure associated with emerging developments in technology, the economy and society that may require modifications in policy • Identification of potential systemic vulnerabilities that may merit government attention
All hazardous industries	• Identification of vulnerabilities that may apply to all hazardous industries and require heightened attention • Opportunity to reinforce good practice on relevant practices with dissemination of lessons learned	• Foresight on potential risk exposure associated with changing market dynamics and new technologies common to a wide range of hazardous industries and processes • Promotion of strategic approaches to reduce systemic risks associated with practices common to a wide range of industries
Society	• Insight on the reliability of the site's risk management approach • Contribution to decisions about the future of the site and development around the site • Opportunity to engage with the site on a risk reduction strategy	• Foresight on the safety risks associated with various industry sectors • Priorities and recommendations for engaging in dialogue with government and industry on industrial risk in the community

which are derived from typical approaches to causality. The scientific literature on lessons learned provides a far richer and more varied description of the various theories than this hand book. For those interested in exploring the topic further, some useful references are listed in **Annex 2**.

Most of the existing literature on accident analysis is targeted at the investigator. As such, it is important to remember in using the material provided here that the level of detail available on the incident determines the depth and breadth of lessons learning. In many reports, there is limited detail on secondary causality. However, understanding the framing of causality may help to extract additional lessons learned from an incident even when details are limited, and even more so, if one finds a pattern of causality across similar incidents.

Text Box 2. Using different accident analysis methods for different analytical purposes

Different methodologies can play different roles in the overall accident analysis

It is often useful to use different theories in combination to disassemble the incident information for analysis. The JRC's Accident Analysis Benchmarking Project considered that analyses often follow a logical progression, starting with:

- understanding the chain of events (chronology)
- followed by a determination of the direct causes (events that produced immediate effects in the chain of events)
- underlying causes (adverse 0r undesirable conditions that facilitated the direct causes)

The project then decided to break down the analyses into three explicit phases and use appropriate methods for each phase as indicated below.

Phase 1: Chronology e.g. Step/ECFA

Phase 2: Causal e.g. Bow Tie, Change Analysis

Phase 3: Underlying causation e.g. AcciMap, MTO, STAMP

Not all analytical methods fit neatly into the above phases. For example, Tripod Beta also aims to generate underlying causes, however, it does not go as far as Accimap or STAMP to generate organizational or systems causality. Rather, these methods can be viewed as existing somewhere on a continuum, with a very simple chronological analysis models on one end and the most complex systems analysis models on the other end.

3.3.1 Root cause analysis as a basis for lessons learning

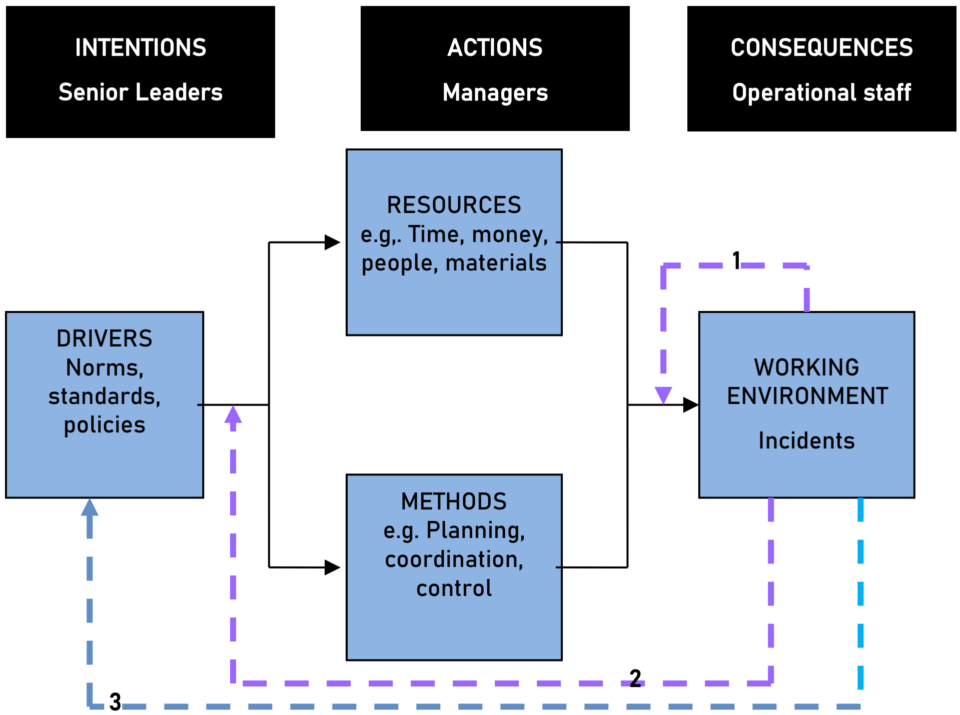
Root cause analysis theories classify causal factors according to their place in a hierarchy of causality that includes immediate causes and a root cause. This approach is adopted by some well-known methodologies, such as, Tripod Beta and Event and Causal Factor Analysis (ECFA). Barrier analysis (e.g., as in the MTO method) is a type of root cause analysis that borrows the nomenclature of James Reason's Swiss cheese theory, in which the underlying causation is considered a number of as failed barriers.

Root cause analysis assumes that the immediate cause is a symptom of a deeper causality, that is, a root cause. Some methodologies for causal identification may only use two layers of causality (e.g., primary and secondary events), but for lessons learning, in many cases, a three-part hierarchy is often useful. This approach starts with the immediate cause, for example, the pipe broke, and proceeds to identify an underlying cause (defect in the maintenance program), and a root cause (the maintenance program is out-of-date). There may be cases where the underlying cause is not a symptom of a third level of causality.

Root cause analysis models are useful for working back from a sequence of events to understand what happened and assign the immediate causes for each event in the incident sequence. An understanding of direct cause and effect is a necessary step before conducting deeper analysis on underlying causes and interdependencies within different parts of a system that may have contributed to the incident occurrence and the range of severity its consequences.

Figure 9. Single-, double- and triple-loop learning

As learning advances from single to double to triple-loop learning, the opportunity for learning is greatly expanded.



1: Single-loop learning
2: Double-loop learning
3. Triple-loop learning

Source: Allford and Guichon, 2007

3.3.2 Single, double and triple loop learning

The "loop" theory, first described by Argyris (Argyris, 1977) is centered on the processing of the information learned. According to this theory, there are different levels of processing, such that "single-loop" learning occurs when only a specific situation or process is addressed, for example, the broken pipe. So-called "double-loop" learning is achieved when the learning is applied more generally to improve the values, assumptions, and policies that allowed certain actions to occur. In reducing chemical accident risk, double-loop learning should lead an organization to review how its management systems and philosophy should be changed to prevent future failures. The concept of triple-loop learning was later devised to build on the idea of learnings aimed at the organization. According to this theory, triple-loop learning is achieved when there is an awareness of a deeper purpose that can influence the strategic thinking of an organization, stimulating adaptation of structural elements to foster continuous improvement. **Figure 9** depicts elements typically involved in each of the different loops.

One way the triple loop learning is applied in chemical accident analysis is to identify the technical failure, and the remedial action that ensures, as the single loop learning. ("Welding activity caused a fire. Any residual substance should be purged completely before the welding starts.") The double loop becomes a learning for the safety management system on the basis of the failure that created the circumstances that made it likely that the pipe would break. ("Personnel should be trained to purge tanks properly.") A triple loop usually is a reflection on the culture or structure surrounding the work and may have organizational implications. ("Management assumes purging is an easy and simple task that doesn't require a lot of training and staff responsible for purging are unaware of the need to check that the purging was complete.")

The organizational learning envisioned by the triple loop theory is generally the most difficult to achieve and, as a result, less common. One barrier to organizational learning is that incident investigations conducted by the site operator will typically not focus on the organizational failures. The organization is not particularly motivated to criticize itself.

However, a major accident often does stimulate internal reflection within companies about organizational factors that may have contributed to the event. Third parties, such as independent investigations and safety boards, also sometimes target when efforts to identify triple loop causality are sincere. Yet still it can be a challenge to identify the organizational vulnerabilities that may have contributed to the event, despite good intentions. Organizations are dynamic systems, and identifying the points in the system where something went wrong is often not easy to trace in a precise way. The specific facts leading to critical decisions may often be elusive with different actors remembering what happened slightly differently. Moreover, few near misses or potential incidents identify organizational failures, so that there may not be a lot of evidence available in the record, beyond the main event, for drawing conclusions.

Moreover, even when organizations do find important learnings, they may not have the structure in place to remember them for long. The culture, the politics, economic pressures and other influences on organizations may work against retaining the memory of what went wrong. In particular, if a company has not already been cultivating a safety-focused culture before a disastrous event, it may not have an infrastructure that will allow the learnings to become a permanent part of its way of working. Moreover, completing a program to incorporate the learnings requires commitment over the long term, that is, often undermined with the re-organizations and changes in leadership, that occur regularly in many corporations. (Cowley, 2020)

3.3.3 People, plant, process approach

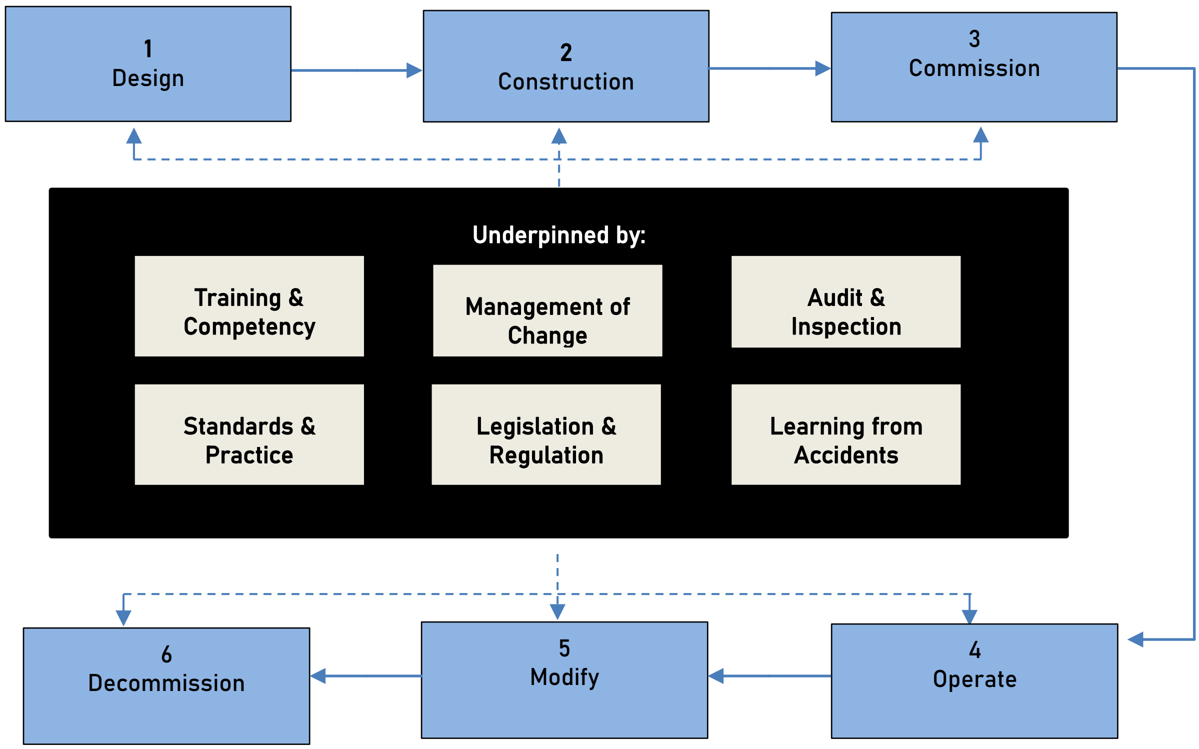
Analysts can also use the People, Plant, Process approach for lessons learning (the "Three Ps"), derived from a philosophy of risk control that centers on maintaining the integrity of the three essential components of an industrial activity, that is, People, Plants and Processes. This perspective is used as a model for establishing safety management systems, in which each element and sub-element of the safety management system, so that practices and procedures, the work flow, the knowledge base and knowledge management, information acquisition and exchange all line up to sustain system integrity. There are elements of the 3Ps in some investigation and analysis methodologies, particularly in root cause analyses, in which failures or barriers are described in terms of "targets" that are acted upon by "agents". People, plant and process elements can all be either targets or agents, and sometimes the target of one action in a sequence of events becomes the agent of another.

This method of identifying lessons learned is intended to identify failure in terms of the interaction between one part of the operation and another. It also is useful for highlighting sequential causality, that each action entails a reaction that may entail another reaction, etc. By using this approach, the lesson learned analyst can also be inclusive of all components whose vulnerability may have contributed to the accident. By explicitly considering each P, the analyst avoids the trap of focusing only on the vulnerability of one element, e.g., the equipment or a human error.

3.3.4 Nonlinear analysis, complex causality and systemic risk

Charles Perrow famously brought forward the idea of complex causality in his ground-breaking book, *Normal Accidents: Living with High Risk Technologies*. (Perrow, 1984) Most recently, researchers such as Leveson, Hollnagel, and Dekker (but also many others) have developed models that explain safety, as a collective output derived from the effective functioning of many parts of the organization. Similarly, Rasmussen conceptualized accidents as a result of interactions within the sociotechnical system that includes actors outside the organization, such as local government, regulatory bodies and trade unions. These models are important in that they can guide hazardous operators towards identifying systemic weaknesses and create narratives that support ongoing double- and triple-loop learning. **Figure 10** shows how various parts of the sociotechnical system can influence risk management in different phases of the life cycle of a hazardous activity.

Figure 10. Influences on risk management across the life cycle of a hazardous activity



Source: Flowchart by Allford and Wood

New insights into lessons learned can arise from by viewing accidents as being caused by a system rather than a linear sequence of events. Thinking in this way helps to give weight to certain types of failures than others that supports establishing priorities in the risk strategy. Systems approaches can also identify how safe operation is dependent on the role of supporting structures in reinforcing strengths and filtering out weaknesses.

There are a number of causal concepts useful to lessons learning that emerge from this perspective. One of the most well-known is common-mode failure, **Common mode failure** refers to anything in the operating environment that provides a function or service to support multiple safety-related functions. As noted by Perrow, most systems have at least one common mode failure, for example, the external environment and extreme weather potential. In reality many industrial sites will have several vulnerabilities of this kind, particularly the electrical infrastructure and computerized operations, but there may be many more on any given site.

Non-linear causality is another formulation emerging from systemic risk theory. This concept refers to a failure that generally occurs largely as a result of a number of things going wrong rather than just one. To some extent, this idea reflects barrier analysis in that a loss of containment may be the result of not just one, but multiple failures prior to the event. However, this idea is intended more to capture situations in which a set of seemingly unrelated interactions occur together in a space of time, they may create conditions for failure. In large part these actions as unplanned or unexpected sequences that are not easily visible in a straight-forward analysis of the safety system. For example, this circumstance can arise simply because of changes occurring in more than one part of the system when the system safety relies on each part being stable and predictable. To give a very simple example, an unexpected equipment failure combined with the unplanned absence of experienced operations staff could result in the replacement staff conducting a wrong procedure and causing an incident.

Close-coupling of causal factors is a version of, nonlinear causality that focuses on the ability to interrupt a disastrous sequence of events. In a tightly-coupled process, components are highly interdependent, such that each step of the process has to be calibrated precisely, occur in a particular order, within a specific period of time. This attribute can enhance system efficiency and it is often the purpose of automated systems to deliver this result. The challenge is always in balancing efficiency with flexibility. As more steps in the process are tightly coupled, there are also more places where a failure can occur that will have a domino effect on the performance of the rest of the system. A simple example could be when an instrument failure gives a wrong signal, e.g., the tank is empty when it is actually full, and triggers an automatic discharging of additional volume of a substance into a full tank.

In addition, **socio-technical causality** (see **Table 4)** expands upon the theory of multi-layer causality to include influences, internal and external to the organization that may play a role in determining an organization's resilience in the face of chemical accident risk. This perspective helps bring influences such as safety culture and market trends into lessons learning. For example, the organization has proper safety procedures in place and recognizes the relevant technical standards, but respect for the procedures and standards may be undermined by management attitudes or the lax approach of government authorities to enforcement.

Table 4. Socio-technical causality: Some currently trending topics (Wood, 2018)

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 complex systems
Increase in outsourcing of personnel	Increasing equipment 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 control processes
New products, processes and market demands	Renewable energies, hydrogen fuels, biofuels, and liquefied natural gas (LNG) industries all examples of sectors in a growth phase where in some risks aspects are limited
Organizational management, including organizational change	Change affecting the entire site or company, e.g., change of ownership, re-organization, 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

Quantitative Comparative Analysis (QCA). It is often easier to talk about complex causality from a conceptual perspective than to conduct such analyses in practice. Imagine if a serious incident happened during the Covid epidemic of 2020-2022. One can think of any number of failure scenarios stemming from the abnormal conditions imposed by this particular situation. Yet it requires considerable speculation to determine which pieces can be attributed to Covid-19 pandemic restrictions, rather than existing site conditions, such as poor management or lack of safety awareness. QCA offers a structured systematic approach to assigning causality to underlying conditions that are both dynamic and interactive with the operating environment. (Cowley, 2020) Precision and certainty of analytical findings rely on one-to-one, one-way relationships. In general terms, as causality becomes more complex, it moves farther and farther away from this ideal model. To a large extent, QCA is built on analyzing complex causality by breaking the causality into measurable one-to-one relationships.

3.3.5 The art of using analytical methods to add value to chemical incident analyses

The conceptual models and frameworks are useful for looking at an incident in different ways to identify contributing factors to the occurrence. The outputs of the models themselves do not represent the outcome of the analysis. Rather, the models offer a way of sorting through the evidence to generate relationships. The analysis itself is performed by the analyst who uses these tools to establish relationships. Then it is up to the analyst to judge the significance of the relationship in light of the objectives of the study.

The art of lessons learned analysis is to be able to optimize methods, resources and time. While the analyst ideally chooses the tool that is most suitable for the objectives of the analysis, time and resource constraints may limit their choices. However, there is a wide selection of methods, many of which can produce similar results. As indicated in **Annex 2**, many of the models have guidance for using them online. Moreover, in many cases, it is not necessary to use a model, especially when performing thematic analyses of groups of incidents, in which case, descriptive statistics are sometimes sufficient to provide the insights the analyst needs. The choice of method is usually based on its suitability combined with its accessibility to the analyst, who often will prefer some methods over others based on training or temperament.

Chapter 3 Summary

- **Learning from Chemical Accidents -** Lessons learned help uncover hidden risks and safety gaps that may not be immediately obvious, compensating for human limitations in anticipating complex failures.
- **Types of Learnings**:- Chemical accident analysis can reveal new safety information, reinforce known principles, and highlight vulnerabilities in design, maintenance, risk assessment, management of change, and safety culture.
- **Systemic Weaknesses and Trends**:- Incidents often reveal broader systemic failures involving corporate leadership, suppliers, regulators, and emergency responders, with patterns across similar accidents indicating industry-wide vulnerabilities.
- **Impact on Various Stakeholders**:- Lessons learned benefit a range of actors, including plant operators, employees, regulators, policymakers, insurers, and society, by improving risk management, emergency response, and regulatory oversight.
- **Analytical Frameworks for Learning -** Root cause analysis, single/double/triple-loop learning, and systemic analysis models help extract deeper lessons from incidents, guiding improvements in safety practices, organizational learning, and policy-making.

4 Conducting learning investigations

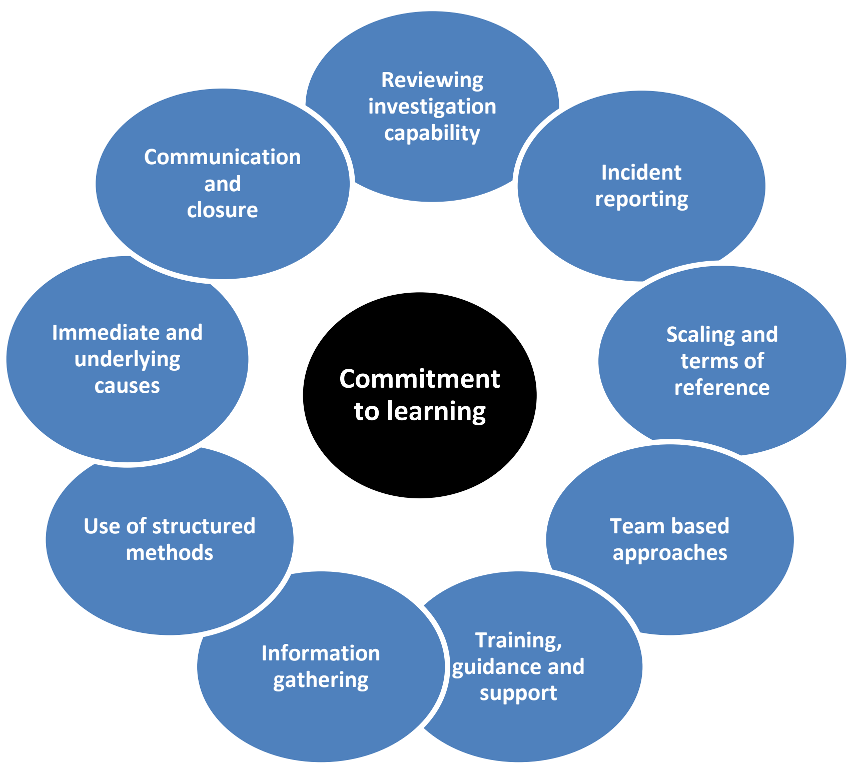
This chapter concentrates on what is termed "learning investigations", that is, incident investigations with an exclusive focus on learning so as to avoid repetition of similar future incidents. Although each incident has a unique set of causes, conditions and consequences, it is generally accepted that adverse events have occurred which mirror past incidents. As a result, industry and wider society is regularly slipping down the learning curve in the prevention of human induced accidents.

4.1 Optimizing an investigation for lessons learning

Learning investigations are about commitment and vision married with practicality to make the best of the investigation for lessons learning within resources and other constraints. A learning investigation is a distinct from a blame-finding investigation, such as a criminal investigation, and operates as a completely separate operation than any other kind of investigation. To describe a learning investigation, this chapter is organized in accordance with the "Ten Point Prompt List" as depicted in **Figure 11.** The presence of all these elements in the investigation is an assurance that learning will occur and that the learning is likely to result in implementation of what is learned.

Central to the investigation process, as indicated in **Figure 11**, is the organizational commitment to learning which informs and shapes the investigation programmer as well as individual investigations. Following this initial condition, the other nine elements are recognizable as discrete stages in an individual investigation such as scaling and terms of reference, information gathering and immediate and underlying causes whilst other elements relate to the investigation programmer itself such reviewing investigation capability. Flaws in one element will adversely impact others and unresolved issues at the front end of an investigation have the potential to derail subsequent activities.

Figure 11. Ten point prompt list – Accident investigation



Source: Rospa website

4.2 Commitment to learning

At the heart of organizational learning from incidents is a commitment to learning which is rooted in continuous improvement in processes and systems. It embodies a culture where incidents serve as catalyst for reflection, analysis and refinement of safety practices. This commitment transcends mere compliance reflecting a dedication to evolve beyond reactive measures towards proactive risk mitigation.

A commitment to learning starts with having a process to identify and filter accidents and near misses, extracting lessons learned from each with an effort proportionate to the severity of the failure that occurred. Learning from incidents is most relevant for the hazardous site and a commitment to learning suggests that every hazardous site will be ready to investigate all incidents that might bring important learnings to the degree that is appropriate. However, society at large, should also have a commitment to learning from incidents. Learning from incidents is in the public interest, especially if the institutions that are designed to help prevent serious incidents are perceived as having failed.

At its core, commitment to learning entails a shift in perspective, viewing accidents and incidents not as isolated failures, but as invaluable learning opportunities. It acknowledges that behind every mishap lies a wealth of insights waiting to be discovered. Such insights can illuminate underlying systemic weaknesses, procedural gaps, or human factors contributing to safety lapses.

Ultimately, commitment to learning starts at the top, with organizational leaders setting the tone and modelling the behaviors that they wish to see reflected throughout the organization. Such leaders priorities safety and embrace a learning mindset, and inspire confidence, trust, and engagement among their teams, laying the foundation for a culture where safety is not just a priority, but a shared value ingrained in every aspect of the organization's operations. A commitment to learning from incidents boils down to whether the organization is ready to investigate incidents and then be prepared to follow through on recommendations and actions.

It is important to note that incident investigation in this context is a "learning investigation" although for the sake of brevity throughout this section, the term investigation is used.

4.3 Incident reporting

Incident reporting relies on the vigilance and diligence of every employee, from frontline workers to management personnel, who play a critical role in identifying and reporting incidents as they occur or come to their attention. Effective incident reporting requires clear and accessible reporting channels and procedures, ensuring that employees can easily report incidents without fear of reprisal or judgment. It encompasses a wide range of incidents, including accidents, injuries, property damage, environmental spills, equipment failures, near misses, and unsafe conditions. By documenting incidents, organizations can identify patterns, trends, and recurring issues, enabling them to take corrective action and implement preventive measures to mitigate current risks.

Text Box 3. Example of a criteria for reporting a chemical incident

Adapted from COMAH Remodelling: Investigation Procedure – United Kingdom (HSE, 2010)

A Seveso Relevant Incident is an incident at a Seveso establishment that is or could potentially have become a Seveso 'Major Accident' and must:

- involve a dangerous substance(s); and/or
- involve a failure of part of the safety management system (SMS)

Seveso relevant incidents include 'Major Accidents', as well as some other accidents, incidents, dangerous occurrences or other near misses (precursors) relevant to Seveso.

Seveso relevant incidents may come to light from reported incidents through other agency reporting channels, from complaints received or from Competent Authority inspection (e.g., inspection of maintenance system records or incident/near miss reporting records).

Moreover, incident reporting fosters transparency and accountability within the organization, as it enables stakeholders to track and monitor safety performance, identify areas for improvement, and measure the effectiveness of safety initiatives over time. It forms the foundation for data-driven decision-making and strategic planning in safety management. **Text Box 3** gives an example of a policy in the United Kingdom for determining incidents that should be reported by hazardous sites. At the time that these criteria were established, the United Kingdom's COMAH programmer, still in existence today, represented the country's transposition of the EU Seveso Directive.)

4.4 Scaling and terms of reference

Together, scaling and terms of reference provide a roadmap for conducting a systematic and comprehensive investigation that yields meaningful insights and recommendations for preventing future accidents. They help streamline the investigation process, clarify roles and responsibilities, and ensure that efforts are aligned with organizational goals and priorities. By establishing a solid foundation at the outset, organizations can maximize the effectiveness and impact of their incident investigation efforts.

4.4.1 Scaling

Scaling involves determining the scope and magnitude of the investigation based on the severity and significance of the accident or incident. It requires careful consideration of factors such as the extent of injuries, property damage, environmental impact, and potential regulatory implications. By scaling the investigation appropriately, organizations can allocate resources effectively and ensure that efforts are focused on addressing the most critical issues.

Text Box 4. Example of criteria for determining the scale of a chemical incident investigation

Adapted from COMAH Remodelling: Investigation Procedure – United Kingdom (HSE, 2010)

Routine vs Major Incident Investigations

A Seveso Routine Investigation is an investigation of a 'Seveso Relevant Incident' that can be carried out and concluded using normal resourcing of the Competent Authority at local level without disruption to normal operations of the Competent Authority.

A Seveso Major Incident Investigation is an investigation of a 'Seveso Relevant Incident' which demands a response beyond the routine, i.e. significant deployment of Competent Authority resources (particularly staff time),

4.4.2 Terms of reference

Terms of reference, on the other hand, establish the framework and parameters for the investigation. They outline the objectives, scope, methodology, and responsibilities of the investigation team, providing clear guidance on how the investigation will be conducted. Terms of reference help ensure consistency, thoroughness, and accountability in the investigation process, while also setting expectations for stakeholders involved in or affected by the investigation. **Text Box 4** shows an example of criteria for determining the scale of a routine vs. major incident investigation from the United Kingdom that would be a typical starting point of the terms of reference of an incident investigation.

4.4.3 Balancing cost, time and quality

An incident investigation can be treated as a project with the aim to strike a reasonable balance between the components of costs, time, and quality (see **Figure 12**). The potential problem is that the three components can become out of balance resulting in unsatisfactory outcomes. If the overarching aim of an investigation is to produce high quality outcomes (due perhaps to the scale of the actual or potential consequence of the incident), then it must be well resourced to assure completion in a timely manner, particularly in terms of effort and personnel resources dedicated to the investigation. If it is not well resourced, then the investigation risks both moving too slowly and potentially failing to achieve its objectives. Similarly, there may be strong pressure to wrap up the investigation quickly which can lead to poor quality outcomes if the resources are inadequate.

Figure 12 . Trade-offs to consider in balancing resources, cost and quality of the investigation

Source: Figure by Allford and Wood

An effective risk-based approach to incident selection for investigation should:

- Consider those incidents with the potential for greater severity and not restrict investigations solely to events with serious adverse outcomes
- Prioritize improvement opportunities based on a comprehensive risk assessment rather than solely focusing on the most severe, sensational, or costly outcomes.
- Consider the organization's adverse event profile and balance the capacity and demand for investigations

An investigation team leader will need to manage the three project components of the investigation, bearing in mind that the investigating organization will invariably need to attend to its business as usual whilst the investigation is active. It is worth noting that near misses or close calls have on occasion been referred to as "free lessons", in the sense that they result in no adverse consequences. This statement is only partially true. Investigations cost time and money. If near misses are to be investigated fully so that they result in the learning that enables the avoidance of repeat incidents, then they are certainly not "free lessons".

4.5 Team based approaches.

An accident investigation is rarely a solo activity with a lone investigator working in relative isolation to the facility under investigation. Accident investigations benefit from a team-based and multi-disciplinary approach with leadership provided by a manager with the appropriate seniority and competence to manage the technical, social, and political pressures that are placed on an investigation (see **Text Box 5**). Membership of the team may involve experts who can provide knowledge of technical aspects surrounding an incident as well as those who have the necessary experience in the conduct of investigations e.g., accident analysis. Such a team may involve front line workers, safety representatives and supervisors with the aim of drawing on their practical knowledge. The advantage is that these team members can become champions for necessary safety changes outside of the investigation team within the wider organization.

4.5.1 Advantages of team-based approaches

Team-based approaches emphasize collaboration, shared responsibility, and diverse perspectives in the investigation process. Rather than relying solely on individual expertise or experience, team-based approaches harness the collective wisdom and skills of a multidisciplinary team to conduct thorough and effective investigations.

These approaches recognize that incidents are often the result of complex interactions between various factors, including human behavior, organizational systems, and environmental conditions. By bringing together individuals with different backgrounds, expertise, and viewpoints, team-based approaches enable a more comprehensive analysis of the incident, uncovering underlying causes and contributing factors that may have been overlooked by individual investigators.

Team-based approaches also promote accountability and buy-in among team members, as each member plays a vital role in contributing to the investigation process and shaping its outcomes. By involving frontline workers, supervisors, managers, safety professionals, and other stakeholders in the investigation team, organizations can foster a sense of ownership and commitment to implementing recommendations and preventive measures.

Text Box 5. Example of an investigation job description for the investigation manager

Adapted from COMAH Remodelling: Investigation procedure – United Kingdom (HSE, 2010)

The Investigation Manager shall form the primary investigation team and shall ensure it is sufficiently resourced. Resourcing considerations include:

- Leam capabilities (to include regulatory/investigative/enforcement skills, experience of previous Seveso routine or major incident investigations, industry sector knowledge, technical specialist skills, office/evidence management skills and administrative support); and
- Other resources (e.g., accommodation and equipment).

The investigation manager should also ensure the primary investigation has sufficient access to legal advice throughout the investigation.

4.5.2 Challenges of team-based approaches

An important challenge is deciding how much diversity of experience and competence is needed for a team. One approach is to consider how likely it is that the event will happen again and the likely consequences if it does, as illustrated in **Tables 5** and **6**. The combination of likelihood and consequence determine the depth of an investigation. The deeper the investigation, the broader the selection of members in the incident investigation team which may mean inclusion of individuals within the same organization but working remotely from the accident location, and when appropriate, from external specialists.

Table 5. Investigation depth

Likelihood	Actual and Potential Consequence			
	Minor	Serious	Major	Fatal
Rare	Minimal	Low	Medium	High
Unlikely	Minimal	Low	Medium	High
Possible	Low	Medium	High	High
Likely	Low	Medium	High	High
Certain	Low	Medium	High	High

Another challenge is associated with team composition. Form a team should keep in mind the potential for conflicts of interest within the investigation team, especially one that recruits heavily from an organizational unit which has directly experienced the incident under investigation. Individuals who are proximate to an incident, either physically or organizationally, are unlikely to act as objective and unbiased team members in an investigation although they may well contribute to the body of evidence gathered by the investigation team

Table 6. Team composition v investigation depth

Investigation Depth	Who Investigates	Immediate Causes e.g., Premises, plant, substances, procedures, people	Underlying Causes e.g., Planning, risk assessment	Underlying Causes e.g., Organization, monitoring, review	Root Causes e.g., Policy issues, resource allocation
Minimal	Unit	Yes	Maybe		
Low	Section	Yes	Yes	Maybe	
Medium	Organization (onsite)	Yes	Yes	Yes	Maybe
High	Organization led team (wider organization)	Yes	Yes	Yes	Yes

4.6 Training, guidance and support

In a learning investigation, it is essential that the team members are focused on cause rather than blame. They should be fully briefed on the scope, objectives, and strategy aligned with the investigation. The team should have a unified vision about how to implement the strategy, Training and guidance are necessary to establish a common perspective in this regard.

4.6.1 Training

Training encompasses programs established in anticipation that an incident investigation will be necessary. The program should be designed to equip personnel with a common set of knowledge, skills, and competencies necessary to conduct thorough and effective accident investigations. At minimum, training should include on investigation techniques, data collection methods, incident analysis methodologies, and relevant regulatory requirements. When investigations are aimed to produce findings to prevent future chemical accidents, they should include training on how to extract and identify lessons learned. By investing in training initiatives, organizations empower their personnel to respond to incidents promptly, conduct comprehensive investigations, and implement appropriate corrective actions to prevent recurrence.

One of the crucial aspects of training is determining the minimum frequency that investigators must practice their skills to maintain competence. Larger organizations have an expectation that near misses and potential chemical incidents will occur routinely so they tend to possess a team of full time and practiced investigators with sufficient investigation opportunities to remain competent. Maintaining competence is more challenging in smaller organizations with part time investigators who are only occasionally called on to investigate mid to low level incidents.

4.6.2 Guidance

Guidance refers to the provision of clear, consistent, and actionable guidance to support personnel throughout the investigation process. The guidance should include the steps to follow when responding to incidents, documenting investigation findings, analyzing underlying causes, and developing recommendations and lessons learned. Guidance helps to ensure that investigations are conducted systematically and in accordance with established protocols, and that the efforts are focused on identifying causes and lessons learned within the scope as defined by the terms of reference.

4.6.3 Support

Support involves offering assistance, resources, and encouragement to personnel involved in the investigation process. Support may include providing access to subject matter experts, consultation services, and technical resources to address complex or challenging aspects of the investigation. It also involves fostering a supportive work environment where personnel feel empowered to seek help, ask questions, and share insights and concerns related to the investigation. Some situations may require coaching on appropriate methods, leads to follow, and how to solicit information from particular witnesses. By making timely and targeted support available, organizations invest in the well-being of investigators, and therefore, the overall success of the investigation in finding out what happened and how a similar event might be prevented in future.

4.7 Information gathering

Information gathering encompasses the systematic collection and analysis of data, facts, and evidence relevant to the incident under investigation. It serves as the foundation upon which the investigation process is built, providing investigators with the necessary insights and context to understand the sequence of events leading up to the accident and identify contributing factors and lessons learned.

The gathering of information is common to all accident investigations, regardless of scope, and can be considered to break down into the three sources below. These are:

- What an investigator sees e.g., by observation/inspection in and around the incident scene
- What an investigator reads e.g., document and records
- What an investigator is told e.g., through interviews and personal testimony

4.7.1 Typical information gathering activities for a chemical incident investigation

In general, information gathering involves a variety of methods and sources, including

- **Interviews with witnesses and involved parties** to obtain firsthand accounts of the incident, shedding light on the actions, decisions, and conditions leading up to the accident.
- **Examination of physical evidence at the scene** to reconstruct the sequence of events and identify potential causes or contributing factors, including documenting the condition of equipment, machinery, or infrastructure involved in the incident, as well as collecting samples or measurements to support further analysis
- **Review of documentation and records**, such as work orders, safety procedures, training records, and maintenance logs, to provide valuable insight into the organizational context surrounding the incident, including the relevant policies, procedures, and practices in place at the time of the accident, and to identify any deviations or deficiencies that may have contributed to the incident.
- **Analysis of data and trends** allows investigators to identify patterns, correlations, and anomalies that may be indicative of underlying issues or systemic weaknesses. This may involve reviewing incident reports, near-miss reports, accident statistics, or other relevant data to identify common themes or recurring problems.

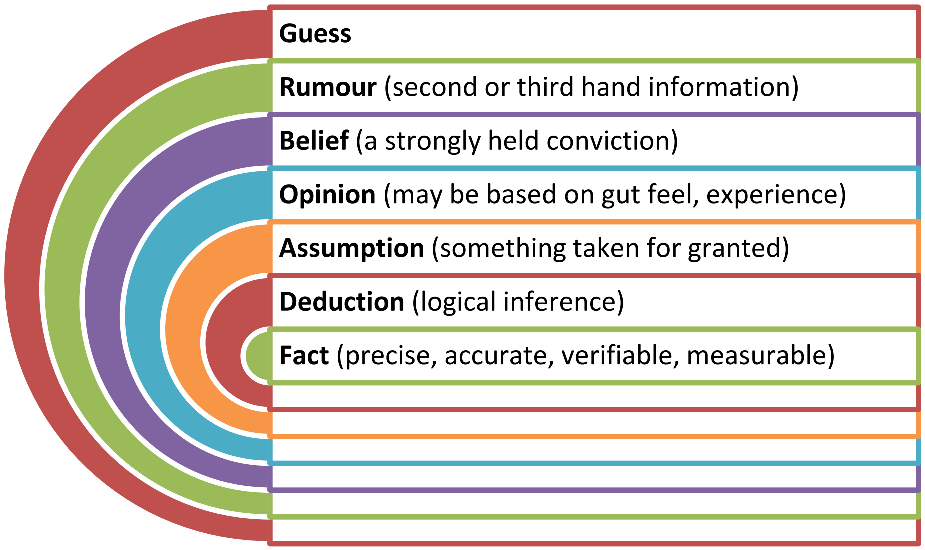
It is considered good practice to corroborate gathered information through two different information sources, e.g., interview and records. It is worth adding that information degrades. Incident scenes can change, paperwork can be lost, and memories can fade. It is crucial that information is gathered as soon as possible after the incident.

4.7.2 Evaluating the reliability of evidence

A commitment to learning from incidents implicitly acknowledges the necessity for action and adaptation based on informed assessments, rather than solely relying on concrete 'evidence', to understand the behaviors and actions of individuals. The aspiration of any investigation team is to gather facts or in the absence of those facts, to test the spectrum of information types gathered during the initial phase of the investigation. When the emphasis is on learning, any identified deficiencies or opportunities for enhancement are embraced, irrespective of whether they are directly linked to the incident.

Not all types of information are equally robust as illustrated in **Figure 13**. There are conclusions based on fact, conclusions based on educated guesses and deduction, and conclusions that are inconclusive. What is concluded may depend on the bias and can limit the lessons learned that are explored and identified.

Figure 13. A typology of sources of information used to derive conclusions across an investigation



Source: Figure by Allford and Wood

4.7.3 Objective vs subjective information

One common pitfall in incident investigation is to confine itself to uncovering the facts or hard evidence often at the expense of informed judgment or opinion. In the case of technical and most of the organizational factors defining the circumstances surrounding the event, is a relatively objective exercise: i.e., it can be established to a high degree of confidence without the need for speculation. There may be records or physical evidence available about the state of equipment, documentation about different people's roles and responsibilities, records of working hours or correspondence about targets, intentions or priorities preceding the event.

However, the kind of evidence needed to establish the context, from the point of view of the people involved, i.e., their beliefs, expectations, and mental model, is often subjective. Human performance is variable, complex, and subject to a multitude of contextual influences. Unless an investigation includes high-fidelity reconstructions or rigorously controlled studies, it is unlikely to be able to show either the existence or the effects of the contextual factors likely to have existed at the time that significant decisions and actions were (or were not) taken. (CIEHF, 2020)

Nonetheless, subjective evidence, if deemed credible, can provide important insights for lessons learning, particularly in relation to human interactions and organizational behavior. Evaluation of the significance and reliability of such evidence depends highly on the judgment and insight of the investigation team. The training, guidance and support should include techniques for assessing the credibility of subjective evidence and criteria for determining how much weight to assign it. They also should include ethical principles to guide the team's decisions in this regard.

4.8 Use of structured methods

The use of structured methods emphasizes the importance of employing systematic and organized approaches to guide the investigation process. Such methods are a necessity in any incident investigations, but what methods are most appropriate depend on the objectives of the investigation… Links to many well-regarded methods to support learning investigations are provided in **Annex 1** and **Annex 2**. Structured methods provide a framework for investigators to follow, ensuring consistency, thoroughness, and effectiveness in uncovering the underlying causes of accidents and developing appropriate corrective actions.

Structured methods also include the use of checklists, templates, and forms to ensure that all relevant information is gathered and documented consistently throughout the investigation process. By providing standardized tools for data collection and analysis, checklists and templates help prevent oversight and ensure thoroughness in the investigation process. These methods can also encompass the use of interview protocols and guidelines for conducting witness interviews. These protocols help ensure consistency and effectiveness in gathering information from witnesses, providing predefined questions, probing techniques, and guidelines for documenting interview findings.

Some organizations use prescribed or preferred methods of incident analysis rather than allow their investigators the freedom to choose their own methods. There are valid reasons for this approach in terms of consistency across the investigation program, resource efficiency and the opportunity to develop in-house expertise in one or two methods rather than several.

4.9 Immediate and underlying causes

The concepts of immediate and underlying causes play a pivotal role in understanding the factors contributing to an incident and the ultimate lessons learning that can be achieved. Immediate causes refer to the direct events, actions, or conditions that immediately precede and trigger the incident. These are often the most visible and tangible aspects of the incident, such as equipment malfunctions, human errors, or unsafe behaviors. Immediate causes provide the immediate context for the incident and are typically what first come to mind when investigating the sequence of events leading up to the accident.

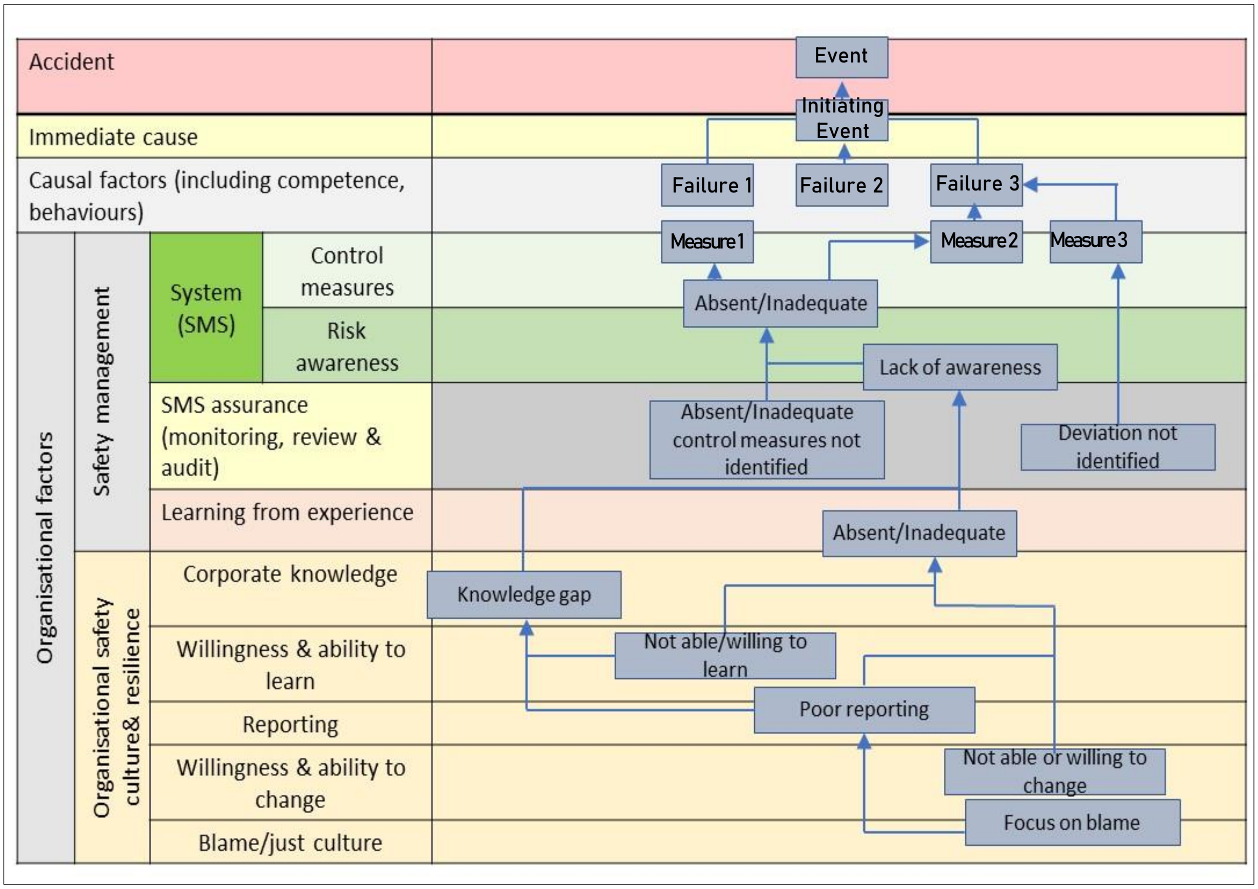
Beneath the surface lie the underlying causes, that is, the deeper systemic or organizational factors that create the conditions for immediate causes to occur. These underlying causes are often less apparent and may involve deficiencies in management systems, organizational culture, or safety practices. They can include issues such as inadequate training, ineffective communication, insufficient supervision, or deficiencies in policies and procedures.

Understanding the distinction between immediate and underlying causes is crucial for conducting a thorough and effective investigation. While addressing immediate causes may resolve the immediate problem, it is addressing underlying causes that can produce lessons learned for preventing similar incidents from occurring in the future. By identifying and addressing the underlying causes of an incident, organizations can implement more effective preventive measures and systemic improvements that address the broader issues contributing to process safety risks.

Most investigations will endeavor to identify immediate cases at a minimum but the depth to which many will venture may vary. The depth of the investigation often depends on the actual and potential consequences of the incident. Most investigations will go no deeper than the level of the safety management system (SMS).

Figure 14 illustrates that accidents are generally the final stage of a long sequence of events in which there is a complex interplay between failures in technical, human and organizational systems. The figure mirrors the learning loop diagram (**Figure 9**) earlier in **Chapter 3** where single loop learning is ascribed to an investigation which confines itself to the immediate cause and perhaps causal factors implicated in an incident. Double loop learning finds equivalence in an investigation which explores down to the level of the SMS and perhaps SMS assurance. Triple loop learning is ascribed to an investigation which delves further into organizational and cultural factors.

Figure 14. Depiction of typical underlying causes and possible lessons that can be extracted from them



Source: French and Steel, 2007

4.10 Communication and closure

Communication involves the dissemination of investigation findings, conclusions, and recommendations to relevant stakeholders within the organization and beyond. Closure represents the formal conclusion of the investigation process. Upon completion of an investigation, it is imperative to disseminate its findings effectively (see **Chapter 7**).

4.10.1 Communication

An effective investigation report should narrate a cohesive story, covering:

- What happened: Providing factual details about the incident or accident and contrasting these with typical scenarios when operations proceed smoothly.

- The context of the event: Including details about when and where the incident occurred, the individuals involved, their roles and responsibilities, as well as the broader organizational and environmental factors influencing the situation.

- How it happened: Describing the deviations from expected events and the factors contributing to these deviations.

- Why it happened: Explaining the underlying causes of the deviations, including failures in barriers or controls, systemic interactions, and individual motivations or incentives.

Text Box 6. Example of communication and closure requirements for a learning investigation

Adapted from source: COMAH Remodelling: Investigation Procedure – United Kingdom (HSE, 2010)

Post investigation, the Seveso Competent Authority shall be able to:

- Identify the immediate and underlying causes and consequences of the incident
- Rectify conditions giving rise to the incident
- Identify any breaches of the law and the appropriate action to be taken in the circumstances
- Ensure that similar conditions are not repeated in other parts of the same premises
- Satisfy the expectations of the public, the media and pressure groups who expect action from the CA when a serious incident occurs.
- Act as a starting point for the analytical assessment of management's ability - a starting point as effective as a basic inspection in some instances.
- Contribute to the Competent Authority's knowledge of the causes of the incident; identify any shortcomings in policy, guidance or legislation and any consequential research.
- Help the Competent Authority evaluate the effectiveness of inspection activity; inform duty holders and the public about the causes of incidents and any relevant findings from investigations and; meet the reasonable expectations of relevant stakeholders in line with other state commitments

The report should maintain objectivity and logic, presenting factual evidence and analysis in an accessible manner. To effectively advocate for change following an incident, readers must be able to discern a clear connection between the evidence, analysis, and recommendations. The readability of the narrative, employing plain language and adopting a clear report structure, also plays a determining role in the impact of its findings.

4.10.2 Closure

For successful closure, the investigation findings should be consolidated into a comprehensive report or presentation that summarizes the incident, identifies root causes, and outlines recommendations for preventive measures. Closure signifies the resolution of the incident and the commitment to implementing corrective actions to address underlying issues and prevent similar incidents in the future. **Text Box 6** shows an example of performance expectations assigned to communication and closure of a learning investigation.

Recommendations and lessons learned should be derived directly from the evidence and analysis, with a focus on performance improvements aimed at preventing similar incidents in the future. These recommendations should be presented alongside their contextual basis to ensure clarity and understanding of the intended changes. **Table 7** highlights the different types of recommendation and the downside risks associated with each in the take up of appropriate action

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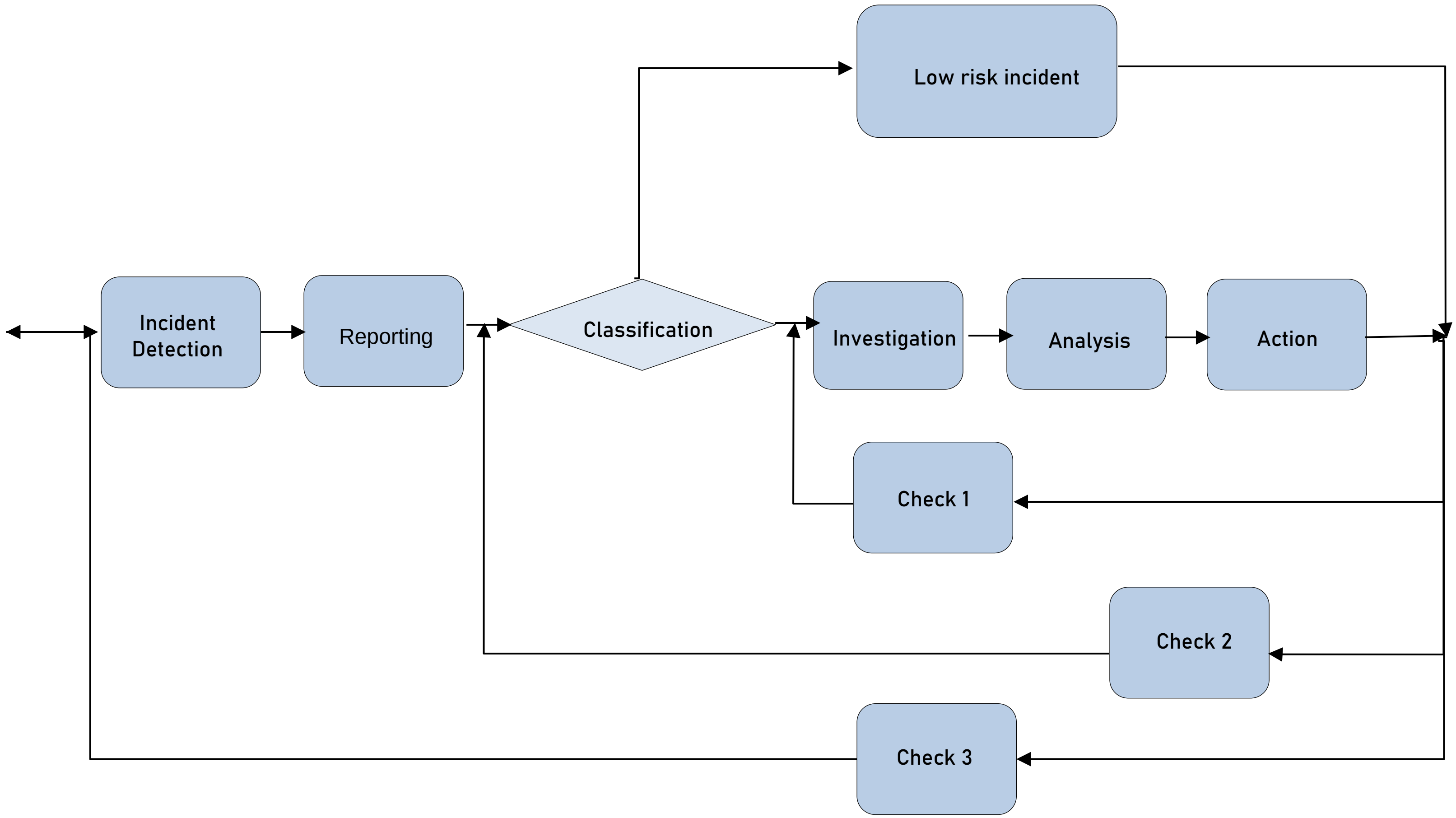
Table 7. Typical recommendations from a learning investigation (French and Steel, 2017)

Type of recommendation	When most appropriate	Risks
A recommendation based on actions targeted at the specific area of weakness identified by the investigation	When the specific actions needed to address the risk are clearly seen by the investigator.	Risk that the solution to the problem is now owned by the investigator rather than the organization that is being investigated
A recommendation that identifies the problem and challenges the organization to find a solution	When the solution to the problem is not immediately obvious and therefore warrants further examination	• Can lead to a delay in the • implementation of measures to address the risk (particularly if the organization has an immature safety culture or is reluctant to participate in finding a solution)
A recommendation urging that a risk be evaluated and suitable actions taken	When the investigator cannot, based on the available evidence, be sure that further actions to address a particular risk are justified	• Can provide a means for a reluctant • recipient of a recommendation to avoid taking substantive actions
A recommendation to address the attitudes and behaviors of managers and/or staff	• When the prevention of an accident is heavily dependent on the correct application of a process by the staff involved and/or the quality of their decision making • When there is no obvious engineered safeguard to reduce reliance on human reliability	Specific and effective actions to address human behaviors and underlying safety culture can be more difficult to define.
A recommendation to conduct a wide ranging review of the entire safety management system and its implementation	When the evidence points to wide-spread inadequacy with the safety management system and/or its implementation	Can be difficult to justify unless the underpinning evidence is particularly strong
A recommendation to address issues with regulatory oversight, or to increase the extent of regulatory oversight	When investigator judges that either: • regulatory oversight was deficient or • that the influence of the regulator would have a major impact on the management of the risk	Can detract from the organization's responsibility to manage its own risks.

Figure 15. Typical process establishing investigation capability for incidents of any risk level



Source: Allford and Guichon, 2007

Most learning investigations will confine themselves to reporting recommendations and leave the resultant actions to the organizational unit which is subject to the investigation. Depending on the scope of the investigation there are times when recommendations may go further by proposing solutions, be targeted at the overarching safety management system or directed at stakeholders such as regulatory authorities

4.11 Reviewing investigation capability

Reviewing investigation capability involves assessing and enhancing the organization's capacity to conduct thorough and effective accident investigations. This process requires a comprehensive evaluation of the resources, processes, and competencies involved in the investigation process.

4.11.1 The investigation process workflow

Figure 15 shows the typical workflow of an investigation process. All reported incidents go forward to classification which essentially screens out low risk incidents from the rigors of the full investigation and analysis process. Low risk incidents will be summarily actioned and monitored by frontline staff. The medium to high-risk incidents will be investigated, subjected to analysis and formally reported with recommendations. Actions to implement the recommendations will be then monitored and tracked. This process requires the training of frontline operational staff to recognize and report incidents which have led to either actual consequences in terms of harm or damage or could done so in different circumstances.

At its core, reviewing investigation capability entails examining the knowledge, skills, and experience of personnel involved in the investigation process. This review includes assessing their training and proficiency in investigation techniques, analysis methodologies, and relevant regulatory requirements. It also involves evaluating the availability and adequacy of resources, such as tools, equipment, and documentation materials, necessary for conducting investigations.

4.11.2 Verifying investigation capability

Figure 15 also indicates points in the workflow that allow opportunities to check and verify investigation capability. The investigation process necessarily starts with the detection of the incidents. At the level of a single incident, management checks (**Check 1** in **Figure 15**) are in place to verify the effectiveness of the analysis, investigation and follow-up actions based on the feedback of the individuals and teams who experienced the incident. Over time, after a considered review of the emerging data from individual incidents, a check (**Check 2** in **Figure 15**) on the classification process of reported incidents will be required. The key question here is whether the classification criteria need to be narrowed or widened for a full investigation based on the outcomes from the investigation programmer and the resources consumed by the programmer.

Periodically, it is good practice to conduct a check (**Check 3** in **Figure 15**) on the criteria for reporting an incident. For example, do the criteria correctly capture high risk vs low risk incidents? Do the criteria assign an appropriate risk level for simple losses of primary containment, such as leaks and spills, as well as events that result in a complete loss of control? Verification of classification criteria, following implementation, is a significant task because any adjustments in reportable incidents, especially near misses or dangerous occurrences, will trigger additional training for front line personnel.

4.12 Reviewing organizational challenges

The review of investigation capability may also trigger questions about the organization's commitment to learning. A learning investigation raises challenges for an organization particularly for senior leaders and managers in the assignment of appropriate resources and priorities. Organizations should also periodically check that the commitment to a robust investigation and lessons learning program remains strong. Suggested questions for self- assessment for each of the elements in **Table 8**.

Table 8. Commitment to learning - Organization self-assessment questions

	Element	Question
1	Commitment to learning	• Does everyone understand and accept that the organization is fully committed to learning from its safety failures i.e. that it is more interested in learning lessons which can help it improve its management of process safety as opposed to merely allocating blame? • Does the organization possess sufficient resource and resilience to enable it to continue as a business whilst an incident is being appropriately investigated?
2	Incident reporting	• Does every employee feel obliged and empowered to report promptly and accurately all incidents and safety significant issues, which come to their attention? For example, are they actively encouraged to report errors and safety failures? • Can they be confident that they will be valued for doing so? Do safety performance targets, for example, tend to act as a disincentive to reporting accidents and incidents?
3	Scaling and terms of reference	• Are there adequate and suitable processes and criteria (e.g., risk/consequence or learning potential) in place to enable the organization to decide on the scale and depth of investigation and to draw up initial terms of reference? • Does the organization simply scale its investigation response according to the severity of injury or does it consider the safety significance of each incident and its potential for improving safety in the future?
4	Team based approaches	• To what extent does the organization adopt an open, team-based approach to investigation, with effective involvement of operative level employees, safety representatives, and supervisors, drawing on their practical knowledge and providing opportunities for them to learn more about safety and become champions for necessary safety change? • Is the team led by a manager with appropriate seniority?
5	Training, guidance and support	• Have all team members received necessary training and guidance to enable them to play their part effectively in the investigation process, for example, training in interview techniques? • Is practical guidance and technical support available to the team from qualified safety professionals?
6	Information gathering	• How adequate are existing procedures in enabling investigators to gather necessary data following accidents and incidents - including for example: securing the scene, gathering essential physical and documentary evidence, taking photographs (for example, using digital cameras), interviewing witnesses etc.?
7	Use of structured methods	• Does the organization make use, as appropriate, of structured methods to enable it to identify the circumstances of which the incident is the outcome? • Does it use such methods to help it integrate evidence, generate and test hypotheses and reach conclusions so it can make recommendations?
8	Immediate and underlying causes	• Do investigations seek to identify and discriminate between immediate and underlying causes? • Is there a clear link between the outcome of investigations and revision of risk assessments? For example, does the investigation establish if and why risk assessments for the activities concerned were inadequate, i..e., had not been properly implemented or had been allowed to degrade?
9	Communication and closure	• Are there effective means in place to communicate conclusions back to stakeholders and to track closure? • Is the implementation of recommendations managed to an agreed timetable with reporting back to the investigation team?
10	Reviewing investigation capability	• Does the organization undertake a periodic review of the adequacy of its approach to investigation with a view to improving its capability to learn lessons from incidents, near misses and to embed these lessons in 'the corporate memory'?

Chapter 4 Summary

- **Learning Investigations -** Investigations should focus on learning rather than assigning blame to prevent the recurrence of similar incidents.
- **Commitment to Learning -** Organizations must embrace a culture of continuous learning from incidents to improve safety practices proactively.
- **Incident Reporting -** A transparent and accessible reporting system ensures that all incidents, including near misses, are documented for analysis and improvement.
- **Team-Based Investigations -** Collaborative, multidisciplinary teams enhance the investigation process by providing diverse expertise and perspectives.
- **Communication and Closure -** Clear reporting and dissemination of findings are essential to ensure that lessons learned lead to actionable improvements.

5 Deriving lessons learned from a single chemical incident

This chapter summarizes techniques for extracting lessons learned from an individual incident report. These techniques can be used in deriving lessons learned from detailed investigation reports but also from the briefest of incident summaries. A summary of the process of deriving lessons learned from single incidents is provided in **Text Box 7**.

The extraction of lessons learning is a process of discovery. As the details of the incident are revealed, it becomes possible to identify the conditions and failures that contributed to the incident's occurrence. The potential learning is highly dependent on the facts and narrative presented by the investigation. There are different ways to approach lessons learning, depending on the objective of the lessons learned. The theory in **Chapter 3** gives examples of different perspectives for framing lessons learning from technological incidents. The theory can help to imagine what can be drawn from an incident.

Text Box 7. Extracting lessons learned from single incidents

Summary of the process

A simple process for deriving lessons learned from single events is described below.

- **Identify what happened, breaking the incident into a sequence of events.** The analyst breaks up the information into a sequence of events, and then look what failure or failures, were involved in each of these steps. The analytical process does not necessarily require an application of any specific analytical method, but in most cases, it is usually helpful to start with a timeline and then eventually work the timeline into a bow-tie model. Links to these any many other techniques are provided in **Annex 2.**)
- **Identify the immediate cause (single loop).** In the bow tie, there may be failures on both sides of the bow tie. In chemical incident analysis, one approach is to first indicate the immediate failures that caused the loss of containment (left side of the bow tie). Similarly, direct causes that failed to stop the event from continuing are placed after the loss of containment. For example, the pipe broke because it was corroded.
- **Identify the underlying causes (double and triple loop).** This step leads to further identification of failures in the safety management system. In this process, the analyst will ask what happened that allowed the immediate failures to occur. For example, in the case of the pipe breaking, the underlying cause could be a failure to conduct timely inspections.
- Notably, there can be more than one underlying cause attributed to the same failure. In the case of the broken pipe used above, there may also have been a failure in the risk assessment to identify the correct frequency of inspections. Similarly, the same underlying cause can be responsible for more than one failure.
- **Identify any organizational and systemic failures.** One can arrive at organizational failure by continuing to probe the underlying cause, as noted in Step 3. This approach is often adequate for most incidents that are not particularly complex. However, for complex failures, and most notably disasters, it may be necessary, or even essential, to review the information through the lens of systemic accident analysis, using approaches, such as Accimap and CAST, and various others. These methods use different frameworks and perspectives to pull out less visible causality, particularly when there are many actors and prior events that may have influenced what happened.
- **Review the double and triple loop causes and create lessons learned for each one.** Some causes may have the same lesson learned. This step requires a combination of logic, reasonable knowledge of the context in which the incident it occurred, and imagination about who might benefit from the information generated from the incident.

It is not necessary to use a particular theory or method for analysis of every incident. For less complex or minor incidents, common sense can be sufficient to provide a basis for extracting lessons learned.

However, for more complex incidents, such frameworks can be useful. Moreover, certain methods, such as systems analysis, are useful for extracting specific types of learning (e.g., did decisions in other departments in the organization adversely contribute to the incident?). Every investigation and analysis is different and therefore, there is no rule for using or using or not using particular theories or methods.

5.1 Recognizing the potential of lessons learning from single chemical incidents

The lessons learning potential of any one incident is conditioned by the circumstances of the event itself as well as the available information about the event. These conditions determine how much room there is for the analyst to explore potential lessons learned. The lessons learned acquired through analysis of investigation findings and summaries depend mainly on the following factors:

- Level of detail and completeness of findings reported
- The scope of the investigation
- The objectives of the investigation
- The complexity of the event
- The perspective of the investigation team
- Resources assigned to the investigation
- The perspective and objectives of the analyst
- The complexity of the narrative

The job of the analyst is to re-assess the facts and conclusions presented in the incident narrative and, using logic aided by analytical tools, to not only confirm, but also, when appropriate to the objectives of the analysis, elaborate on the original author's findings. **Text Box 8** summarizes tips on how to obtain an objective and comprehensive analysis. The IOGP guidance on lessons learned analysis.

5.1.1 Level of detail and completeness of findings

The lessons learned potential is dependent on the completeness and thoroughness of the investigation and the documentation of investigation findings. Even the most severe or complex incidents will have banal lessons learned if the investigation, or documentation of investigation findings, leave out important details, especially in regard to technical failures and risk management. Nonetheless, the depth and breadth of the investigation and the investigation report are dependent on the nature of the incident.

Moreover, in open sources, some incidents are only available in a summary report form. The brevity of such reports does not necessarily limit their value for lessons learning, depending on what is described and the level of detail. For example, the French ARIA database contains thousands of technological incidents, including a great number of chemical incidents that are summarized in a few paragraphs[8]. The information provided is curated by the staff of the Ministry of Environment that selects the important details for the summary. The reports vary somewhat in their usefulness because not all reports contain sufficient causality information. To a large degree, the detail that the curators can extract is limited by resource, the completeness of the investigation, investigation priorities, analytical competence of the investigation team, and the opinion of the curator on what should be included.

[8] The ARIA database also produces longer reports for a select number of incidents.

Text Box 8. Tips for producing useful and relevant lessons learned

The obvious cause is usually not the most important finding.
Use the "why?" question to identify deeper causality. For example, why did the pipe fail? It failed because it was not designed for the volume of the release. It was either the wrong design or an unpredicted release. Other evidence in the report may indicate which of the two is more likely.

Have realistic expectations
Not every incident is a lessons learned goldmine and the majority of near misses and minor incidents will not yield lots of information. Information may be limited because the incident minor or because there were limitations to the investigation.

Apply your own common sense and knowledge to the evidence
Critical thinking can take the findings much further than is sometimes imagined. Valuable lessons learned can be found in short descriptions provided there are precise details that give good clues to the causality.

Consider what is not in the report and whether missing pieces are significant
Is the absence of information on procedures or other control measures an omission or is it because they did not exist. Was the investigation uninterested in certain findings and decided not to include them? There are sometimes clues in the text that can help answer these questions and provide insight on information gaps in the report.

Magnify learning by studying groups of accidents
Studying patterns across incidents can multiply the lesson learning output from any one incident.

Recognize positive learnings
Remember to look at what went well. While most lessons learned are about what went wrong, incidents can also confirm good practice and it is important to acknowledge what worked.
Look for blame in systems not people.

Naming, shaming, and blaming individuals should never be the objective of an investigation
At the core of an incident there are usually failures in management and procedures, not people. If the human factor is the cause, then the investigation itself has failed. . The fear of blame interferes with obtaining the true story of what happened and learning and sharing lessons from the event.

Causation is not correlation
The analysis should seek to understand the mechanisms underlying causality so as to separate circumstantial evidence of cause and effect from true causality.

Recognize the limits of the investigation report
Recognize that the findings of the investigation are limited by its scope. If there is no discussion on a relevant topic, e.g., training, you cannot make a negative or a positive assumption about whether it played a role in the incident (butt you can still conclude that it would have been good to have it).

Consider all reasonable possibilities and use evidence to support including or excluding them.
Don't focus on the last person to touch the equipment or the last failure in the sequence of events. The underlying conditions that led to the incident may have existed for some time.

Don't give "human error", or simple technical failures (e.g., "the pipe broke"), as the root cause.
Human error *and other simple technical failures are* not the end-point, you need to understand the context of why the error*/ failure* occurred.

Force yourself to "test" your conclusions against other possibilities
In this way, you can reduce or prevent "confirmation bias", which is the tendency to search for and interpret information in a way that confirms a pre-existing belief.

In any case, the depth and breadth of the findings are not necessarily measures of the value of an incident for lesson learning. For example, near misses and other minor incidents may have fewer lessons than more serious incidents. In these cases, the lessons may not be any lesser in value even if they are fewer. A more limited set of findings can simply be indicative of a less complex event, not necessarily a less significant event from a learning perspective.

5.1.2 Quantity vs quality

What matters to the analyst is not the quantity of findings but the quality of the investigation and the information that is available regarding its key findings. Nonetheless, to the extent that some critical aspects of causality were not explored in the investigation, or have been left out of the report, the potential lessons learning benefits of the incident will also be limited. In sum, incident narratives are valuable for lessons learned to the extent that they that they identify and explain all possible contributing factors as well as provide adequate detail for evaluating the importance of each factor and the way it may have contributed to the event. This aspect is discussed in more detail in **Chapter 4** on Investigation.

5.1.3 The scope of the investigation

The scope and objectives of the investigation also can determine the degree to which certain types of lessons learning are revealed more than others. All investigations normally have a scope and objectives that are defined by a number of influences, such as resources, stakeholders, and causality. However, the scope can also be viewed as a bias that affects the outcome of the investigation. Bias in investigation may affect what lessons learned are identified (e.g., human factors) or simply not explore all the lessons learned available.

By definition, a thorough investigation will attempt to identify all the main elements of direct causality. However, the extent to which the investigator explores underlying causes of different causal aspects depends on a number of factors. In the first instance, the severity of the event generally determines how much resources and effort will be invested in the incident investigation.

5.1.4 The objectives of the investigation

The scope of the investigation is intrinsically linked to the objectives of the investigation. The objectives generally align with the needs of the organization(s) paying for the investigation. For any responsible operator, one assumes that the investigation will be designed to identify lessons for improving the technical and systems management failures. When there are serious consequences, the operator may also need to gather information to dispute enforcement measures or to defend itself in civil and/or criminal litigation.

A government investigation may also have similar objectives as the operator's investigation, seeking information on potential improvements and evidence for enforcement and any legal action. Some government investigations, e.g., those of national safety boards, may aim purely at improvements, focusing on one or several of any number of targets, for example, industry practices, government oversight, or regulatory requirements. Political objectives may also play a role in directing the attention of the investigation.

Nonetheless, the objectives of any incident investigation are always tempered by other limitations, especially financial resources and competencies available. Access to witnesses and evidence may also sometimes play a role. These considerations may require the investigation team to pursue certain aspects over others. For example, an investigation team may forego confirming the exact nature of an explosion because the lab experimentation required is too costly and cannot guarantee a meaningful result.

5.1.5 The perspective of the investigation team

The perspective of the investigation team will also determine how lessons learned are described. For example, the investigation team could have an opinion that industry standards work better than government regulation and therefore, lessons learned are depicted in terms of what the industry can do to reduce chemical incident risk. In contrast, an investigation team from a national safety board may believe that more regulation is the answer and develop recommendations that reflect this point of view. Operator investigations may try to avoid implying a failure of corporate leadership. Investigations influenced by labor unions may focus more on management failures. Different organizations will prioritize some types of findings and learning over others and the analyst should take that into account in rendering their conclusions.

The investigation findings are further influenced by practicality. In particular, for very serious incidents and disasters, the circumstances surrounding the incident are usually quite complex. They may generate an abundance of lessons learned useful for a large number of actors. With limited resources, and keeping in mind that reports have to have focused messages, an investigation team in such cases may choose to make recommendations that are most relevant and value-added in the context of the investigation's main audience.

5.1.6 The perspective and objectives of the analyst

The analyst's competence should include sufficient process safety knowledge, a basic understanding of the various analytical frameworks, and familiarity with the roles and information needs of different stakeholders. This combination of skills allows the analyst to transform the information into knowledge for different stakeholders. A competent analysis can maximize learnings from even the simplest narrative.

Another useful approach is to transform lessons from an incident in a specific type of facility into a more generalized lessons learned, thereby offering learnings for a broader range of stakeholders. Two examples of transforming information into generalized lessons learned is provided in the **Table 9.**

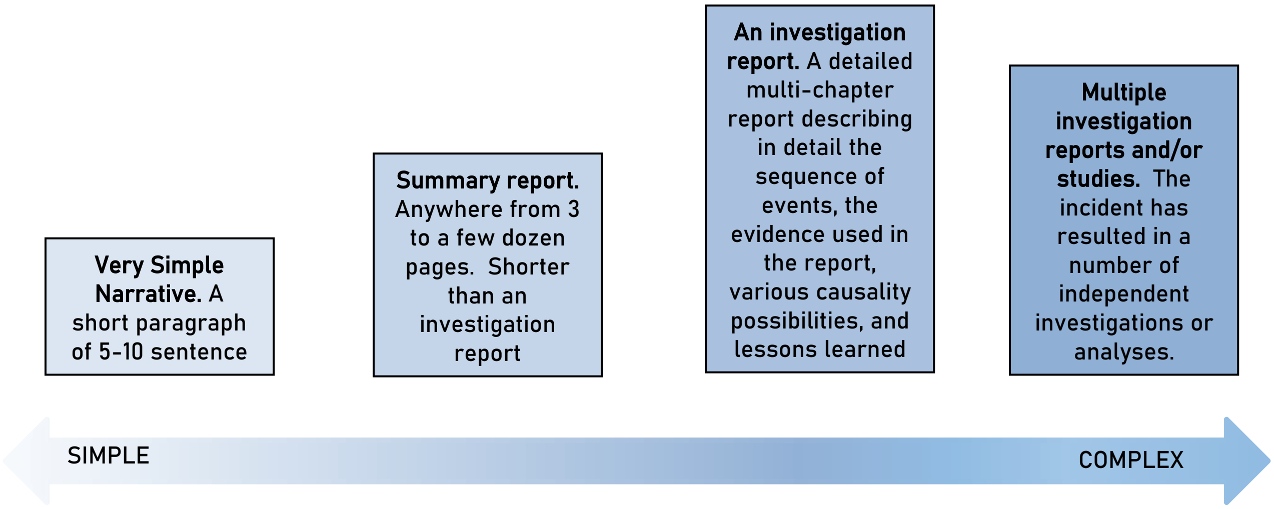
Table 9. Examples of how one lessons learned from an incident can be generalized for a wider audience

Lessons Learned (Situation-Specific)	Lessons Learned (Generalized)
The pipe broke because it was corroded and should be replaced	There was no documentation of the pipe composition. It was a pipe that was difficult to reach and therefore, it was not directly inspected. It was assumed to have been installed at the same time as another pipe in the same vicinity. After examination, it was revealed that the pipe was older and did not conform to current pipe standards. The lesson learned is that older sites should not exclude less accessible equipment from routine integrity tests also on less accessible equipment or make assumptions about the age and composition of equipment in the absence of documentation.
Many fire fighters were injured or killed because they had incomplete knowledge about the substances inside an establishment on fire.	The quantity of ammonium nitrate in the warehouse did not meet the regulatory threshold for a hazardous establishment so the inventory was not known to the local responders. Joint emergency response exercises either did not take place or, if they did occur, never focused on ammonium nitrate hazards, so the fire fighters did not expect that type of incident at that site. A generalized lesson is that inventories of hazardous substances should be shared with local fire departments, and routinely updated… Fire fighters should consult the inventories before responding to an incident at any site in order to avoid injury and maximize the effectiveness of the response.

5.1.7 The complexity of the narrative

In the first instance, the complexity of the incident will frame how much an investigation can produce. The level of complexity is determined by the level of detail and the length of the report description, as illustrated in **Figure 16**. The simplest kind of chemical accident is a near miss from a technical failure, in which, despite a well-functioning safety management program, the failure occurred. In such cases, the result can be a single loop lesson only that is, in essence, not a lesson but a local failure that is not applicable generally and simply requires a corrective action.

Figure 16. An illustration of different levels of detail in incident narratives from very simple to very complex



Source: Figure by Wood and Allford

Nonetheless, simple narratives have value. It is very often the case that the report is written as a single-loop incident even if there are wider implications for the safety management system. In single-loop reports, the analyst always must challenge the narrative that the incident was simply a technical failure that had no learnings for management. Using logic and deductive reasoning, it may be possible to extend conclusions to identify potential double loop learnings and/or recommendations.

For example, it may be that several sites have had similar incidents and therefore, the operator's process of identifying vulnerable locations may be flawed. Or, reviewing incidents across different companies, one might find that this a fairly commonplace issue and there may need to be a revision of how an operator determines when equipment needs to be upgraded to resist degradation.

5.1.8 Uncertainty in incident findings

Moreover, investigation of chemical incidents does not always lead to definitive answers about what caused the accident. There are many chemical incidents for which the direct causes remain unknown. For example, it is relatively common for incidents that started with ignition of a flammable substance that the ignition source is never identified with certainty. Similarly, explosions often leave little or no trace of the sequence of events leading to the explosion, such as procedural errors that may have been committed. When there is uncertainty, determination of causality can be as much influenced by the evidence as by the competence, technical knowledge and resources, and the biases of the investigating team.

This sample case seems to largely consist of single loop learning. The operator (it is assumed) had taken pains to eliminate vulnerabilities of this nature but had overlooked this particular piece of equipment. Since there is no other information, one has to assume that there is no technical lesson to be learned (the operator knew about this risk already) and there is no meaningful improvement suggested for the safety management system.   There is a corrective action, but not really a lesson. The corrective action is that the site should conduct a review to determine if there are any other vulnerable locations where the equipment has not been upgraded. The result of this action could also have a lesson that the method to identify vulnerable locations was flawed, but this lesson cannot be derived from the incident report as it is written.

The analysis of more complex narratives is not necessarily different from that of simpler narratives. More detailed incident summaries will require filtering the information to distill the main conclusions. However, the job is still to determine what findings are most significant and to maximize the information that can be obtained from a report through techniques involving logic and inference.

5.2 Interpreting incident information for analysis

This section elaborates on these concepts and offers advice on approaches and tools that can help the analyst maximize lessons learned of any particular incident narrative. In general, the analysis starts with making preliminary judgments about what happened and forming questions about what went wrong. From there, the analysis follows a systematic process of focusing on each direct cause and asking what allowed that failure to occur. In this way, indirect causes that are the main source of lessons learning can be identified. Each step of this process can be aided by an analytical method. Typically one uses a timeline and then transitions to a method that accompanies the timeline with causality (e.g., such as a bow tie).

This section describes the various techniques that the analyst can use to optimize learning from a specific incident. Specifically, the following techniques are described:

- Obtaining double-loop conclusions from single-loop stories
- Reviewing the incident description in terms of common references or standards.
- Deducing plausible causality on the basis of common sense
- Identifying gaps in the information and their potential significance
- Using hazard identification tools, e.g., bow ties, to simplify analysis
- Using accident analysis models to extract layers of causality

The analyst does not have to rely exclusively on the conclusions of the investigation team. Using the evidence, the analyst can make conclusions about different topics not explored by the investigation team or even disagree with the report conclusions. Another good source of analytical advice is the guidance for human factors investigations published by the International Association of Oil and Gas Producers (IOGP), Demystifying human factors: Building confidence in human factors investigation.

The section uses actual reports (or report excerpts, described in **Cases 1 to 5**, to illustrate these principles.

5.2.1 Obtaining double-loop conclusions from single-loop stories

Even if information is not enough to support a double-loop learning, using common sense and logic, the analyst may still be able to identify double-loop recommendations. As an example, **Case 1** (see **Text Box 9**) is superficially single-loop that can have double-loop implications via deductive reasoning. In this case, although it was not specifically cited as a lessons learned, it can be concluded from the description that the assessment procedure for identifying corrosion/erosion vulnerabilities in the process equipment was flawed.

In contrast, **Case 2** in **Text Box 9** does not contain any single loop lessons learned. The technical failure is not explained. As an alternative, the analyst could use generalized information for lessons learning, for example, compiling a list of some of the common types of damage to gaskets that cause them to fail. Such an elaboration might help to support the (partial) double-loop lesson learned that is provided in the narrative, and indeed, this lesson learned could be elaborated in much more detail using the knowledge of an experienced process safety analyst.

In conclusion, simple narratives can sometimes be used to obtain more information for risk management than is often perceived at first glance. Nonetheless, the analyst must always have air-tight logical arguments to defend conclusions and recommendations that are not explicitly in the report.

5.2.2 Reviewing the incident description in terms of common references or standards.

This technique may be useful when there is sufficient detail on an aspect of the incident, e.g., the process followed or the equipment that can be evaluated in terms of prevailing norms or standards. With such information, the analyst can check whether the situation described in the report corresponds to prevailing

Text Box 9. Case study examples of lessons learned potential of different kinds of narratives

Case 1 Large release of methane from a pipe in an ethylene oxide plant (Excerpt)

A leakage was discovered in a plant of ethylene oxide in a pipe containing methane. Probably the leakage started 3 days previously and increased up to an amount of approximately 200 kilograms an hour on the day that the leakage was discovered. On the whole the leakage was 120 kilograms an hour resulting in a loss of 22 tons of highly flammable hydrocarbons. The leakage took place in the curve of a methane pipe (situated high above the ground) through several small holes in the pipe.

The probable cause is condensation of water in the transport gas. The transport gas that contains CO2, reacted with the water forming carbon dioxide. The carbon dioxide damaged the inside of the pipe. Most locations had been equipped with steel to prevent the erosion. In this case, the operator had not expected the damage to take place in that exact location.

Original information source: eMARS database – Incident #290, occurring 27-2-2005

Case 2 Fire in a refinery's unit manufacturing aromatite free diesel (Excerpt)

A fire occurred in a refinery's unit which manufactures aromatite free diesel. Initiating event was a release of diesel-oil from the pumps gasket. A failure of pumps gasket caused the diesel oil release. Released oil caught fire. Prevention of abrasion and failures of process equipment could be achieved by drawing up instructions for inspections concerning pumps, compressors, tanks and pipelines.

Original information source: eMARS database – Incident #749, occurring 1-10-1997

Excerpts from JRC Lessons Learned Bulletin #14: Learning from incidents involving liquefied petroleum gas. (LPG)

Case 3 An accidental release of LPG occurred during a ship to shore transfer (Excerpt)

A bursting disc fitted to a 4 inch spur of the West 14 inch Import pipeline operated, resulting in 163 tonnes of unstenched liquid Propane (LPG) being released into a storage tank bunded area. At some unknown time prior to the start of the release, the bursting disc on the West import pipe line ruptured during a routine ship to shore discharge. …

However, two bursting discs are on site, one on each of the two import pipe lines. The bursting discs had not been included in the sites planned preventative maintenance program and evidence suggests that they had not been changed in over eleven years. It is believed that the bursting disc probably failed due to fatigue. The manufacturer of the bursting disc confirmed that this type of disc is now obsolete. They also recommend that the bursting disc is changed every year.

End of excerpt

Many incidents are known to involve violations of equipment limitations, standardized procedures, and various other well-established requirements (e.g., hot work, ATEX). The analyst should routinely look to see if there is evidence in the event description that a known protocol was applicable but not followed. The original report only noted the error in the failure to inspect and replace the bursting discs. However, a review of this incident also indicates a lessons learned regarding equipment somehow overlooked by the inspection, maintenance, and obsolescence programs.

It would have been even more interesting to know the vulnerability in the safety management system that caused these discs to be overlooked, but the investigation did not recognize or explore the underlying causes.

Original information source: eMARS database – Incident #926, occurring 27-10-2008

Case 4 Release of chlorine following a voltage jump in the electrical supply (Excerpt)

The company was operating in normal mode; the gases produced by the chemical reaction (a mixture of chlorine, nitrogen, hydrochloric acid and carbon dioxide) are separated. In the event of a system failure, the gas is directed through a vacuum created by two fans to a scrubbing system to destroy the chlorine. At 1:40 p.m., a public network failure was followed by a power failure of the company's emergency power supply, causing the 2 fans to stop; 120 kg of chlorine gas are then released at ground level because the valve which sends the gases to the chimney is closed in the event of an electrical failure (error in the design of safety).

The operator re-examines its installations with regard to a total loss of electrical power, supplements the emergency generator driven by steam by a diesel engine, improves the gas detection system thanks to additional detection systems (redundancy) and a link with the neighboring society and improves alarm procedures.

End of excerpt

Example of additional lessons learned derived from this report (from JRC Lessons Learned Bulletin #15: Learning from incidents involving power supply failures)

Risk assessment. The release of chlorine gas and the failure to detect the gas suggest that the risk assessment may have overlooked particular factors. It may not have considered that the backup power supply could fail. The risk assessment should also ensure the adequacy of detection systems and whether the fail-safe positions of control valves are programmed appropriately.

Original information source: ARIA database 14438, occurring 15/11/1991

Case 5 Ammonia release in the air from a manufacture of food

This is the full description of the case.

Operator's mistake during demolition of installation. A pipe was cut in a wrong way (during demolition works). 700 kg of ammonia was released. One asthmatic worker was hospitalized. Works for demolition of dangerous installation have to be done by following safety procedures.

End of case description

Analysis. This is an extreme situation in which very little information has been provided about what happened. However, one can speculate quite easily that a risk assessment was not conducted before demolition. Moreover, there are only a few explanations for what specifically may have led to the wrong cutting of the pipe. Either the operator did not verify that all equipment had been emptied of contents and sealed off from the rest of the site, or the operator did not consult a diagram showing connections of the installation under demolition to other equipment outside the installation that contained substances.

Original information source: eMARS 00791 occurring 15/06/1998 standards pertaining to the relevant process, equipment, safety procedures, etc. The specific reference that could be consulted depends on entirely on the context.

An example is given in **Case 3** in **Text Box 9**, in which the only lessons learned provided in the report are not really lessons learned, but corrective actions. However, there is enough detail in this case for the analyst to extract their own lessons learned. In the text box, a suggested lessons learned is that LPG equipment is highly standardized area and the operators should have up-to-date knowledge about the operating conditions of their equipment. A lessons learned study on LPG incidents is cited as a reference for this lesson learned.

The description in **Case 3** also provides information that suggests lessons learned for the operator's programs for inspecting equipment and managing fatigue and obsolescence.

If there is enough information available, the analyst can use deductive reasoning to speculate on other possible causalities that are not mentioned in the report. In such cases, the analyst must apply the necessary rigor to these conclusions as required by deductive reasoning. The findings from deductive reasoning should be presented as credible options and sometimes they can also be assigned a likelihood.

Text Box 10. Principles to follow when using deductive reasoning

Using deductive reasoning requires a disciplined approach

When making conclusions, for example, using deduction or gap analysis,, the analyst must also consider the following requirements and limitations:

- The analyst has to have sufficient knowledge, either through research or experience or both, of similar scenarios, to make a reasonable deduction about missing parts of the narrative relevant to causality.

- Before reaching a conclusion about a possible missing piece, the analyst should speculate on all the possible explanations that could complete the narrative.

- The analyst should then assess the likelihood and only use their explanation if they can reasonably conclude that what they think may have happened is a *far more logical* explanation than any other alternative. This is a *high bar* but it sometimes can be reached when there are very few alternative explanations that make sense in certain contexts. Case history of similar incidents should support this assessment.

- Even if the analyst has a high level of certainty about a missing piece or pieces, they must qualify the conclusion as a *potential* conclusion (not a certain one) in any argumentation, especially in reference to causality and lessons learning.

- Speculation on missing information is limited by the level of detail and context. There have to be hints in the text that can lead to further exploration. If not, the speculation is simply imagination and not valid. For instance, it is not that often that incident narratives include information about the organization's role in the incident. In such circumstances, the analyst cannot make a reasonable assumption about the organization's role in causality.
- Deductive reasoning must satisfy the following argument: *There is no possible interpretation of the argument whereby its premises are true and its conclusion is false*. Deductive reasoning is a powerful tool provided the analyst can justify conclusions on the basis of knowledge and evidence with plausible explanations. The conclusions must be able to withstand any reasonable doubt. In addition, the findings from this reasoning should not be stated as fact because the facts themselves are not completely known.

Using deductive reasoning to come up with other causal factors or lessons learned that are not present in the report, or are even contradicting a report conclusion, the analyst has to adhere to a strict discipline as outlined in **Text Box 10.** An objective evidence-based approach, with qualifying language, is essential. Deducing plausible causality on the basis of common sense

Sometimes the author of the information source provides a reasonably detailed description of the event, but fails to include lessons learned that could easily be deduced from the facts supplied. There may be various reason for missing information. Certainly in some cases, this oversight could be due to a lack of competence or experience in deriving lessons learned, but in many cases, it may be deliberate. The complexity of the event, the resources and expertise available, a tight schedule, and many other factors can constrain the investigation to focus on specific learnings and ignore others.

In particular, more complex incidents are a rich source of lessons learned and may be viewed from a variety of perspectives. In these circumstances, the investigating team will often prioritize lessons learned to provide a coherent narrative and, also to be consistent with investigation objectives. Hence, there may be a number of lessons learned that are available in the report but not elaborated. **Case 4** in **Text Box 9** is an example of findings that did not explicitly present risk assessment as a factor in the incident. However, the analyst identified an opportunity to derive a lessons learned on risk assessment from the facts presented.

Case 5 in **Text Box 9** has only 3 sentences, but the fact that the pipe was cut is an interesting clue. The narrative assumes that this mistake was that of a worker, but it may have also been a management failure. While the true cause is not known, the description provides enough information to indicate that cutting the pipe is a mistake that occurs. The lesson learned is not that the worker committed an error. Rather, the learning is that the operator must do everything possible to avoid that such an error is committed. Despite the simple description, there is a lesson to be learned here.

Other reasons that some lessons learned may be overlooked can be due to political or legal constraints. For example, the settlement of court cases based on chemical incidents can include an agreement to exclude certain details from the public domain. Or, in the case of the operator's investigation report, the management may require the investigator to limit the lessons learned to certain topics and avoid others that may be particularly sensitive from a management perspective. Likewise, depending on the political context, the government inspector could also be constrained to adopt the same limited set of lessons learned into the national (or multinational, such as the EU) reporting system.

5.2.3 Using hazard identification tools, e.g., bow ties, to simplify analysis

Applying standard tools for hazard identification can help provide a framework for interrogating the narrative, for example, finding missing barriers, as described above, or simply to impose order on the sequence of events, highlight where safety barriers failed, and actors, equipment, procedures, etc., that may have been involved.

Many analysts find the bowtie analysis a simple and easy way to impose structure on the story. **Figure 17** shows how a bowtie is constructed. The bars before the loss of containment list the possible control measures that were implemented to prevent the release. The bars after the loss of containment event should depict mitigation measures that were meant to minimize the consequences of the release.

Most bowties of chemical incident scenarios are complicated with many barriers on either side of the loss of containment. **Figure 18** is an example of a branch of a more complex bowtie diagram. It depicts a potential bow tie analysis indicating a scenario that can start with either of two types of mechanical failure (corrosion, incorrect flange assembly).

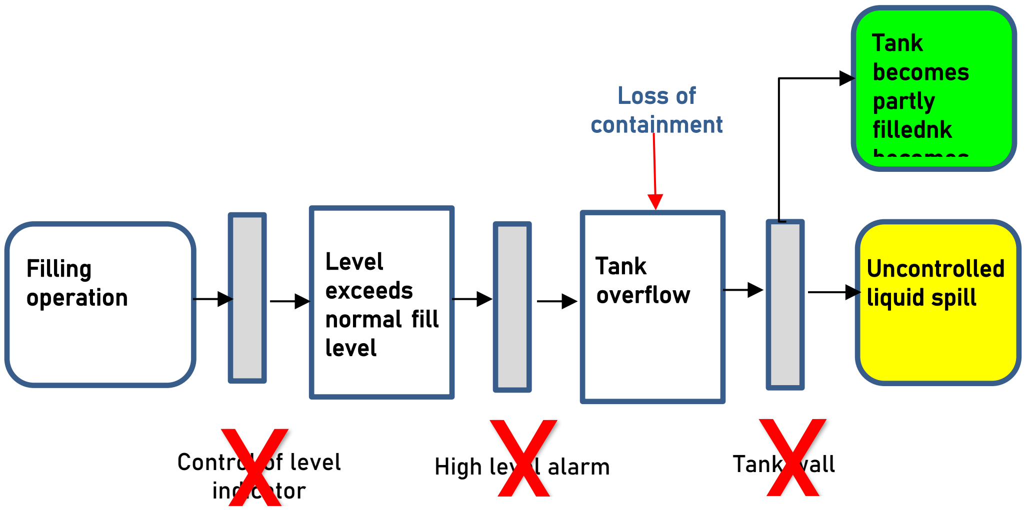
Still, hazard identification models are limited in their ability to deal with indirect causality. They are helpful tools for tracing direct causality and the sequence of events, especially as they relate to technical failures. They are not tools that support underlying causes very well. As described in the next section, there are additional techniques that can be applied to explore indirect and organizational causality.

5.2.4 Identifying gaps in the information and their potential significance

It may also be useful to review the sequence of events and consider details that might be relevant that are not mentioned. For example, when mechanical integrity is a factor, there are a number of underlying issues that may be relevant, depending on the type of equipment. In the case of a corroded section of piping, one would have questions about inspection frequency, how the inspection frequency was determined, the location of the corroded piece in the process, the frequency of exposure to corrosive substances or conditions, temperature and pressure of normal operating conditions, etc.

Figure 17. A branch from a bow tie analysis of the Buncefield fire (United Kingdom, 2005)

This diagram shows showing missing barriers. The same analysis can also be used to show barriers that did not just fail, but were missing entirely.



Source: Wood, Tripod Beta Analysis, 2018

Case 5 is an example of a very short description of an incident where the specific failure that caused the accident is not identified. Nonetheless, the author's inclusion of the statement that safety procedures were not followed is quite helpful. One can then use this clue to make a reasonable judgment about what the missing safety procedures might have been. Knowledge about proper procedure in the context of a demolition that there are two possible types of procedural failures. There is not enough information to know which one is correct (or a third possibility, i.e., both procedures were overlooked). For lessons learning, there is no need to know exactly which one was not followed. It is enough to learn that, if these actions had been taken, it is unlikely that there would have been a dangerous release.

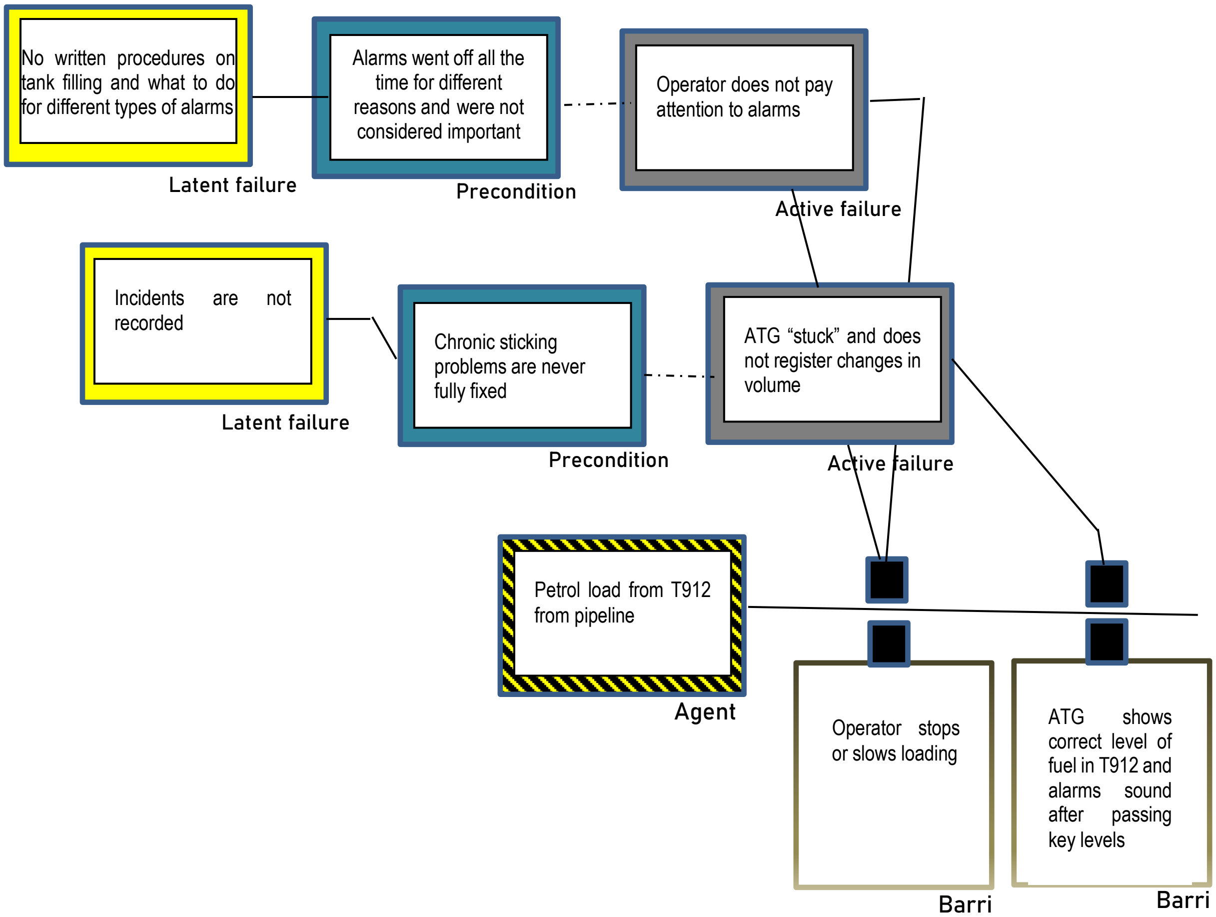
Hazard identification tools can also be used effectively for this purpose. In the bowtie in **Figure 18**, one can identify a selection of failed barriers in the Buncefield analysis. In this case, the barriers existed but were not sufficient. Using this and other hazard identification tools, the analyst can infer gaps at any level of causality, direct, indirect, or organizational.

When identifying causes, and deriving lessons learned from them, it is important to adhere to the principles of deductive reasoning outlined in **Text Box 10.**

5.2.5 Using accident analysis models to extract layers of causality

Accident analysis models are not only useful for structuring investigation findings in detailed and complex investigation reports. They are particularly valuable for imposing order on an incident narrative that has a complicated chain of events in which there are numerous pathways of causality. There are a plethora of techniques available for structuring events to elucidate specific aspects, whether underlying causes, understanding the role of the system, or specific to certain types of failure, such as organizational and human factors,

Figure 18. Part of a Tripod Beta analysis of the Buncefield incident



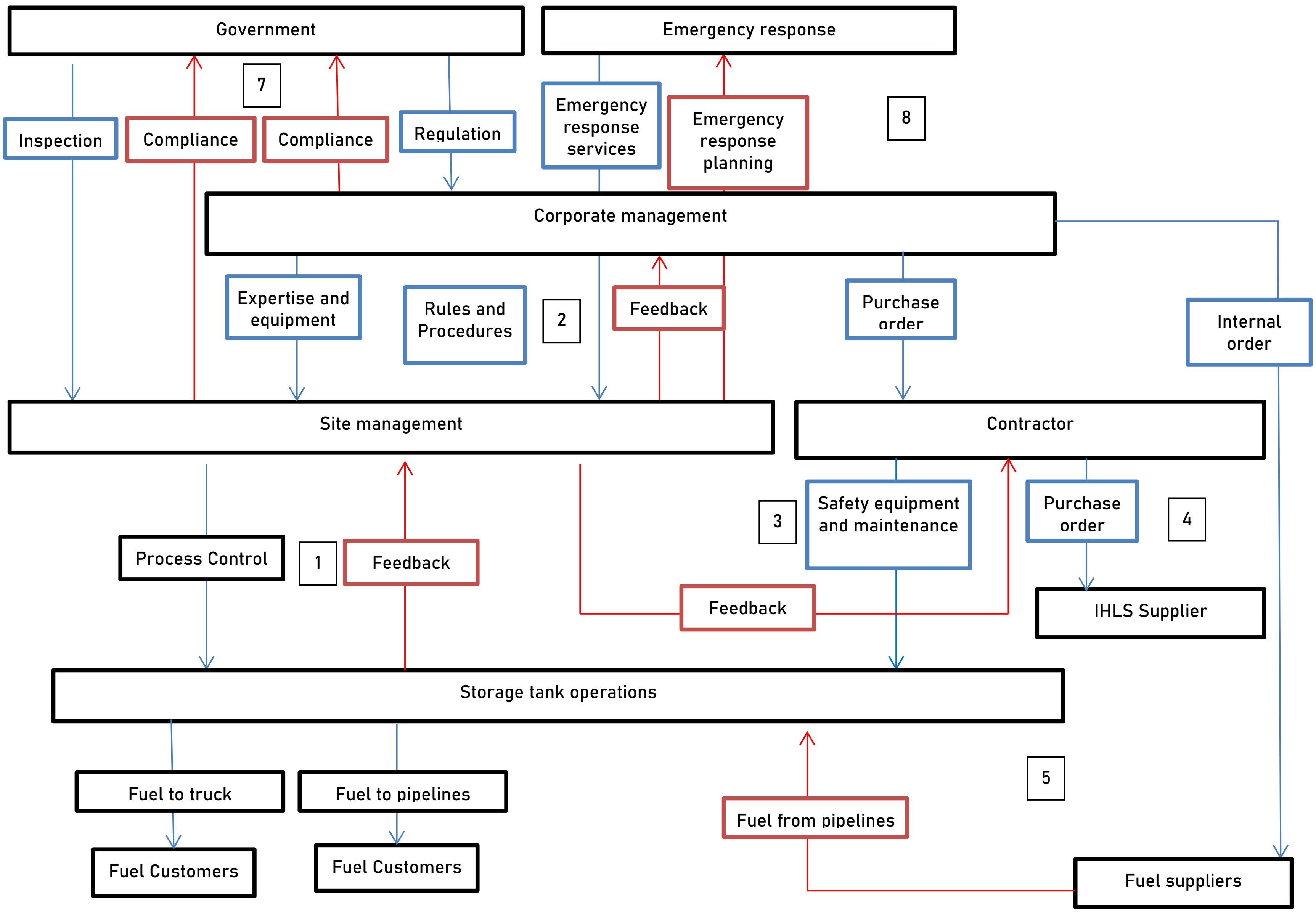
Source: Wood, Tripod Beta Analysis, 2018

In the JRC's Accident Analysis Benchmarking Exercise, it is advised that these techniques are mixed and matched to address the three crucial steps of analysis were outlined and associated with specific types of analytical models, as follows:

- Phase 1: Chronology, e.g., Step/ECFA
- Phase 2: Causal, e.g., Bow Tie, Change Analysis
- Phase 3: Underlying causation, organizational, systemic analysis, e.g., AcciMap, MTO, Tripod Beta, CAST

The JRC's Benchmarking Exercise tested many of these techniques their usefulness and ease of use for analyzing given accident analysis narratives. The Accident Analysis Benchmarking Exercise project report describes the results of these efforts and also links to more information on various techniques, including those applied in the project.

Figure 19. Diagram from a CAST analysis of the Buncefield disaster



Source: Wood, Cast Analysis, 2018

Figure 18 shows a part of a Tripod Beta analysis of the Buncefield incident (the same event analyzed in **Figure 17**). The "Agent" in the figure is an event in the sequence of events. The "active failures" are direct causes. The active failures are connected to barriers that failed. (Failure is symbolized by the broken black rectangle above them. If a failure has not failed, the rectangle above is solid black) pre-conditions and latent failures constitute different aspects of the indirect causes leading to a particular event in the sequence.

Figure 19 is a schematic tool that is recommended to support the systems analysis approach of the CAST method. The sections marked with numbers 1 through 8 are all areas where feedback loops broke down. The combination of failures involving expected interactions (or behaviors) that did not occur resulted in a systemic failure. From the perspective of this analysis, the system had insufficient resilience to prevent the failure that led to the Buncefield disaster. A systemic failure of this type points to weaknesses in organization norms of behavior, such as management style, leadership priorities, and culture.

Chapter 5 summary

- **Deriving Lessons from Incidents.** The chapter outlines the process of extracting lessons learned from chemical incidents through detailed investigation and analysis.
- **Importance of Investigation Detail and Scope.** The depth and breadth of the investigation significantly affect the quality of the lessons learned.
- **Methods for Analysis.** Techniques like common sense, deductive reasoning, and hazard identification tools (e.g., bowtie analysis) are crucial for revealing underlying issues and systemic failures.
- **Flexibility in Analytical Frameworks.** Analysts need to adjust their use of analytical frameworks based on the incident's complexity and available information.
- **Ensuring Comprehensive Lessons.** Applying the right methods and being adaptable ensures that the lessons extracted from the incident are thorough and beneficial.

6 Extracting lessons learned from groups of events

Analyses across groups of incidents that share selected commonalities can yield a variety of powerful lessons learned relevant to a specific type of substance, equipment, process, technical control measure, management measure, or industry. Moreover, certain studies can yield a range of findings for different actors, especially when studying patterns that link also to responsibilities that go beyond the specific installation or site. These studies can highlight potential vulnerabilities across an organization, industry, or in association with specific human tasks, or for users of particular substances and equipment. Pattern identification can also reveal correlations with other causal factors, e.g., a certain activity is often associated with poor training, for example.

The chapter details a systematic approach for analyzing groups of chemical incidents, emphasizing the study of common themes across multiple events rather than focusing on individual cases. It explains how to manually filter, code, and convert qualitative accident narratives into quantitative variables using tools like spreadsheets or statistical software. By grouping incidents based on shared characteristics such as substances, processes, or equipment failures, analysts can uncover trends and correlations that single incident studies might overlook.

Text Box 11. Procedure for analyzing groups of chemical incidents

Step-by-step procedure for extracting patterns and trends of lessons learned from groups of events

Following this summary, each step will be described in more detail in this chapter.

1. **Define the main objective and scope of the study.** The scope is determined by the theme the analyst intends to explore.

2. **Select cases for study.** Using appropriate keywords, search forms, and data mining, search in the available databases for incidents that share the theme's characteristics.

3. **Establish the analytical framework.** The framework consists of the spreadsheet in which qualitative data will be coded into quantitative fields.

4. **Codify each case within the analytical framework.** This step takes the analyst from a conceptual framework to the operative framework, turning the broad categories, such as substance involved, equipment type, industry type, causal factor, etc. into distinct variables (representing individual characteristics of each incident) for analysis.

5. **Assign values for each case within the analytical framework.** This process converts the qualitative data into quantitative data and often takes place simultaneously during Step 5. (5 and 6 are iterative processes, such that the analytical framework can continue to be modified, e.g., more variables added based on new information, until all cases have been coded into the spreadsheet.)

6. **Use quantitative techniques to analyse the data.** Once the data have been extracted and properly organized, they can then be analyzed quantitatively for patterns and correlations.

7. **Summarize findings and develop lessons learned.** Based on Step 4, the analyst then assembles an analysis of the findings and makes lessons learned recommendations.

6.1 The art of analyzing chemical incidents thematically

Mastering manual analysis is fundamental to learning how to extract meaningful patterns of failure and causality from groups of incidents. The steps outlined in **Text Box 11** describe the typical process for developing lessons learned from the study of patterns and trends identified in groups of events based on a specific theme. The process essentially employs a technique that converts mostly qualitative data (accident narratives) into data that can be analyzed quantitatively. The steps described in **Text Box 12** are an abridged version of how this type of analysis is performed. For an in-depth explanation of how this works, there are several online resources available, such as, at the time of this writing, the Atlasti website.

> **Text Box 12.** Converting qualitative data into quantitative data
>
> **Turning qualitative information into quantitative data: How stories can become data**
>
> "[It is] essential to recognize that qualitative data is inherently rich in detail and context. It provides narratives, experiences, and emotions that can be complicated to capture with numbers alone. Examples include interview transcripts, open-ended survey responses, or field notes that capture observations and conversations. These are all treasure troves of insights that can reveal not just what is happening but also why it's happening.
>
> To use [these] data quantitatively, researchers can use various techniques and methods, often starting with coding. Coding involves breaking down the data into discrete parts and labelling these parts with codes. These codes can then be grouped into categories, themes, or patterns. Once this step is completed, you can generate quantifiable information by counting the frequency of each code, theme, or category."

By manually translating their data into uniform codes, the analyst will understand the limits and possibilities the data holds for statistical analysis. In most instances, the analyst will realize that inferential statistics are not applicable and not even necessary tor telling a story that is generally applicable under similar conditions in any relevant industry.

The analyst will also discover the limits and possibilities for using digital analysis techniques on their data. Automated analyses can be useful tools for the experienced analyst, who has ideally already performed lessons learned analyses using classic methods, as described in this chapter. There are numerous reports of chemical accident studies in the scientific literature that apply such tools. They rarely succeed in producing meaningful results when the application of the tools ignores fundamental principles about matching analytical methods to the characteristics of the datasets.

6.1.1 Typical characteristics of chemical incident data

The analyst must know the characteristics of their data. In particular, they must understand the variability and variety of conditions and factors influencing the event, the importance of context, the many ways that authors of reports can use to describe the same event, and how many ways that particular event can occur can vary. From the process of selecting incidents to transforming the raw data into variables, the analyst will discover that their studies will have more valuable results if they take account of the following principles:

- "Chemical incident" is an umbrella term for many types of incidents. This term represents a large, heterogeneous class of events. There are hundreds of substances, operating conditions, procedures, equipment, processes and failures that can characterize these incidents. As a study objective, it is generally not possible to do all but the most generic causality and lessons learned analyses using a group of chemical incidents when they do not all share at least one common condition.
- For chemical incidents, linking the lesson learned to a specific element of causality is critical to achieving a meaningful result from any study. The lessons learned that emerge from the study then become relevant to all operators who may also possess the same condition, e.g., working in

the same industry, in the same type of process, or with the same substance. Hence, studies of lessons learned are generally only useful when the sources of incident information are filtered to analyze only incidents that share the defining characteristic.

- There are many incidents with multiple causality. In other words, the release event did not occur due to one failure but several failures occurring in sequence or in parallel. Complex incidents can provide useful information for many different kinds of lessons learned studies related to specific causal factors, but also for studies of systemic risk as it applies to chemical incidents.

In other words, chemical incidents are heterogeneous and context-dependent. Meaningful analysis of chemical incident requires recognizing the significance of any one act or condition in the context of the event.

Recognizing context is also necessary for transforming causality into a lessons learned. The analyst breaks the incident narratives into distinct variables of actions, of conditions, of objects and types of failures involved in the accident, based on their judgment, that in the context of the incident, they played an important role. Then, based on the narratives, each variable has many types that can be assigned to it, e.g., the variable "equipment involved" can include "storage tank", "process reactor", "rail tanker", "hose", etc.

To identify patterns, the collective types of actions, conditions, objects and failures involved in all incidents studied can then be counted. The characteristics of one variable can also be correlated quantitatively to find a pattern of relationships with other variables in many instances (e.g., the instance of the failure type "hose" occurred 7 out of 10 times with the action type "wrong loading procedure"). When interesting patterns are related to a specific combination of variables, it may create the motivation for another study about lessons learned of incidents linked to that combination, e.g., a study of loading and unloading incidents involving procedures for connecting hoses to transport vessels.

Moreover, the typical size of topic-based chemical datasets is about 25-100 events. This is not "big data" as is required for many artificial intelligence techniques. The time and effort required for manual data analysis is arguably much less than programming and interpreting outputs with more sophisticated methods. The last section of this chapter (6.9) provides an overview of criteria and advantages and disadvantages to help analysts decide whether it is worthwhile to use alternative methods to analyze chemical accident data.

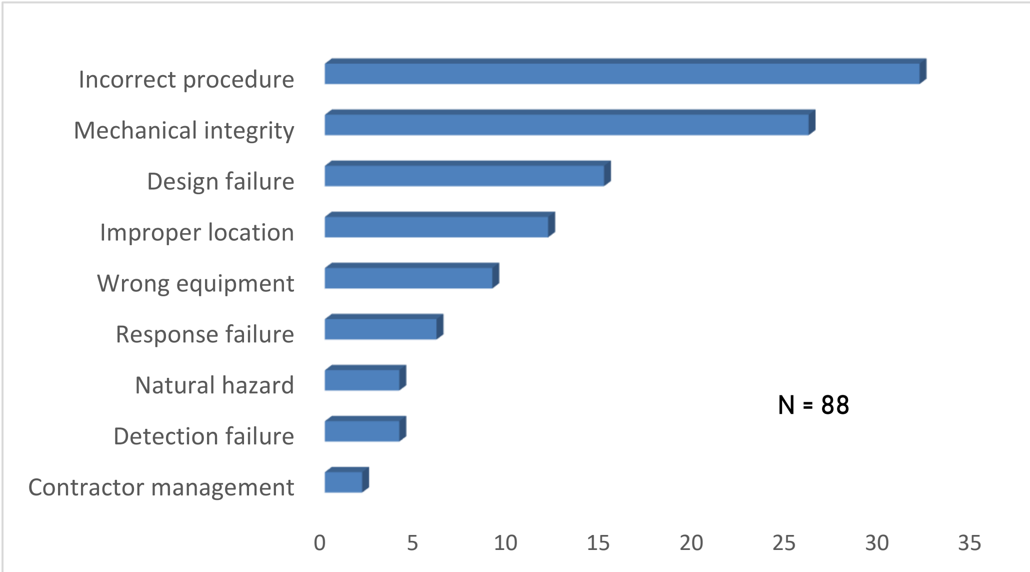
6.1.2 Benefits of analyzing chemical incidents thematically

The importance of learning lessons from one incident depends on the context. Generally, there is a lot to learn from very serious incidents and disasters for many actors. One minor or near miss incident can also point out a critical flaw in a specific plant condition in the plant, e.g., a process, a procedure, equipment, maintenance, etc. However, a potent tool for learning lessons is analysis of studies across groups of incidents based on a theme, e.g., incidents involving corrosion in refineries, lessons learned from emergency response, etc.

Case 1 in **section 5.1.3** is a good example of how an accident that, by itself, has limited opportunity for double-loop learning, can be important to finding patterns of failure in the study of collections of incidents that have common features, e.g., they are on the same site or unit, or involve the same or similar equipment, process, substances, etc. However, within the analysis of a collection of similar incidents, there may be an opportunity to identify a pattern of characteristics that produce this vulnerability. With this new information, the likelihood that the operator would fail to identify this pattern is small.

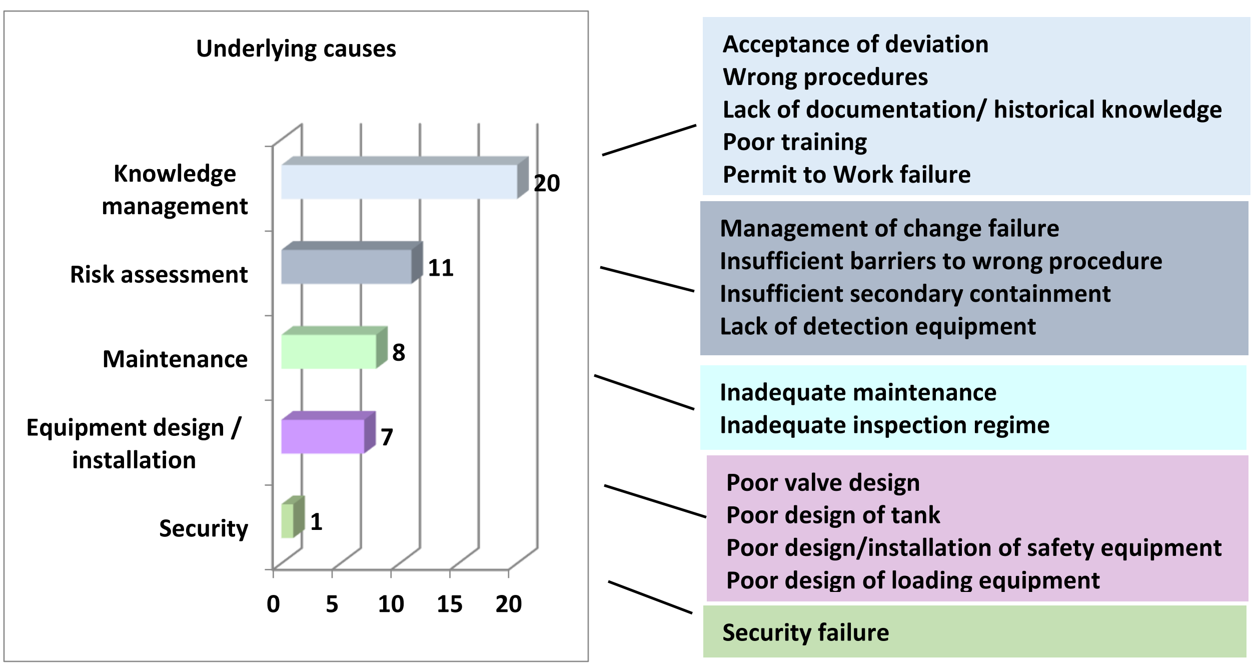
Examples of the output that can be produced from a thematic study are shown in **Figures 20** and **21.** In principle, industry or government staff can benefit from performing these analyses as well as inputs to hazard assessment, particularly for new processes and significant process changes. Such study may also be warranted when a serious incident or near miss has occurred on the site, or even in the wake of a relevant incident occurring in another company or even in another industry.

Figure 20. Analysis of underlying failures associated with a study of incidents involving liquefied petroleum gas (LPG)



Source: Wood, 2019

Figure 21. Analysis derived from a study of incidents occurring in tank farms (2015-2019) reported to the EU eMARS database



Source: Wood, 2021

6.2 Step 1 - Define the main objective and scope of the study

The purpose of a thematic study is to create and analyze a reference dataset to obtain certain learnings. Hence, the first step is to determine the objectives of the study and then, based on the objectives, define the scope.

6.2.1 Define the main objective

The main objective is simply a description of what the analyst wants to learn from studying a set of incidents. The objective usually centers on the study of a set of incidents involving a specific risk factor, e.g., a hazard, a condition, a control measure, an activity, etc., to identify lessons learned for controlling the same type of risk anywhere else it may be relevant. There are any number of topics around which to build a study, depending on the interest of the analyst. Thematic studies of chemical accidents may often be quite simple. They can revolve around anyone of a number of themes. Typical themes include learning lessons about incidents involving:

- A specific substance, e.g., ammonium nitrate, liquefied petroleum gas
- A specific process, e.g., wastewater treatment, loading and unloading
- A specific type of equipment, e.g., a heat exchanger, a distillation tower
- A specific condition, e.g., involvement of contract staff, a natural hazard event
- A specific technical control, e.g., pressure valves, gas detectors
- A specific safety management practice, e.g., management of change, equipment maintenance
- A specific industry, e.g., hydrogen production, metal processing

6.2.2 Define the scope and criteria for selecting incidents to study

The objectives establishes the general boundaries of the study, but a further refinement is sometimes necessary to achieve targeted results. The analyst will have to define the theme more precisely to apply to specific situations of interest and/or to obtain coherent learnings. Definition of the scope should take into consideration particular incident attributes that can either strengthen or weaken the usefulness of the findings. Typical considerations may include, are not limited to:

- Geographic location (Any accident anywhere or limited only to a specific region?)
- Mode of operation (Fixed facility, transport, offshore, pipeline, etc. or all of them?)
- Type of industry (If the study involves a topic other than an industry-specific element, e.g., a substance, a piece of equipment, are all industries relevant for the study?)
- Incident impacts (e.g., Exclusion or inclusion of near misses)
- Type of lessons learned (e.g., communication aspects, management of change, emergency response, other elements of the safety management system, failure mechanism, etc.)

Selection can also be based on efforts to identify broader trends, related to changes in technology or market preferences, for example, **Table 2** in **Chapter 3** also gives examples of themes of this nature that can be explored. Notably, selecting incidents may require a slightly higher level of attention, possibly support from data mining tools, and trial and error with selection of key words.

There are many other ways that a scope can be further refined with additional criteria, far too many to mention here. The potential for differentiating the analysis is generally proportionate to the number of cases that can be found that are relevant to the study objectives. The larger the dataset, the more there are options for focusing the study in a particular direction.

Moreover, an overbroad definition of scope will not yield a coherent analysis because the contexts and conditions across incidents involving the feature in question may vary widely. Conversely, defining the study to narrowly risks having incomplete and limited findings. In other words, defining the boundaries of the study is critical to achieving meaningful results. For example, analyses of pipeline accidents are associated with a specific substance, such as, natural gas, because incidents in other types of pipelines may be of a very different character due to pressure and temperature conditions, range of size (diameter) of the pipelines, and the properties of substances that they carry, as well as potentially other factors. On the other hand, studying lessons learned from dioxin releases similar to the 1976 accident in Seveso, Italy, would yield a very small dataset, since there have been very few releases of this nature following this incident.

6.3 Step 2 – Select cases for study

Selection of cases is usually a two-step process that starts with data filtering and finishes with manual selection of a subset of the cases identified by viewing each case individual. Due to the heterogeneous nature of chemical incidents, it is unusual to have much more than 100 cases for a thematic analysis of chemical incidents. A "large" dataset might be > 100 incidents. Where there are a few decades of experience with the topic, such as industries, substances, equipment and management controls that have been in use for some time, datasets may run from 50-100 cases. Even for older technologies, records are sparse before the advent of the Internet in the early 2000s. For incidents involving newer industries or technologies, the datasets may be even smaller.

6.3.1 Creating a subset of potentially relevant cases from data sources

Incidents are usually selected from one or more sources of incident cases, depending on the scope. If the scope of the analysis is inside a specific country or company, then national or company databases may be used. However, if there are no such limitations, the analyst can choose from a wide range of open sources as described in **Annex 3.** A few industries and substances have dedicated databases, such as the International Association of Oil and Gas Producers database and the HIAD hydrogen incident database. However, most sources typically cover a heterogeneous mix of chemical incidents requiring data mining to find relevant cases.

Databases in open sources often have their own filtering tool, e.g., ARIA, ZEMA, eMARS (see **Annex 3**) usually based on Boolean search techniques. Boolean searches generally work for a variety of study topics, provided the analyst knows the kind of terminology that would be associated with the topic. Even topics with non-uniform terminology, such as safety management measures and some types of failure mechanisms, can be found through Boolean searches, with some creativity.

6.3.2 Registering the subset of cases in a spreadsheet

As the analyst identifies a relevant case, each case should be registered in a master spreadsheet. The master spreadsheet should already allow dividing the data into a few general descriptive fields. At minimum, each case should have a unique identifier, fields indicating the data and the location, the source and the unique identifier at the source, and a box (or boxes) that contains the narrative description. For this process, the analyst can use any traditional spreadsheet software, e.g., Excel, or data management software (e.g., SPSS, SAS).

The narrative descriptions can be copied fully into one box or several boxes, e.g., separating out the sequence of events from descriptions of causes, consequences and other elements. If left opened, the boxes will be large, making it difficult to use the spreadsheet. Hence, it is recommended to fix the row widths so that only a portion of the text shows. The narrative descriptions should be input at this stage because they contain all or most of the data needed for the analysis.

At this point, the process of "coding", begins, that is, the transformation the information on each incident into separate individual variables that allow the analyst to filtering, compare and quantify accident characteristics. **Figure 22** shows an example of fields that might be used in this step to identify each case in the subset. Sometimes it can be also useful at this stage to identify the substance, the industry, or other easily extractable and identifiable, elements, depending on the needs of the analyst.

A narrative is normally a copy/paste of the information in free text as provided in the report, such as the descriptions of Cases 1 – 5 provided in **Chapter 5**. This box than serves as the master reference inside the database for all the information on the case. This information is then broken into analytical elements in the remaining columns of the spreadsheet for quantitative and comparative analysis as shown in the **Figure 22**.

To some extent, the process described in Step 3 (Establish the analytical framework) can already start here. The analyst can choose to start identifying variables for the entire spreadsheet as incidents are entered in the database. The process is by nature iterative so the order in which the steps are carried out can be determined by the analyst as practical.

6.3.3 Filtering the subset to discard non-relevant cases

After the filtering processing is complete, the analyst may conduct a manual review of each case selected that is, skimming the text of each case, to ensure that it belongs in the dataset, then rejecting those that were mistakenly identified in the initial filtering process. Sometimes this stage is skipped at this point, especially if the database is particularly large. In this case, the filtering process might be more practically applied in Step 3 because, when establishing the analytical framework, the descriptions of each case are read in-depth. In any case, at some stage of the coding process, some additional cases may be re-considered and excluded from the dataset.

6.4 Step 3 - Establish the analytical framework

Once all the relevant cases have been selected, the analyst begins the process of sorting the data into an analytical framework. For anyone who has performed data mining, data sorting is virtually the same process as data preparation techniques that are used prior to performing automated data mining. During this process, the analyst will be adding more fields to the spreadsheet template.

6.4.1 Creating the categories of analysis (fields)

The data sorting process consists of the analyst reading the narrative descriptions of each incident and identifying categories of information for analysis. Typical categories include equipment, equipment part, type of process operation, initiating event, direct cause, indirect cause, type of impact, magnitude of impact, etc. These categories then became the additional field headers in the spreadsheet.

6.4.2 Assigning a range values to each variable category

At the same time, that the categories are being selected, the analyst can also begin assigning values to each category for each case. In reading each case, the analyst will identify a value for each case, ultimately ending up with a range of values assigned to each category. How values are recorded will depend on the analyst's plan to process the data.

At this stage, it could also be possible to use artificial intelligence (AI) to populate variables. However, such techniques will only provide an initial conceptual framework. Since the AI will not understand the context, the analyst will still have to review each case to confirm and modify the framework for items that AI did not identify as significant for the analysis. For this reason, it may be that in many cases using AI will not necessarily save the analyst any time. However, there could be advantages that the AI may pick up variables that the analyst would not identify immediately.

6.5 Step 4 - Codify each case within the analytical framework.

The process of coding the narrative requires that, for each field, a range of values is fixed based on the values present in all the incidents in the dataset. For single choice fields (only one variable is assigned per case), the analyst chooses the range of values based on the collective range of values found in the case studies. While going through the cases, the analyst may continue to add to the list of values for each category until satisfied that all possibilities for that field have been identified. For example, for type of activity ("TYPE_ACTIVITY"), one might have four values, "normal operations", "storage", "loading/unloading" and "maintenance". Another variable could be the item that failed ("ITEM _FAILED"), such as "valve", "security measure", "procedure", and "sensor". As shown in **Figure 22**, each case would be assigned one of these values. The subsequent analysis would usually start with counting how many cases were assigned this value.

Figure 22. Example of analytic framework showing two fields with multiple possible values

CASE	TYPE_ACTIVITY	ITEM _ FAILED
001	NORMAL OPERATIONS	VALVE
002	STORAGE	SECURITY MEASURE
003	STORAGE	PROCEDURE
004	LOADING/ UNLOADING	PROCEDURE
005	NORMAL OPERATIONS	SENSOR
006	MAINTENANCE	VALVE

For multiple choice cases, in using Excel, a simple approach is to assign each value in each category its own field header, so that each of these "new variables" have a numeric value of "1" or "0". For example, to indicate containment types associated with an incident, one might have one field per containment type, e.g., a reactor vessel ("CONT_REACTOR"), a storage tank ("CONT_TANK"), a pipeline ("CONT_PIPELINE"), and unknown ("CONT_NON-SPECIFIED"). A "1" assigned to a variable means that the element was involved in the incident and a "0" assigned to the variable means that it was not involved (see **Figure 23**). Using the binary system, the number of times a particular element was involved across the data set can be easily summed. In addition, the assignment of individual fields for each characteristic facilitates making correlations with other variable. Nonetheless, this approach makes for very long spreadsheets. However, the spreadsheets can also be divided into worksheets according to subtopics (e.g., type of equipment, consequences, etc.) to ease visualization and manipulation.

Figure 23. Example of use of binary fields for multiple choice

CASE NO.	DATE	CONT_REACTOR	CONT-TANK	CONT-PIPELINE	CONT-NON-SPECIFIED
065	12-09-2017	0	1	1	0
066	02-02-2020	1	1	0	0
067	22-12-2021	0	0	1	1

Some automated data processing programs, e.g., SPSS, may be able to process multiple choice fields (more than one variable selected in the cell). If such a program is used, then the creation of individual binary fields for each value in the field is not necessary. One can also create a custom formula in Excel for counting multiple choice values. However, binary fields in Excel tend to be quite versatile for processing purposes, and easy to export without losing the data organization, if one decides to export the data to SPSS or another processing program.

The end result of this step is an analytical framework that is then used to codify the information for each case. The framework consists of master list of analytical components associated with the dataset. For chemical incident analysis, it is expected that most of the variables are qualitative not quantitative, except for volume (e.g., of substance released), number of deaths, injuries, costs, etc. A simplified version of a typical analytical categories are depicted in **Figure 24.** In practice, these categories are usually further elaborated with more categories, e.g., initiating event, safety management system (SMS) failure, equipment part, mitigation action, number evacuated, environmental impact, etc. Also, some categories, such as the "cause" category, may be broken into several subcategories, e.g., Direct Cause 1, Direct Cause 2, Underlying Cause 1, Underlying Cause 2, etc., since many incidents may have a sequence of cascading events where there is not just one "cause" but several. It is important to capture all these factors because they are helpful in identifying patterns of failure across all the incidents, even if failures happened in a different place in the sequence or resulted in different outcomes.

Figure 24. Typical analytical categories in a chemical incident analysis

Type of activity	Substance	Equipment Type	Cause	Item that failed	Lessons learned	Emergency response	Deaths	Injuries	Property damage	Other impacts

Text Box 13. Organizing data into discrete categories

The importance of segregation of data or analyzing "like with like"

A disciplined organization and separation of analytical elements into discrete categories is essential to achieving a credible and coherent analysis. For example, a type of equipment (e.g., a pipeline) should not be assigned to the same category as one of its components (e.g., a gasket on the pipeline). As another example, direct causes will refer strictly to technical failures, actions, or external forces that had an influence on the sequence of events until the end of the incident (resulting in impacts or a stopping of the event). Indirect causes will be a separate category from direct causes and consist of double loop type influences, e.g., lack of training, outdated procedures, inadequate risk assessment, etc.). The analysis may require individual subsets of these larger categories, for example, direct causality may be divided into procedural failures and technical failures.

If elements of different character are mixed and analyzed together, e.g., direct and indirect causes are not separated, there can be mistakes or confusion in the analysis, and the lessons learned may not emerge very clearly.

6.6 Step 5 – Assign values for each case within the analytical framework

This step is often conducted simultaneously with Step 4. As the analyst reads through each case, the elements of the analytical framework are established and the values can be assigned to the variables for each case. However, the analytical framework will only be complete when the last case is read and analyzed. Hence, it is likely that the analyst will have to go back and read each case again to add and re-assign values. As noted in **Text Box 13**, a disciplined structure and meticulous assignment of values in the proper categories is critical to having clear and credible findings.

Every piece of relevant information should be captured in the database. Even if a value occurs only once in the dataset, it is not unimportant. Only one data point is needed to establish a potential risk factor. For example, only one event in the entire database may have occurred because of a flooding event, but this fact confirms that this type of incident could result from this particular type of natural hazard. Therefore, it is not insignificant. (Natural hazard events causing chemical incidents or Natech events, are a small portion of chemical incidents, but they often have on average more severe consequences.)

Thematic studies usually only represent a small subset of all the incidents that could happen following a particular theme. As is well known, serious chemical incidents are low probability events. In most countries, tolerance for acceptable risk starts at 10^{-5}. Therefore, in a dataset of a mere 100 cases, having a unique value is not necessarily meaningless.

6.7 Step 6 – Use quantitative methods to analyze the data

Chemical incident analysis primarily relies on nonparametric descriptive statistics of single categories or of patterns that exist across cases or between categories. See **Text Boxes 14** and **15** for a discussion of chemical incident analysis using nonparametric descriptive statistics and inferential statistics. Counting of simple statistics can lead to ranking incidents associated with one specific factor, answering questions such as:

- How many incidents involved a pressure valve failure?
- How many times was there a release greater than 5 tons?
- How many times was a communication failure associated with a loading and unloading incident?
- What process unit was most commonly involved in these types of incidents?

Text Box 14. Statistical analysis for chemical incidents datasets

Chemical incident analysis is usually best suited to nonparametric descriptive statistical methods
In casual conversation, descriptive statistics and inferential statistics are often all mixed together as if they are the same thing. In general, any data can be described using descriptive statistics. However, only a certain type of data can also be analysed usefully using inferential statistical methods. In this context, chemical incident data are usually best suited for descriptive analysis because they do not meet criteria for valid inferential statistical analysis.

What are non-parametric descriptive statistics? Datasets with variables that express qualities rather than numeric values are nonparametric datasets. This analytic technique aims at describing and analysing a dataset's main features and characteristics without making any generalisations or inferences to a larger population. The techniques are ideal for qualitative (and ordinal) data and small datasets.

The most basic descriptive statistics are those that count how many cases have the same characteristic. For example, a basic descriptive statistic for a study of chemical incidents could be how many incidents occurred during the loading and unloading process, or how many occurred during maintenance. Chi-square tables and cross tabs are also frequently used tools for identifying relationships between different variables.

What you can find out from descriptive statistics. Descriptive statistics are very powerful. Their main limitation is that they cannot give the analyst a proof of particular relationships in terms of statistical significance. Expert judgment in descriptive substance is generally a legitimate substitute for statistical significance. The context, plus simple frequency analysis, can often yield powerful results to drive lessons learned. For example, if one finds 10 cases connecting a certain chemical release with a specific piece of equipment. If in 4 out of 10 cases, the incident occurred during maintenance, it may not be significant. However, on reading the case, the analyst might recognize that in each case, despite differences in some of the circumstances, the cause of the release was the same. In this case, one can conclude that this a finding worth of a lessons learned.

Anyway, contrary to what is often believed, meaningful findings do not depend on the proof of their statistical significance. A large part of incident analysis is simply to identify vulnerabilities so that they can be addressed. In this sense, one unique case, that identifies previously unforeseen vulnerabilities, is just as important to findings as twenty cases identifying the same causality.

These simple findings can either reveal a surprising predominance of certain factors, or that a factor that was considered important is not very influential. They can be enormously powerful sources of information when studying groups of incidents to investigate the conditions, causes and outcomes of incidents in involving the same substance, the same industry, the same sector, the same equipment, same type of failure, etc. Descriptive statistics to characterize patterns in thematic groups of incidents can also lay the groundwork for exploring why a certain attribute is so often associated with a certain type of incident.

For example, **Figure 25** is an example of a quantitative analysis derived from an analysis of the narrative of 90 reports of chemical incidents involving power failure. Each of the 90 cases studied was individual reviewed and then coded as to what the narrative indicated was the functions that were affected by the power supply as described qualitatively in the reports. Once each case was assigned a value for each of the variables above (0 = not involved; 1 = involved), a total was calculated for all cases that involved the specific function. This specific analysis was calculated using an Excel spreadsheet.

Text Box 15. The limitations of inferential statistical analysis in the context of chemical incident analysis

What are inferential statistics?

Inferential statistics involves using data from a sample to make generalizations or predictions about a larger population. It relies on probability theory and techniques like hypothesis testing, confidence intervals, and regression analysis to assess relationships and draw conclusions. Unlike descriptive statistics, which simply summarizes data, inferential statistics helps determine the likelihood that observed patterns are due to chance.

Why inferential statistics are not often used for chemical incident analysis

Inferential statistical analysis is only appropriate to use on random and unbiased subsets of data (the “sample”) that are drawn from the population of interest. This condition requires that:

- All data in the dataset must be collected from the same “population”
- The data for study are selected randomly
- All incidents have to be meet the same defining criteria to qualify for the dataset
- The data must be of sufficient size to yield meaningful results

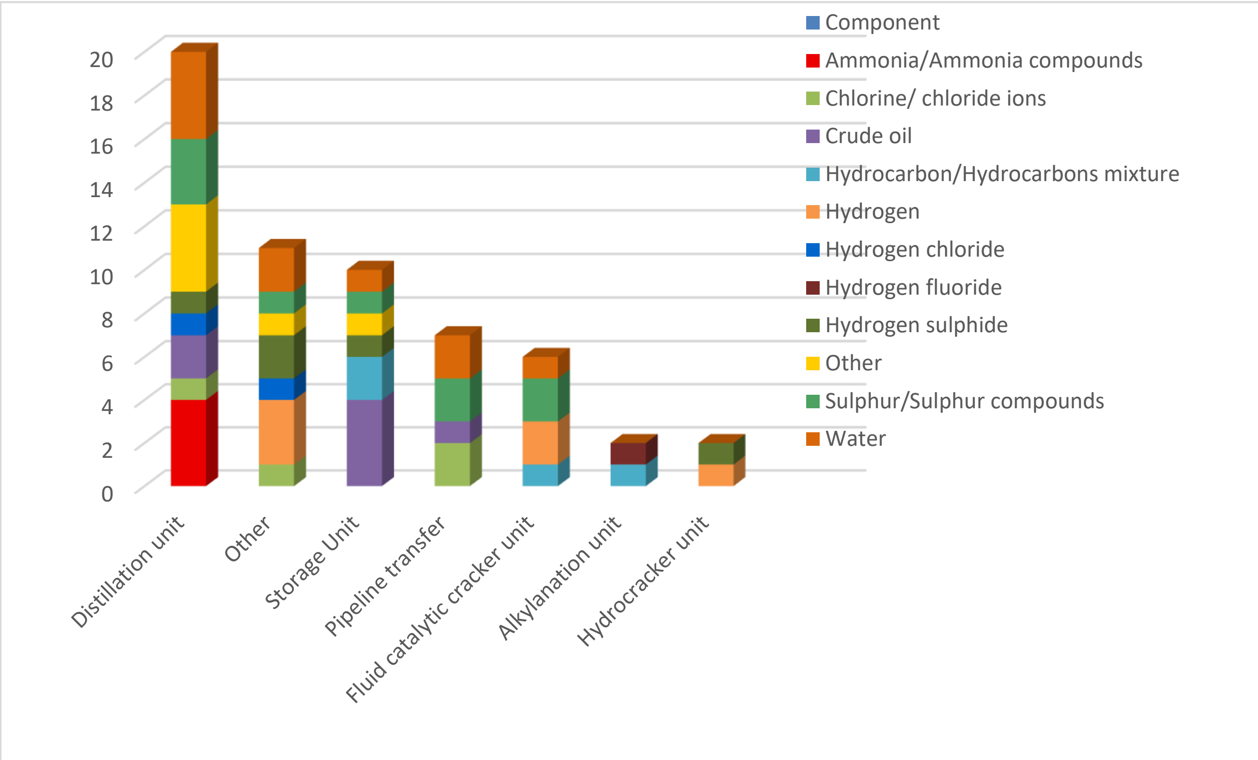
The universe of chemical incidents that can occur is too broad to be considered a “population”. For meaningful results, a reference “population” should be more narrowly defined by a defining set of characteristics, and at minimum, industry, process, substance, and equipment involved, and possibly others depending on the topic of study. Even in the same company, chemical incident may not share all these same characteristics. Moreover, similar incidents do not occur frequently enough to form a representative population.

Hence, without a dataset from a defined population of a sufficient size, using the data to derive assumptions about probabilities and correlations across the study is not possible. This limitation means that some types of statistical analysis, no matter how desirable, are not valid, including:

- Time series analysis (change in frequency of incidents over time)
- Correlation (e.g., the presence of two or more variables makes something else more likely)

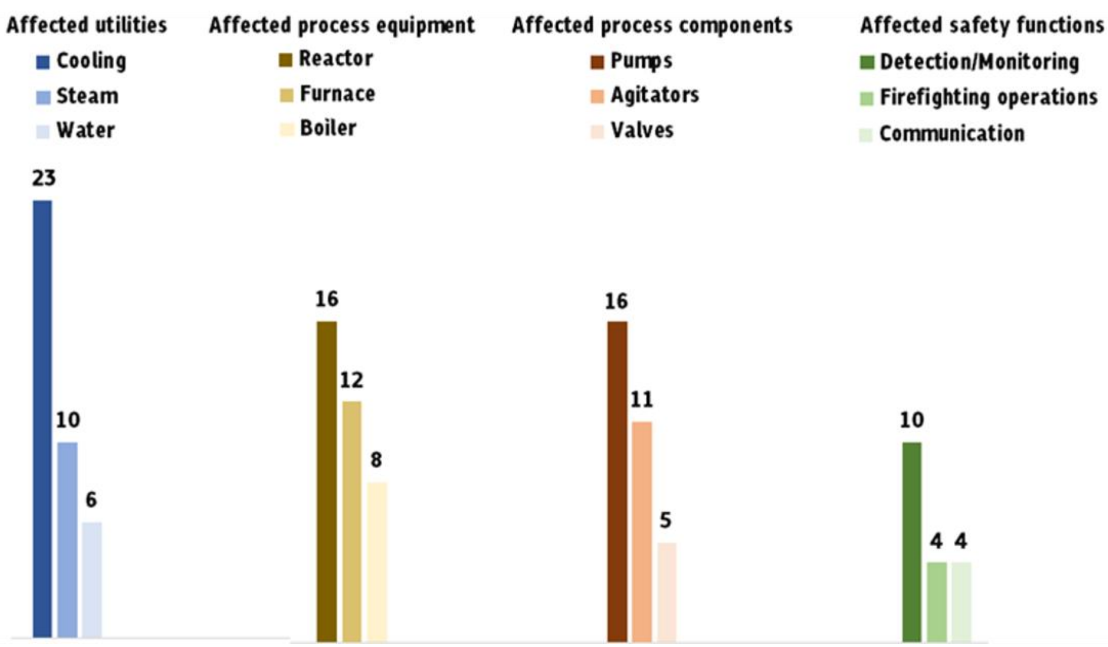
Nonetheless, when justified by logic, the analyst can still make the same conclusions using common sense, even if they cannot obtain a numerical proof.

Figure 25. Example of a matching of data using SPSS (Process substances contributing to corrosion failure in association with the process unit of origin



Source: Koutelos and Wood, 2021

Figure 26. Example of quantification of qualitative data (Process utilities, equipment, components and safety functions affected by the power failure)



Source: Wood et al., 2013

Other programs, such as the IBM statistical analysis software, SPSS, can also be used if more sophisticated statistical methods are needed. **Figure 26** was produced from an SPSS analysis that quantified substance or substance type in relation to the process unit of origin at a petroleum oil refinery. As with **Figure 25**, the narrative of each of 53 cases was analyzed to assign a 0 or 1 value to each of the categories indicated in the graph. Using an SPSS function, substance categories were sorted and quantified in relation to the process unit with which they were associated according to the narrative of the incident report. **Figure 26** shows the frequency with which each type of substances was found in relation to the originating process unit.

In general, it is advisable to quantify the distribution of values for each variable because the findings from this simple analysis usually creates the priorities for more sophisticated analysis. One can initially start by looking at extreme values (highest and lowest, for example) and asking questions about whether these values are associated with the occurrence of other values. Sometimes, in small data sets, sorting the data against the variable of interest, can already lead the analyst to make connections between variables. For example, it may become clear to the analyst, in viewing the incidents associated with loading or unloading operations that the vast majority of such events occurred because the driver had little or no training.

For larger data sets, with many events or many variables, it can be helpful to use more sophisticated tools, such as statistics programs (e.g., SPSS), data mining, and customized programming (e.g., using

Text Box 16 Example of lessons learned derived from a study of multiple cases on a specific topic (corrosion-related incidents in petroleum oil refineries)

Excerpt from a study on lessons learned from corrosion related incidents in petroleum refineries

"… According to the eMARS database, corrosion failure is responsible for one out of five of each major refinery accident occurring in the EU alone since 2000. This analysis of 99 corrosion-related accidents occurring in refineries over the last 50 years was an effort try to help the expert community maintain a focus on conditions that may put critical refinery equipment at risk of corrosion failure.

In this regard, the following findings and conclusions are highlighted:

- Corrosion of equipment continues to be an important source of accident risk potential at EU and OECD refineries. The study identified 40 accidents occurring since 2000. Half of the accidents were estimated to have had very high consequences, particularly in terms of impacts on the environment and in terms of economic costs for the refinery itself as well as potentially the surrounding community.
- Generally, significant corrosion failures occur either because the hazard was not properly identified or the hazard was substantially ignored. There is an enormous variety of corrosion phenomena that can occur, yet the list of factors that may contribute to any corrosion failure, whatever type, is relatively short. The factors mainly involve the presence of various known corrosive agents, exposure to certain conditions, and equipment composition and configuration. Still it requires a certain level of competency, particular in regard to production processes (versus storage and transfer), to recognize that all the conditions are present to create a significant corrosion hazard. However, there appeared to be a number of cases studied in which the corrosion risk was quite obvious, and yet the management chose to ignore or underestimate it.
- The lack of an adequate hazard identification, or inadequate assessment of the associated risk potential, cannot be attributed to any one fundamental cause. It is sometimes a clear management failure in not having competence to make a good analysis, but not always. It appeared from the studies that experts sometimes overlooked how the various elements of a process could combine to create the conditions for accelerated corrosion. There is also a question about how much experience specifically in mechanical integrity disciplines is available at some refineries to diagnose these properly."

Python). These programs can help the analyst in manipulating data to find more complex patterns, and the analyst can create comparative graphs, possibly even make simple statistical correlations, depending on the size of the data, to find and illustrate patterns. Data mining programs apply particular algorithms that are conducive to finding connections between variables and cases that the analyst may not readily observe from simple visualization and quantification of the data. For example, one can explore whether there are patterns linking specific causality, equipment involvement, etc. vs. severity of an incident. Or alternatively, one can look at whether certain indirect causes are more commonly associated with certain direct causes more than others.

6.8 Step 7 – Summarize findings and develop lessons learned

Once the analyst is satisfied that all interesting patterns have been identified, it is time to derive conclusions from the analysis. There are usually several parts to the conclusions, starting with the range of types and the severity of impacts that the incidents studied represent. The analyst may then describe the results from quantifying single variables, explaining factors that tend to be common or less common across the cases, and also mentioning factors that are outliers that can lead to a significant release or important consequences.

Another section should address patterns involving connections between variables, such as a linkage between pipe configuration and higher tendency for releases due to corrosion. In addition, quantification of single variables as well as patterns across incidents can lead to the development of accident typologies, e.g., incidents caused by loading and unloading events, or incidents where failure to properly identify waste streams leads to a reaction during waste processing. **Text Box 16** provides an example of the kind of lessons learned that can be derived from studying a group of cases to find patterns related to a specific common characteristic of the incidents.

6.9 Manual data analysis vs. automated approaches

In this modern age, it is valid to ask whether manual coding of data will soon be obsolete, with the possibilities offered by data mining and artificial intelligence. Certainly, advanced computational methods may prove useful in some types of analyses. However, data mining and artificial intelligence methods have much more selective requirements surrounding their use than traditional mathematical statistical models that can be calculated manually or using simple spreadsheet tools. Moreover, experience with manually-coded analysis, using classic spreadsheet tools and data management software, is normally the best route to acquiring the necessary knowledge for judging whether a statistical method is appropriate for a particular dataset.

Meaningful results using automated techniques depend on the datasets meeting certain criteria, for example, in terms of size, completeness and homogeneity. Specifically, one has to assess the choice to use these methods against the following criteria:

- **The time it takes to perform the analysis.** The time required to ready the data for analysis so that the chosen analytical methods can be applied.
- **The value of the results.** The relevance, reliability and importance of the results that can be achieved using the chosen analytical methods.
- **Statistical validity.** Choice of analytic method should take account of statistical limitations associated with small databases and nonhomogeneous qualitative data.

Based on these criteria, most chemical incident databases are best suited for nonparametric statistics. However, if the analyst incorporates other statistical analysis methods in their study, they should take account of the conditions described in **Text Boxes 14** and **15**. In addition, they should have sufficient competence to make judgements about the use of different methods as described in the next section.

6.9.1 Minimum competence requirements for using automated statistical approaches

The analyst also needs to have the following competences:

- Sufficient knowledge of statistical principles to evaluate the characteristics of the data for statistical analysis using the methods being considered for the study. Analysts who are considering applying any automated statistical methods should already know the limitations of the methods in relation to their study dataset.
- Sufficient knowledge of the contents of the dataset in order to assess that the data meet the criteria required for using a particular statistical method, or whether the data can be adapted to meet the criteria without straining the time and resources available for the study.
- Sufficient competence in chemical incident analysis to influence the design of the study to ensure it achieves the desired outputs
- Sufficient competence in the chosen statistical method(s) to influence the study design to produce value-added information for chemical process safety

In sum, chemical incident analysis requires the analyst to have both sufficient statistical competence and experience in working with chemical incident data. It is absolutely necessary that the analysts of chemical incident data should themselves understand the principles behind the main statistical approaches, mentioned **in Text Boxes 14** and **15**. It is not sufficient for the analyst to employ a data scientist to help with chemical incident analysis to compensate for the analyst's insufficient statistics training.

The data scientist, who is not a process safety expert, is often not able to assess the suitability of the data in a discipline, such as process safety, where they have no competence. .There have been several studies published using machine learning and data mining for chemical incident datasets that are not appropriate for those applications. This situation occurs because the process safety expert did not know themselves the conditions necessary for successful application of such techniques. Nor did they have a discussion with the data scientist about whether those conditions were fulfilled.

6.9.2 Sacrificing quantity to obtain quality

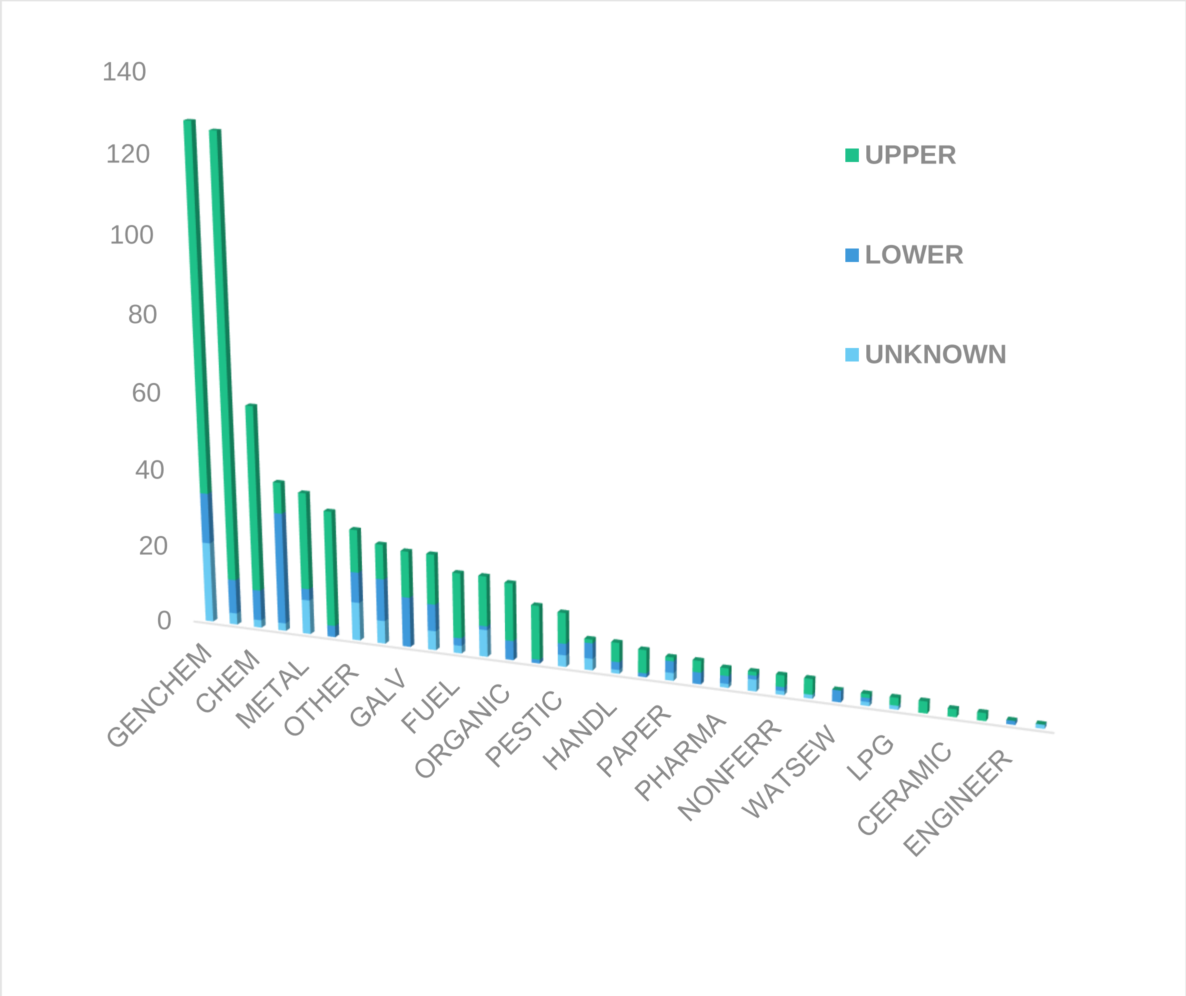
Lessons learned analysis is predominantly a job that involves working with very small datasets, usually around 25-100 incidents. These databases are too small to obtain any value from machine learning or data mining techniques Sometimes these techniques can play a supporting role (e.g., finding common keywords).

Large open sources of chemical incident databases are sources of data but, except for study of the most general themes (how many involved an explosion?), they are not ideal datasets for lessons learning or trend analysis. A common mistake in chemical accident data analysis is to ignore the vast differences in chemical accidents and treat them as if they are all very much the same. However, this is not the case. The only element in common for some chemical accidents is the fact that they started with a chemical release.

From a statistical perspective, most chemical accident information sets are collections of subsets of chemical accidents that represent many diverse types of incidents. A chemical accident in a storage facility of a refinery is of different character than an accident in an explosives manufacturing facility. An accident in process operations in a paint manufacturer is very different from an accident in a metal processing unit. There can also be large differences in types of accidents in the same industry, involving the same substance, and the same equipment.

In other words, there are many, many different kinds of chemical accidents represented inside chemical incident open source databases. According to the eMARS database, there were 32 different industries associated with the 690 reportable major chemical accidents occurring in the EU since 2000 (see **Figure 27**). For meaningful results, the analyst has to choose a theme and study subsets of incidents that meet the thematic criteria. Since chemical incidents registered in open source databases are highly variable, the analyst usually ends up studying only a small subset of incidents that are relevant to their theme.

Figure 27. Industries represented in major accidents reported to the EU eMARS database since 2000 (as of October 2023)[9]



Source: Wood and Guagnini, 2023

6.9.3 Limitations of machine learning for small non-homogeneous datasets

For machine learning to extract lessons learned from chemical accidents, it requires sufficiently large data sets of homogeneous data to train and then extract information from the other accidents that belong to the dataset. The choice to use artificial intelligence requires careful consideration of whether the database has enough homogeneous data to serve this purpose. This decision must involve the strong participation of an expert in chemical accident lessons learned analysis. The failure to consider the statistical fitness of the dataset for artificial learning has doomed many a project to very mediocre results.

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[9] (The Upper and Lower and Unknown categories refer to the two- tiered system of the EU Seveso Directive that determines the requirements imposed on a site. The legend on the x axis are abbreviations for different industries, GENCHEM = general chemical, CHEM = chemical installations, etc.) This study was intended to show the industries associated with major accidents reported to the EU eMARS chemical accident reporting system in terms of whether the site was "lower" or "upper" tier sites. The assignment of lower vs. upper tier site is dependent on the volume of hazardous substances present on the site. Upper tier sites have exceeded a volume threshold higher than that of lower tier sites and therefore, they are subject to more stringent obligations, according to the Directive.

Machine learning is an ineffective tool when working with highly different contexts and large inconsistencies in individual data entries. In particular, the variety of perspectives and motivations of authors of chemical incident reports means that the reports are written in many different ways. In some cases, data essential for a part of the analysis is missing, such as causality. Missing data is particularly a problem where there is not an investigation report, but only an accident summary.

Machine learning cannot deduce relationships without many examples of the same event in different contexts. Chemical incident databases are too small and have too much internal variation to allow machine learning to make predictions. On the other hand, humans recognize the similarities of different contexts naturally, and can transfer learning from one context and apply them universally to other contexts where they apply. In many accident summaries, the description of the sequence of events is sufficient to deduce causality, even it is not explicitly identified. Such deduction requires understanding the context. Whereas computers, at least right now, need to learn these relationships through a painstaking resource- and data-intensive process.

6.9.4 Opportunities for data mining

In contrast to machine learning, data mining is not necessarily limited by either the size or the homogeneity of a dataset. The question for the analysis is whether or not, in terms of the three criteria, time, results and statistical value, it is a better option than manual coding into a classic spreadsheet or statistical package. For technical questions, the analyst will most likely be working with smaller datasets because the differences in a heterogeneous database of ten are in the technical context.

However, data mining for questions that have a more horizontal nature, such as human factors, and therefore, applicable to chemical accidents of all types, could possibly involve much larger datasets. For smaller datasets, data mining makes little sense because it is often more time consuming to code the data for the data mining programming than just to code the data directly into a spreadsheet. The small datasets cannot take advantage of the opportunities that data mining offers for finding statistical relationships across the database. Often, repetition of individual elements maybe too few to establish statistical reliability. In any case, a spreadsheet or an SAS or SPSS program, can find these correlations easily once the data is manually coded. In sum, manual coding can be much faster than data mining in these circumstances.

Yet once the codes have been defined, they may be useful for filtering, e.g., obtaining relevant cases from other large datasets. Hence, the value of data mining is dependent on the needs and scope of the project and the time needed to achieve results another way. However, the analyst must also recognize that, with both data mining and artificial intelligence, past errors may not be representative of future errors. Using past data mining or artificial intelligence results may not work well if there are significant changes going on in particular industries. For example, incidents occurring in waste management facilities ten years ago, before the proliferation of lithium-ion batteries and biofuel sites, may be quite different from incidents that are occurring today.

6.9.5 Use automated methods when appropriate but with caution

It is important to emphasize that no competence in advanced methods of computation is necessary to extract rich and relevant findings to learn lessons on a specific chemical accident topic. It is simply advised that, if there is a desire to use such tools for a group analysis, the analyst needs to first be competent in the fundamentals of analyzing lesson learned by working with the data directly. It is hoped that this chapter can show analysts, how to work with the mostly qualitative data offered in chemical incident reports and databases to achieve interesting and relevant results.

Data science tools may help in suggesting fields and correlations, but rarely can these tools actually perform a competent analysis. The tools are not expert in process safety. The analyst is. For this reason, at every stage of the process of chemical incident analysis, the knowledge of the analyst is required to refine, add, discard and elaborate on the outputs from the automated tools.

Chapter 6 Summary

— **Group Analysis Focus -** The chapter emphasizes studying groups of chemical incidents to identify overarching patterns, rather than analyzing individual events in isolation.

— **Data Transformation -** It details how qualitative accident narratives are manually coded and converted into quantitative variables using tools like spreadsheets or statistical software.

— **Structured Methodology -** A systematic process is outlined, including defining objectives, selecting relevant cases, and establishing an analytical framework to capture shared characteristics.

— **Trend Identification -** By grouping incidents based on common themes, analysts can uncover trends, correlations, and systemic vulnerabilities that might be overlooked in single-case studies.

— **Balancing Techniques -** Although automated methods such as machine learning can assist, the chapter underscores that manual analysis is essential for extracting meaningful insights from small, heterogeneous datasets.

7 Dissemination and applying lessons learned

This chapter takes a look at what happens once the lessons learned are established. Although the focus of the handbook is on deriving lessons learned, what is learned has to be relevant for the next steps in the process, that is, dissemination and implementation. These aspects are complex topics in their own right and require another handbook to describe the skills and good practices needed to perform them effectively.

However, since knowing what happens to the lessons learned helps in the identification of the lessons learned, this chapter will give an overview of what dissemination and implementation entail. It will also summarize typical challenges with dissemination and implementation and the main principles considered important in their proper execution. Some of the references in the annexes of this handbook can also provide more in-depth knowledge about theory and practice.

Dissemination and implementation are intrinsically linked. As such, all the potential options for promoting implementation should provide direction on how to shape the dissemination strategy. Hence, even though dissemination is considered a step prior to implementation of the lessons, in reality, one has to think about implementation first and then shape the dissemination around it. For practical purposes, dissemination strategy is presented first in this chapter followed by implementation considerations. However, in practice, the two strategies to a large extent should be developed in parallel in time, with each one evolving with the other.

7.1 The importance of a dissemination strategy to maximize the value of lessons learned

The intention of dissemination is to stimulate learnings to be applied in practice. Therefore, in planning dissemination, there are a number of considerations. The possibilities for dissemination depend on the severity of the accident and/or the lessons learned that can be potentially extracted. Dissemination of near miss information can be equally as important as dissemination of serious incidents, although the dissemination strategy may vary slightly.

In general, an operator should have a general dissemination strategy with potentially some differentiation based on established criteria to determine the appropriate strategy for incidents, especially those that may have serious implications for future safety of the installation, those that have broad relevance for a broad range of company operations, or that may hold valuable learnings for other stakeholders. The strategy should consider mechanisms for dissemination, the audience that could benefit from dissemination, and what communication approaches could have success in advancing application of the learnings among target audiences.

7.1.1 Disseminating incident information to promote lessons learned

The purpose of dissemination of lessons learned from industrial accidents is to stimulate reflection in the site, the company, or among other stakeholders, on an existing situation based on insights resulting from a process safety failure. That reflection should result in an awareness of potential vulnerabilities associated with certain operations, and when necessary, corrective actions that rectify unsafe situations, or actions that materially improve norms and practices to avoid such situations in future.

Table 3 in **Chapter 3** provides a table with an extensive list of possible audiences for different kinds of lessons learned. The vast majority of minor events, especially near misses, will be only relevant at site level, but as this handbook shows, the value of an incident is not limited by what is of relevant for the site where it occurred. Other sites, other companies, other industries and the regulators can bring new perspectives through their own analyses, driven by their unique priorities, experiences and competences.

Moreover, in this handbook, dissemination of incident information, in full or as a detailed summary, for all practical purposes, is considered synonymous with dissemination of lessons learned. In chemical accident risk, and other areas of technological risk, details about the context and conditions where the incident occurred, such as the sequence of events and the various contributing factors, are usually necessary to maximize understanding of the lessons being learned. These details are essential to establishing the precise nature of the lessons as well as to evaluating their significance in overall prevention of process safety incidents and mitigation of their effects.

In addition, many users of the information need the detailed incident information in order to establish relevance to their own situation. For example, the details on context will help another company to confirm the relevance of the incident to their own operations. In the same way, a regulator or industry organization will need to have enough context to identify what lessons from the incident could also apply to existing standards, regulatory requirements, or risk management tools. Other industries, companies or experts of many kinds may find new or additional insights on lessons to be learned, or incorporate findings into scientific studies of substance behavior, for example, or incidents related to specific risk management topics, such as corrosion or human factors.

7.1.2 What is meant by dissemination

In simple terms, dissemination is the act of spreading information to those who do not have the information. For lessons learning from chemical accidents, the act of spreading information can encompass a number of types of activities. Typically, they can be categorized into the following types of communication pathways:

- **Oral communication:** Presentations, discussions and exchanges in meetings, bilateral conversations

- **Formal reports:** Reports and summaries that communicate the essence of the findings including lessons learned

- **Electronic communication:** Exchanges within email distribution or Teams networks or similar forums, bilateral exchanges, bilateral requests to pass on the information to other distribution networks and forums

- **Online communication:** Portals for hosting links to reports, summaries, presentations, transcripts of exchanges

- **Databases:** Registration in databases where others can search for relevant incidents, learnings, and analyze them for their own purposes and/or for a network of stakeholders who can use the information

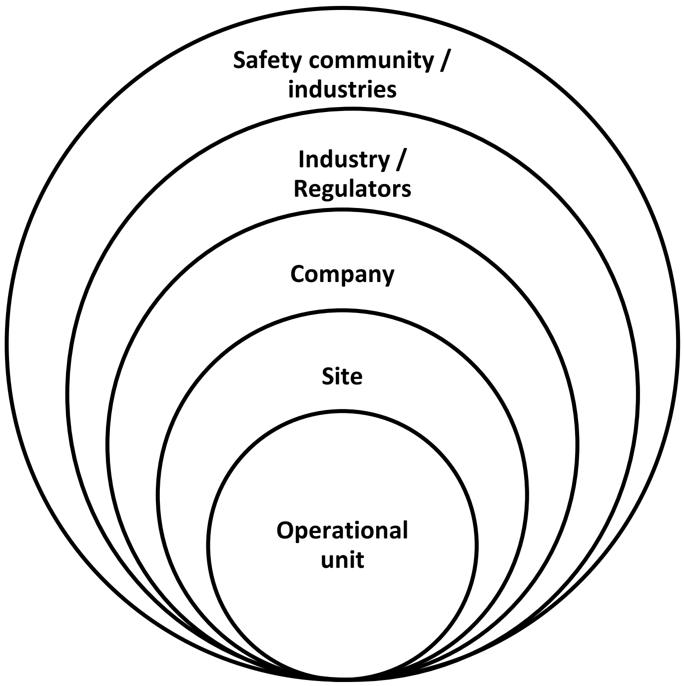
- **Routine safety briefing**: An established summary report on the safety performance over a defined interval, intended for both staff and top management. It can also be useful for industry associations and authorities.

- **Dissemination campaigns**: A combination of several elements above, often crafted for a specific very serious incident, aiming not only at peers and workers, but also at company and industry leaders, politicians and other influential actors.

7.2 Determining the target audiences

The dissemination strategy for different incidents depends largely on their perceived value to potential audiences. The diagram in **Figure 28** shows typical audiences based on their proximity to the incident, starting with the specific operational unit where the incident took place, then moving outwards in a hierarchical fashion with the safety community at large and other hazardous industries being the most general group.

Figure 28. Potential target audiences for incident information



Source: Figure by Wood and Allford

The strategy for disseminating incident information may be based on a typology related to the kind of incident and the resonance that the information has inside and outside the site where it occurred. The operator or authority may decide to use the existing criteria that guides investigation and/or reporting of incidents. Many operators have tiered systems that start with near misses as the lowest tier and catastrophic accidents as the highest level. Depending on the operator, there may be only two types (e.g., near miss or limited impact and serious incident) or three tiers (the two-tiered system plus catastrophic incident).

Some expert organizations and governments have developed and published their own classification systems. For example, the Center for Chemical Process Safety (CCPS), in its publication on Process Safety Metrics (CCPS, 2022), differentiates the learning value of incidents into a four-tier hierarchy for the purposes of identifying which ones are useful for which kind of safety performance data (lagging or leading indicators). While the CCPS typology for lessons learning has different aims than lessons learning, the idea of differentiating incidents according to learning opportunities can be useful in identifying the appropriate dissemination path for each.

Some factors that can help differentiate incidents for dissemination purposes include:

Incident severity level. The severity level is potentially an indicator of complexity of the learnings from an incident, and for this reason, it can be valuable for identifying potential for investigation as well as target audiences. It is not necessarily an indicator of the significance of the lessons learned that can be derived from an incident, since incidents or near misses that do not have serious impacts, due to effective layers of protection, or shear dumb luck, can have very important lessons learned. For this reason, potential severity level is often used in lieu of actual severity level. Various organizations, such as the Center for Chemical Process Safety (CCPS, 2022), have established criteria for assessing severity level. Another well-known severity ranking system is the European Scale of Industrial Accidents which establishes 6 levels of severity for numerous impact categories, including human and social consequences, economic consequences and environmental consequences.

Complexity and multi-dimensional aspects. The complexity of the causality can also influence the dissemination effort. In particular, complexity increases with the degree to which causality is affected by different factors, for example, the involvement of one or more elements of the safety management system, the occurrence of one or more equipment failures, or the number of actors or operations that may have had a role in the failure(s) that occurred. Causality that has multiple dimensions generally means that many actors in the company, and possibly outside it, have something to learn about the incident.

How the lessons can be applied. The potential opportunity for learning lessons on different safety aspects will also determine the relevance of the incident for different audiences. Lessons learned can be identified for numerous safety aspects including procedures, equipment, human factors, management, substance behavior, reactive hazards, operations such as maintenance and loading/unloading, etc. The type of lessons learned is a factor in determining the audience for the learning.

Relevance for different audiences. The decision about how much effort to dedicate in communicating incident lessons and other details beyond unit level (in addition to perfunctory reporting) depends largely on the degree of relevance to other installations and the company at large and importance to external stakeholders. In a large site or company, where different units are handling similar processes or product, sharing incident information may increase relevance when it turns out that other sites have had the same type of incident.

Also, relevance of single incidents vs. groups of incidents may differ. When grouped together, minor incidents that occurred in the same place or period of time could yield some insights that the single incident does not.

Other factors that can influence the dissemination strategy include complexity (many lessons for many safety aspects, double and triple loop lessons), timing (a similar accident just happened at another company), opportunity (the incident relates to a current hot topic, such as cyber safety), etc.

7.3 Who disseminates the information

The more important the lessons, the more important it is to think broadly about who can pass on the information. The investigation of the incident, or study of a series of incidents, will normally produce recommendations that are assigned to operations staff of the units involved and the site. The recommendations may also.have wider implications for company procedures and the safety management system.

Chemical incidents occur mainly in industry but also can occur in the public sector, such as military sites, hospitals and universities. The site and its operating organization generally have a leading responsibility in disseminating the lessons learned from important incidents. However, other organizations, particularly industry associations, government inspectorates, investigation authorities and academic institutions also often play a role in dissemination. The collective effort of all these actors helps to reinforce a lessons learning culture among all those who are working at reducing chemical incident risk.

7.3.1 The role of the company

Dissemination of incident information is also a powerful vehicle for raising risk awareness in the site and in the company. For example, presentation and discussion of the incident can be used in safety meetings, but also regular meetings of other units, to promote a general awareness of the risk that are associated with working on the site. In an ideal situation, the company itself has a leadership with a vision that includes high risk awareness of all its staff. In this case, the company would have established mechanisms (briefings, recommendation memos, internal news headlines, etc.), promoted by the leadership, for creating visibility around safety events and stimulating improvement.

The company can also initiate propagation outside the company through its own online dissemination of investigation and study results, presentation of incident information at industry association meetings and conferences, and scientific articles, reporting to industry and government databases, and similar efforts than can instigate projects to study improvements or changes in standards and tools for risk assessment, monitoring and oversight. The availability of information in a database, or directly online, also allows other experts to analyze the information in the context of their own projects and the use of the incident information by other stakeholder forums, including regulators and related industries. All these actors magnify the exposure to the information through multiple dissemination routes.

7.3.2 The role of the government

There are a number of good practices in place in various parts of the world that demonstrate how government can also be an engine of lessons learned dissemination. These practices include:

- Requiring sites to have a program for investigating incidents and applying the lessons learned

- Requiring sites to report serious chemical incidents and near misses to authorities
- Establishing a public repository of serious chemical incidents and near misses
- Monitoring reporting and analyzing incidents and incidents trends and sharing with operators and other inspectors
- Establishing independent investigation boards for investigation of chemical incidents in fixed facilities, transport and/or pipelines
- Promoting lessons learning through thematic inspection campaigns

Since the 1980s and continuing into the 2000s, the number of national governments who impose requirements and actively engage in promoting lessons learned continue to grow. **Text Box 17** highlights the many open sources of lessons learning in EU government and industry, influenced by the emphasis on accident investigation and sharing of lessons learned in the EU Seveso Directive as a means to maintaining and improving chemical process safety.

Text Box 17. EU government initiatives to share lessons learned from high hazard (Seveso) establishments

Since its inception, the EU Seveso Directive has fostered an awareness among EU authorities and industries of the importance of sharing lessons learned from chemical accidents with other relevant authorities and industries in the EU. The first sentence of Article 21 says

> "Member States and the Commission shall exchange information on the experience acquired with regard to the prevention of major accidents and the limitation of their consequences. This information shall concern, in particular, the functioning of the measures provided for in this Directive."

The Lessons Learned Bulletins published by the European Commission itself fulfils its obligation to disseminate lessons learned from chemical accidents reported to the eMARS database. However, many EU competent authorities in Member States also are actively engaged in disseminating lessons learned. The French Ministry of Environment's Bureau for Analysis of Industrial Risk (BARPI) is one of the most prominent organisation in this regard, through its ARIA online database that hosts over 50,000 reports of chemical accidents occurring mainly over the last 30 years, but also some from earlier decades. BARPI also routinely performs topic focused analyses of accidents and publishes a semi-annual newsletter highlighting its most recent analyses. Numerous other EU authorities that publish investigation reports and lessons learned to enhance sharing of information about chemical accident causality. Some countries investigation reports or chemical accident summaries available publicly online, including Germany, the Netherlands, and Finland. Various industry organisations also publish chemical accident reports and lessons learned, such as the Process Safety (VDI), the Energy Institute, the IChemE Safety Centre, and the European Centre for Process Safety (EPSC). A collection

There are many other examples of government taking an active role in ensuring incidents are investigated for lessons learned. Other well-known government initiatives for lessons learning from chemical incidents include several investigation boards, some of which focus on chemical incidents exclusively, like the U.S. Chemical Safety Board or safety (e.g., the Dutch Safety Board), the Swedish Accident Investigation Authority). Quite a few countries have national transportation safety boards, covering all transportation, or by transportation mode (air, rail, etc.), that also cover hazardous materials incidents, including sometimes those in pipelines. The High Pressure Gas Safety Institute, established under Japanese law, publishes a database of > 20,000 chemical incidents dating back to 1965.

Annex 3 provides a list of online sources of chemical incident data that includes these and other government sources.

Annex 4 provides a list of links to published reports of various national investigation boards that investigate chemical incidents.

7.3.3 The role of industry and professional associations

Industry and professional organizations are well-positioned facilitate sharing across industry as well as promote incorporation of lessons learning into standards and good practice. Chemical manufacturing and oil and gas industry associations are particularly engaged in promoting sharing of lessons learning in their industries, as evidenced in **Annex 3**. The Energy Institute's Toolbox provides summaries of lessons learned from process and occupational safety incidents, organized by work activity and highlighting high risk situations. Various other industry organizations such as the Center for Chemical Process Safety (CCPS) and International Oil and Gas Producers (IOGP), have published online databases containing details on chemical incidents.

In addition, there are examples of industry collaborating with government to support dissemination of learnings from chemical and other safety-related incidents. **Text Box 18** describes the Safety Forum, a Norwegian initiative associated with offshore oil and gas exploitation that fosters collaboration to promote safety, including sharing of experiences and lessons learned.

Text Box 18. Government, industry and labor in Norway make lessons learning a common priority for oil and gas explanation in the North Sea

The Safety Forum, led by the Norwegian Ocean Industry Authority (Havtil), was established in 2000 by as a central arena for collaboration and debate between companies, unions and government on important health, safety and environmental (HSE) challenges in the petroleum sector in Norway. The aim of the forum is to promote work on safety and the working environment in the Norwegian oil and gas sector. Many initiatives to enhance HSE have emerged from the forum and its various actors over the past two decades.

- In addition, following a number of safety challenges and serious incidents, the Norwegian Ministry of Labour and Social Affairs appointed a tripartite working group in 2016 to study and arrive at a common assessment of health, safety and environmental conditions and trends in the Norwegian petroleum industry (report from the tripartite group, 2017). In its conclusions, the commission recognized a need to improve learning from incidents and transfer of experience across the industry. The Safety Forum followed up these recommendations, meeting several times to review and discuss and review frameworks and regulations that form the basis for cooperating to achieve a high level of safety. Recommendations that emerged from this effort emphasized activities to foster joint learning of employers and employees and joint problem solving among all stakeholders.
- The Always Safe web platform is an example of one initiative that aims to implement the tripartite recommendations. Always Safe is a collaboration between several industry stakeholders that offers learning packages to be used as a team exercise, facilitating engagement of managers and personnel on important safety issues, and promoting feedback and resolution on outstanding safety issues.
- In addition, Havtil also publishes its investigation and audit reports online that are searchable by company name and safety topic, among other keywords. These and similar activities provide good examples of how to share experience across organizations.

7.3.4 The role of international organizations

There are a number of international organizations engaged in promoting sharing of lessons learned from chemical incidents across continents. Among the most prominent are the Organization for Economic Cooperation and Development (OECD) and the United Nations Economic Commission for Europe (UNECE). The third edition of the OECD Guiding Principles for Chemical Accident Prevention, Preparedness and Response (OECD, 2023) represents a collection of four decades of lessons learning from chemical incidents in OECD member countries. The UNECE has published guidance on thematic topics, such as risk management of oil terminals, based on the collective learnings from various countries based on lessons learned from incidents and good practice. (UNECE, 2015) There is considerable scope in the EU and elsewhere for publicizing chemical accident information and making information from chemical accidents more conducive to filtered searches on specific topics.

7.4 Methods of dissemination

Depending on the type of incident and the target audiences, there are a number of diverse options for delivering information on an important incidents. Some typical options are presented in **Table 10**. This table can be matched with the **Table 3** in **Chapter 3** to determine how different audiences might be reached through these different mechanisms.

However, the act of dissemination is not in itself sufficient for communication. The manner and format in which the information is provided are equally important. The **manner of presentation** refers to techniques that help to reaching a target audience and delivering a convincing narrative. These techniques include the sequencing of information, the organization into sections and subsections, the level of detail added to specific sections, the emphasis on particular messages, the feedback loops (e.g., linking earlier statements to later statements), supporting images, and other enhancements. Keywords and contextual information are particularly important for helping audiences to recognize the relevance of the findings of an investigation or study. The key messages should stand out clearly and be well-justified with sufficient detail.

The **format of presentation** is determined by the dissemination mechanism itself. For example, online publication can be a preferred solution for providing findings from investigation of a complex accident to the many audiences that may have an interest in it. Or, if the analysts intend to reach a scientific audience, then they might publish a scientific article.

In addition, **reporting an incident in an online database**, operated by an industry or national government, for instance, also can promote the use of information again and again in studies performed by different organizations lessons learned and trend analysis. In registering an incident in a database, the reporter should be mindful that users of these databases often do not have access to the person who reported the information. Therefore, there is no one that can answer questions about the information if it is unclear. Hence, accident reporting of this nature requires the use of a logical structure to the information and a very clear written explanation of what happened. It is also particularly important to qualify the precision and accuracy of details (e.g., if the number is an estimate, or if the identity of a chemical involved is uncertain, it should be noted).

7.5 Obstacles to dissemination

Dissemination can become routine and more effective if supported by the team, the site and the company. Similarly learning has a better chance of taking hold when application of lessons learned are a value of the company. When the company is invested in an effective dissemination and an effective learning, it continuously improves its ability to manage both successfully.

Some companies may be reluctant to provide accident information due to concerns about reputation and liability. These companies apply a defensive legal strategy that automatically views revelation of key details of certain incidents as potentially laying the groundwork for lawsuits.

Table 10. Dissemination methods for incident information and lessons learned (p. 1)

Dissemination methods	What is it?	Advantages	Disadvantages
The investigation report	The full version of the investigation report with complete information on findings, including the details of the sequence of events, causes, and lessons learned	• Useful for audiences who have similar situations. • Useful for audiences who want to do their own analyses, as in Chapters 5 and 6 of this handbook	• Not allowed very often in the private sector • Even when allowed, there may be legal considerations that require keeping some information confidential • Only specialized (e.g., internal staff, the oversight authority, experts, researchers) audiences will need, and take the time, to read all the details
The investigation report summary	A summary of the investigation report that focuses on the main findings that could be relevant to most audiences	• The best vehicle for broad dissemination, both internal and external • Useful for communication with top management • Some incidents, e.g., some near misses, are only short summaries anyway	• It takes some skill to write a useful summary, balancing brevity with the need for key details.
Presentations and meeting exchanges	A summary designed to be presented orally	• Ideal for safety meetings but also for presentation to other company teams and management • Useful also for presentations at conferences and workshops • Powerful tool to stimulate broader discussion that can lead to implementation of lessons in practice and further dissemination of the lessons	• One-time exposure to the information • Potentially limited audience • Single incidents presented only orally may be easily forgotten

Table 10. Dissemination methods for incident information and lessons learned (p. 2)

Dissemination methods	What is it?	Advantages	Disadvantages
Transforming Investigation findings into an organization's database	Inputting the information in a database of an organization, such as the company, an authority, or the industry association. In this case, some information may be transformed into objective fields for filtering.	• Usefulness depends on the design of the database, especially if it is easily searchable and downloadable • Most helpful for finding accidents with information relevant for specific situations, for finding patterns across accidents, etc.	• Free text narrative should always be the core of each incident report, but standardized fields are useful for filtering, e.g., type of operation, type of equipment, etc. A site or company can use more standardized fields because it has a finite universe of options. The options are more limited in databases run by a public entity. It would be helpful to have a universal keyword nomenclature, but there is not.
Transforming Investigation findings into a bespoke database	Creating a custom database for a group of incidents as described in chapter 6 of this handbook	• Can greatly facilitate pattern finding across incidents in a focused study • Bespoke databases can turn a lot of data into standardized fields, as described in Chapter 6, for quantitative analysis and pattern finding in relation to common factors, single and double loop causality, and lessons learned	• Time-consuming • Requires a dedication to learning the skills outlined in Chapters 5 and 6
Grouping incidents to tell a story	A presentation technique that can help audiences to assimilate learnings	• Lessons are usually learned when they are presented in a structured format, one of which is a story. One can use groups of incidents to reinforce a particular narrative about lessons learned associated with specific types of incidents	• Requires a group analysis and skill in putting together a memorable presentation
Grouping incidents for pattern recognition in a structured format, e.g., a template or model	A research and presentation technique that can help assimilate learnings but also develop schemas that can be applied broadly to analyze hazards and assess risks	• A more scientific approach that sets the causality and lessons learned in terms of a model that can be applied systematically. • Useful for hazard identification and risk assessment to apply lessons learned systematically to incidents with similar characteristics, e.g., same process, substance, etc., or to assess universal causal factors, like Natech and human factors	• Requires a sufficient a number of incidents to establish patterns of causality • Requires some training in research-related skills to develop, justify, and validate models and related tools

However, the company leadership has a responsibility to create opportunities to share while still protecting legal and reputational interests. Every incident worth sharing can be evaluated regarding the options for making essential information available in a legally safe way. The prevalence of a predominantly legal perspective when an incident occurs can result in the default blocking of sharing of information among necessary actors in the company, including the workers that are affected, but also within the industry. It is not a trivial matter by any means, but the important aspect is to find a balance between conflicting values of self-protection vs. communication of important information. If the company values sharing information, it will have strategies for sharing sensitive incident information in a protected manner with those that can benefit from it. Some examples include sharing through an anonymous open source database run by the industry or government, making oral presentations to target audiences at conferences and other events, working with collaborators in other organizations to do a study of similar incidents along thematic lines, etc.

7.6 Finally the learning – applying the lessons learned

The ultimate goal of incident investigation and analysis is to prevent future incidents. Every step in the process, starting with the investigation through to dissemination, has an impact on the likelihood that the lessons learned will be applied and be permanent. In this sense, from the start of the process, a vision should evolve of potential safety improvements implied by the lessons learned.

The lessons learning process at this final stage often requires different skills and priorities than investigation and analysis, particularly for lessons that go beyond the unit where the incident took place.

- Leadership and communication skills focused on persuasion and negotiation can be critical
- Broad-based thinking and an openness to ideas often may be required to produce workable solutions, particularly if there are costs and many actors involved
- An inclusive process, involving different parts of organizations, from workers to managers, and many departments, e.g., from operations to accounting to strategic planning
- Different perspectives are particularly necessary to imagine how proposed solutions will actually play out in various parts of organizations that play a role in the solution
- An active interest in seeking insights that expose potential obstacles to implementing solutions, e.g., whether they are indeed practical, if they have significant disadvantages that undermine their benefits, and potential ways to overcome these challenges

7.7 Leadership and organizational learning

An organization's disposition to learning is essential for maximizing learning from incidents. **Text Box 19** provides typical characteristics of a learning organization. Achieving a learning culture requires corporate leadership that establishes a lessons learning strategy to foster continuous improvement throughout the organization.

7.7.1 Elements of a learning organization

In essence, effective application of lessons learned requires a dedicated strategy that facilitates a dynamic and adaptive approach so that every function of the site recognizes its role in maintaining site safety and is a potential beneficiary of the learning process. Such an approach some dedicated resources to lessons learning (e.g., for investigations and analysis) and an engagement of all staff as both resources and recipients for learning.

While the core of all operational and administrative functions adhere to standard practices and procedures, there must also be ongoing support structures for identifying vulnerabilities and gaps that these norms may overlook. These support mechanisms could include:

Text Box 19. Characteristics of a learning organization (Adapted from Weibull et al., 2020)

- **Presence of an open "no-blame culture".** The leadership can have a tremendous influence on whether a site has a learning culture, by actively promoting neutral exchanges on failures and potential failure scenarios. Such a trust environment is often recognisable from certain attributes, such as ample communication about past failures, co-operation on all levels to prevent failure, and extensive exchange of competence and experiences across the organisation about risks and risk management associated with known hazards.
- **Promoting reporting and exchange by the company**. Allocation of adequate resources and time for maintaining high safety awareness is also important. For example, companies can promote reporting through simplification of the process, and routinely giving training on the importance of prompt investigation of incidents and implementation of improvements. Regular discussion and distribution of information, such as safety alerts, lessons learned and key performance indicators, is another way of promoting reporting and exchange of information.
- **Making good quality narratives available.** Lessons learned is often about telling stories in a way that both the lessons are memorable and can be easily generalised for application in other contexts. Making good quality narratives available from investigation reports and in databases online may help spread a selection of good stories and important lessons learned.
- **Making databases more readable and searchable.** The use of an efficient search engine and keywords can help promote use of the database. An additional technique is to present the accidents in a list or as a result of a search as short summaries, so that the user can filter the selected accidents quickly, and only click on links to the full report of those that fit the user's criteria. Where there are language differences in the work place, a translation function may be necessary, for example, in multinational corporations or on sites where many line workers are not native speakers of the national language.
- **Reinforcing the relevance of lessons learned through action.** There is nothing more powerful than demonstrating the importance of lessons learned by applying them when they are relevant. Companies have several opportunities to incorporate lessons learned into routine activities, through process hazard and job analyses, in audit and control functions, review of processes and procedures, change management, discussion in safety meetings, and various other functions.

- Process for identifying and investigating incidents and near misses
- Accessible register of incidents and near misses for the site, organization, and industry
- Availability of updated accident lessons learned of relevance to:
  - Design decisions
  - Hazop and other hazard assessment exercises,
  - Assessment of risks associated with operational and administrative changes, and
  - routine updates of safety management systems, e.g., management of change, maintenance procedures
- Dedicated resources for researching and updating lessons learned knowledge
- Regular team meetings to discuss deviations that may have occurred and a process for communicating to other teams with potentially similar vulnerabilities
- Regular reporting of updates and improvements from lessons learned

7.7.2 Becoming a learning organization

To achieve effective organizational learning from incidents is far from impossible. There are many examples of organizations showing leadership in learning from chemical accidents in the current time frame and past decades. A notable example is the lessons learning implemented by the French government and the European Commission in response to the explosion of a fertilizer factor in Toulouse, France in 2001 (see **Text Box 20**).

There are always many (too many) chemical accidents that offer opportunities for learning at all levels Since the Toulouse accident, there have continued to be a plethora of serious chemical accidents each year around the world, including many all-out disasters, that offer lessons for risk governance like Toulouse. Government institutions can and do often respond constructively in the aftermath of serious chemical disasters. In addition, many non-government organizations, like the Organization for Economic Cooperation and Development (OECD), the Energy Institute, the U.S. Chemical Safety Board (CSB), and

Text Box 20. Learning lessons from the catastrophic explosion of a chemical plant in Toulouse, France in 2001

On 21 September 2001, an explosion occurred at the AZF fertilizer factory in Toulouse, France resulting in 30 fatalities, an estimated 10 000 physical injuries, and in addition, around 14 000 people reported suffering from post-traumatic acute stress. Property damages were also significant, including damage to 27 000 houses in the vicinity of Toulouse and 1.5 to 2 billion euros further material damages.

In follow-up to the incident, the industry and the French government reflected deeply on the implications that the event had at all levels, from a purely technical perspective up through to the global system that allowed the event to happen. These reflections stimulated a review of a number of policies in the French governance of chemical hazard sites and also at EU level in the Seveso Directive, including whether the criteria qualifying ammonium nitrate sites for high hazard coverage was fit for purpose, whether there were changes needed in the way safety assessments were performed, and whether land-use planning precautions around hazardous sites were sufficiently protective of surrounding communities. On the Seveso Directive was ultimately amended in 2003 incorporating new definitions of ammonium nitrate in association with threshold quantities that, when exceeded, triggered coverage under the Directive throughout the EU. In addition, a number of provisions were introduced to promote harmonization of risk assessment approaches for land-use planning. Over the next several years, the European Commission, Member States and industry collaborated to produce additional technical guidance for land-use planning to support this vision.

The Toulouse accident also resulted in a new regulatory framework for hazardous site risk governance in France including a new regulatory framework. The new framework was organized around three main topics: risk assessment, lessons learned from accidents and near-misses, and access to information and transparency. Moreover, to address land-use planning around hazardous sites, two new instruments were introduced, one to strengthen limitations on future construction around these sites, and the other to reduce incompatibilities with existing situations of concern. The instruments incorporated a combination of financial compensation and planning mechanisms to facilitate implementation of these concepts.

It was hoped that these measures would pave the way for a new era of sustainable development for both industry and urban areas in France and the EU in general. A commitment to learning the lessons of Toulouse was considered the only way to generate the renewed confidence of all stakeholders in the ability of society to enjoy the comfort and prosperity afforded by a vibrant industrial economy while minimizing the downsides of its risks. The implementation of these measures continues through current times.

numerous other industry and government institutions, actively work towards learning and disseminating lessons learned. The limitation they often face is the varying commitment of their constituencies, resulting in less resources and engagement, because low probability accidents often cause a loss of interest when a long time lapses between incidents.

Overcoming such inertia requires a cultural shift and a commitment to removing obstacles to learning. As noted in **Tables 7** and **8** in **Chapter 4**, there are many such obstacles to learning observed in organizations suffering major incidents. These tables list some typical obstacles that occur in different parts of the process of learning from incidents. An organization can start to improve its learning capability by working to address these obstacles, using some examples of the “enablers” in these tables.

Numerous researchers in the field of organizational learning have studied factors that influence an organization’s ability to change. The relatively recent promotion of safety culture emphasizes a climate of psychological safety and mutual trust, but many experts also agree that creating such a climate is highly dependent on leadership. Cowley’s research on learning from chemical accidents also highlights that effective learning depends on a discreet balance of discipline (fixed administrative practices) and adaptive practices (Cowley, 2020). That is to say, the system always has a way to incorporate changes to the rules on the basis of sense-making, open communication and collaborative problem-solving. It is also recognized that it is no small feat to achieve an effective, beneficial entanglement of these two different kinds of practices is difficult, but it is arguably the only viable way forward to enable continuous learning to control chemical accident risk.

The commitment of the top management, the CEO and senior executives, is critical to adopting the kinds of leadership practices that encourage learning. Administrative and adaptive processes can be effectively implemented through a range of management approaches, some of which clarify the rules that cannot be broken (e.g., directive approaches), and others that foster opportunities for innovation and learning (sometimes called “managerial” or “democratic” approaches). Enabling’ practices are a third kind of management lever that can facilitate networks and constructive exchange and thereby build bridges between the fixed way of doing things (the administrative practices) and the new ideas to make them better (the adaptive practices).

Chapter 7 summary

- **Importance of Dissemination Strategy –** A clear dissemination strategy ensures that lessons learned are effectively shared and applied to improve safety.
- **Methods of Dissemination –** Lessons can be shared through reports, meetings, online databases, and structured communication campaigns.
- **Identifying Target Audiences –** Different stakeholders, from site workers to regulators, must be engaged based on the relevance of the lessons learned.
- **Challenges in Dissemination –** Legal concerns, reputational risks, and organizational resistance can hinder the sharing of critical safety information.
- **Organizational Learning and Leadership –** Strong leadership and a learning culture are essential for applying lessons learned and preventing future incidents.

8 Conclusions

All technological incidents are the result of failure in one or more aspects of a human enterprise that has been made possible through the innovative use of science and engineering. There are hundreds, if not thousands, of everyday products and services that are amazing feats of human ingenuity. Products such as airplanes, automobiles, trains and ships, as well as modern drugs, household products, abundant agriculture, fuel for any activity, computers are all made possible through feats of science and engineering. Likewise, all essential services, e.g., roads, electricity, radio networks, satellite, etc.,, that connect humans to each other and our activities to sources of energy, sound and light, are also only possible through tremendous advances in science and engineering. Chemical engineering is essential to every single one of these outputs, so ensuring minimal risk for processes and interactions involving chemicals in all environments, the factory, the marketplace, and even in public services, like hospitals and medical laboratories, has to be a top priority for a sustainable society.

These achievements are indeed spectacular, and underpin the functioning of our modern industrial societies. However, their failures can be equally spectacular. Science and engineering advances are made up of advancements in human understanding of chemical and physical properties of the natural world. Using this knowledge, new products and services are conceived by mixing and matching the various properties in evermore imaginative and complex ways, sometimes without a full understanding of why something works exactly, but that somehow it does.

In particular, the complexity means that knowing how something works requires the knowledge to understand how processes work and how components interact with other components (including humans) and what output they can produce. This knowledge is essential to managing the risks if something goes wrong. Many technological accidents result from a knowledge failure, that is, the knowledge was either lost or ignored. Many operations have a confidence in their knowledge of the basic operations and how they work. However, in high risk activities, effective risk management requires more than basic knowledge. Foreseeing potential failure is not just a matter of applying common sense to common knowledge about an operation. Rather, it requires insights that go well beyond the surface and are sometimes not even intuitive. In particular, interactions between components of complex systems are not always obvious. There can be many permutations of error combinations, i.e., when more than one interacting component is in failure mode at the same, that are recipes for disaster. These failures may consist of engineering faults or oversights, but also can be a consequence of human error, or vulnerabilities in the organizational and social infrastructures that are supposed to ensure effective control over the risk.

For this reason, effective risk management and oversight requires the judicious application of lessons learned to prevent future chemical incidents and control their impacts. It is necessary for avoiding repetition of mistakes of the past, and for ensuring the practices and frameworks that guide management of these risks remain continually updated with new information and emerging risks. No one can know it all and even all are computational ability can predict the risks of the future. It is hoped that this handbook can help authorities and industries to build robust competence in learning and improving from mistakes and tragedy, in the field of chemical disaster risk, but also in all technological disaster risk fields.

Summary of Key Points

- **Learning from Incidents Prevents Future Accidents**
  Systematically analyzing chemical incidents helps identify risks before they escalate, ultimately enhancing safety and preventing major industrial accidents.
- **Structured Learning Is Essential, Not Optional**
  Without clear frameworks for extracting lessons, valuable insights from accidents can be lost—structured methods are critical to meaningful learning.
- **Near Misses Matter as Much as Accidents**
  Minor incidents and near misses are early warning signs; investigating them is just as important as studying major events to uncover vulnerabilities.
- **Blame Blocks Learning**
  Separating lessons learned from blame encourages open reporting and fosters a culture where learning takes precedence over punishment.
- **Lessons Extend Beyond the Chemical Sector**
  The principles of learning from incidents apply across sectors—like nuclear, aviation, and transport—where technological risks exist.
- **Competence Drives Effective Learning**
  Lessons learned require skilled investigators with process safety knowledge, analytical thinking, and objectivity to extract meaningful insights.
- **Group Analysis Reveals Systemic Weaknesses**
  Studying patterns across multiple incidents exposes recurring failures in systems, leadership, or safety culture that single cases may not reveal.
- **Clear Communication Turns Insight into Action**
  Lessons must be shared clearly and strategically with the right stakeholders to ensure they lead to actual safety improvements.
- **A Culture of Continuous Learning Saves Lives**
  Organizations committed to learning from every incident—big or small—build safer systems and more resilient operations over time.
- **Strong Leadership Enables Real Change**
  Lasting safety improvements depend on leaders who champion learning, support open reporting, and act on the insights gained from incidents.

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List of abbreviations

Note: All items marked with a * are analytical approaches that can be found with reference links in **Annex 2**.

AABE	Accident Analysis Benchmarking Exercise
AI	Artificial Intelligence
AICHE	American Institute of Chemical Engineers
ARIA	Industrial accident database managed by the French Ministry of Environment
BARPI	The administrative branch of the French Ministry of Environment that manages ARIA
CAPRI	Name of the chemical accident data portal of the European Commission Joint Research Centre
CAST	Causal Analysis based on System Theory, an accident analysis technique*
CCPS	Center for Chemical Process Safety
CEFIC	European chemical industry forum
CEO	Chief Executive Officer
CIEHF	Chartered Institute of Economics and Human Factors
COMAH	UK legislation for Control of Major Accident Hazards
CSB	Chemical Safety Board (United States)
eMARS	The EU chemical accident database
EPSC	European Process Safety Centre
ESREDA	European Safety, Reliability & Data Association
ETBA	Energy Trace and Border Analysis, an accident analysis technique
EUROCONTROL	International air safety organization
FECC	European association for the chemical distribution industry
FRAM	Functional Resonance Analysis Method, an accident analysis technique*
FTA	Event Tree Analysis, an accident analysis technique*
HIAD	JRC Hydrogen Accidents and Incidents Database
HSE	Health and Safety Executive (United Kingdom)

INERIS	French National Institute for Industrial Environment and Risks
IOGP	International Association of Oil & Gas Producers
LFI	Learning from incidents
LOPA	Layers of Protection Analysis (risk assessment approach)
LPB	Loss Prevention Bulletin
LPG	Liquefied Petroleum Gas
MORT	Management Oversight and Risk Tree analysis method*
MTO	Man-Technique-Organization, an accident analysis technique*
Natech	Natural hazard event causing a technological accident
OECD	Organization for Economic Co-operation and Development
PYTHON	A high-level, general purpose programming language
PHA	Process hazard analysis
QCA	Quantitative Comparative Analysis, an accident analysis technique*
SAS	A statistical software developed by the SAS Institute
SMS	Safety management system
SPSS	An IBM statistical software platform
STAMP	Systems theoretic accident model and process, an accident analysis model*
STEP	Sequentially Timed Events Plotting, an accident analysis method*
SWOT	Strengths, Weaknesses, Opportunities, Threats (analytical tool)
TRIPOD BETA	An incident investigation and analysis methodology
TSE	To some extent
UK	United Kingdom
UNECE	United Nations Economic Commission for Europe
ZEMA	The German Central Reporting and Evaluation Office for Major Accidents and Incidents in Process Engineering Facilities

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Annex 1. Evaluation of accident analysis methods using objective criteria and SWOT analysis from the JRC Accident Analysis Benchmarking Exercise (Wood and Allford, 2020)

This annex includes analytical tools created by the Exercise. The project is briefly summarized below. For more information, the full report is available online here.

The JRC Accident Analysis Benchmarking Exercise (AABE) was conceived as a study that could provide practical insights to the process safety community in choosing an analytical approach for investigating accidents, and in analyzing and drawing conclusions from an investigation report. The vision of the project was to engage a cross-section of experts working for or with competent authorities and industry to take part in an exercise to look at how different methods could be useful in different investigation contexts. Given that accident investigation and analysis methods has been studied by a wide variety of experts globally, and that it is a shared concern of many industrial countries around the world as well as rapidly emerging economies, the JRC chose to broaden the collaboration to partners outside the European Union.

The objective of the AABE was to compare findings produced by application of different accident investigation and analysis methods to a defined set of accidents and evaluate the use of the methods against agreed criteria. The criteria was designed to evaluate the effectiveness of the method in helping to generate different types of information, as well as its user-friendliness, and other relevant strengths and weaknesses associated with its application. This part of the exercise resulted in development of an analytical framework for process safety experts in making decisions about which analytical methods to use for analyzing and investigating accidents, depending on the objectives, the type of accident, resource constraints, etc.,

The participants determined that the project should aim to produce a semi-quantitative evaluation of each method used to help potential future investigators and analysts to choose appropriate methods and to also evaluate the results of investigations where a particular method, or methods, has been used.

Table 11 List of analytical methods used

#	Method	New URL
1.	Storybuilder	http://tiny.cc/Story
2.	ARIA 3 (BARPI method)	This is not published on the web.
3.	Organizational Analysis of Safety (OAoS)	http://tiny.cc/Reason
4.	ECFA (Events and Causal Factors Analysis) ETBA (Energy Trace and Barrier Analysis) MORT (Management and Oversight Tree)	http://tiny.cc/MORT1
5.	ESReDA Cube	http://tiny.cc/Cube
6.	Chronology Description	No web reference. This is a simple timeline.
7.	Event Tree (ETA)	http://tiny.cc/ETA
8.	Fault Tree (FTA)	http://tiny.cc/FTA1
9.	STEP (Sequential Timed Events Plotting)	http://tiny.cc/STEP10 (p. 45)
10.	DISC (Design for Integrated Safety Culture)	https://tinyurl.com/y23r2djn
11.	MTO (Man, Technology and Organisation)	http://tiny.cc/MTO10 (p. 50)
12.	ECFC (Event and Causal Factors Charting)	http://tiny.cc/ECFC10 (p. 27)
13.	Barrier Analysis	http://tiny.cc/barrier1 (p. 30)
14.	Root cause on a tiered sorting basis	Derived from multicriteria decision analysis
15.	Tripod Beta	http://tiny.cc/tripodbeta (p. 56)
16.	CAST (Causal Analysis using System Theory)	http://tiny.cc/CAST1
17.	Accimap	http://tiny.cc/accimap
18.	Bow-Tie	http://tiny.cc/bowtie1

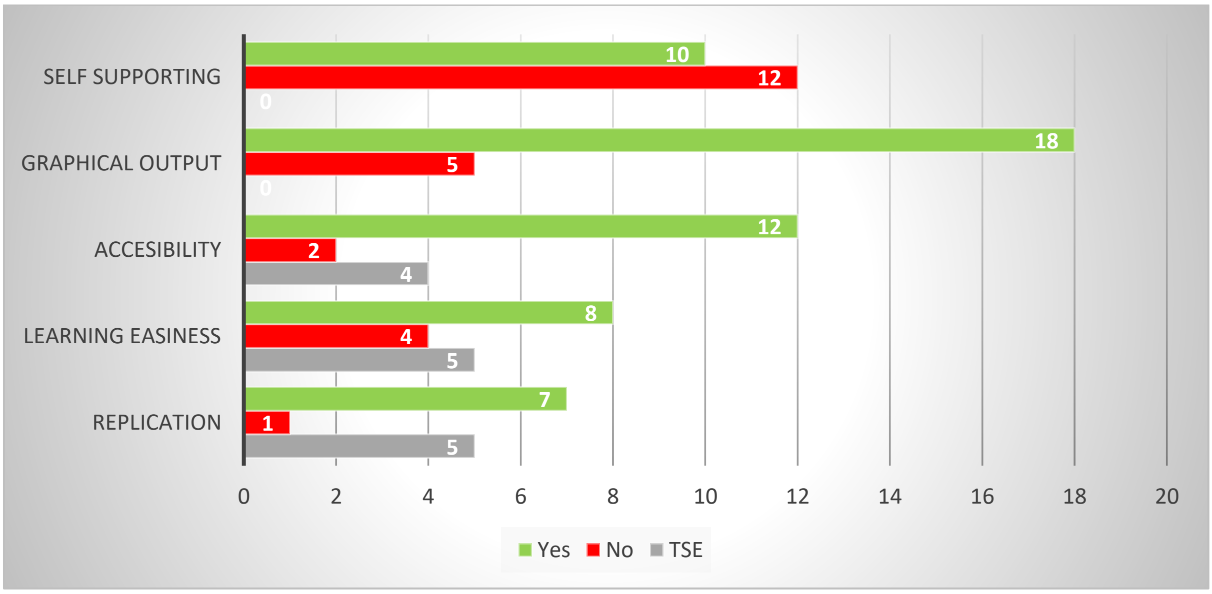
Participants were divided into teams of 2-5 experts whose members could work together or separately on analyzing the same incident. Team members were invited to select their own methods of analysis for each analytical phase (Chronology of events, Direct Causality, Indirect Causality). Each of the eight teams applied at least two methods, but some teams tested 3, and some 4, techniques (see **Table 11**).

The participants also developed a number of evaluation methods. For each response categories, the participants were required to choose from a range of predetermined responses as shown in **Table 12.** The results of the Methods Evaluation Table are compiled in **Figure 29** and **Table 13.** The table aggregates the results of twenty-five individual method evaluations. STEP, Tripod Beta, AcciMap, Fault Tree and Event Tree analyses received evaluations from more than one team. As complementary information, **Table 14** contains a consolidated SWOT analysis of each method from the team or teams that used them.

Table 12. Methods Evaluation response options

Criteria	**Description**	**Range of possible responses**
Self-supporting	Some methods intend to cover the whole event analysis process whereas others could be (are) used as input for other analysis methods	Yes/No
Graphical output	Some methods propose a diagramme of the accident sequence (graphical representation of the scenario). It is intended to help understanding of the event and to provide a tool for better communication between investigators	Yes/No
Accessibility	For some methods documentation is freely accessible while for others documentation incurs a charge.	Yes/To some extent (TSE)/No
Learning easiness	Can method be used with no "extensive formal accident analysis training" and/or with no "deep" knowledge about some scientific domains (e.g., sociology, engineering science…)	Yes/To some extent (TSE)/No
Scope of analysis	A method will address different levels of the sociotechnical system.	1. Work and technological system
		2. Staff level
		3. Management level
		4. Company level
		5. Regulators and associations
		6. Government level
Duration	According to method used duration of an analysis could differ	Days/Weeks/Years
Replication	Even if an analysis method allows some flexibility, it needs to be sufficiently robust so that its results/outputs do not depend on the analyst(s) [different analyst(s) would reach (more or less) the same result applying the same method on a specific event]	Yes/To some extent (TSE) /No

Figure 29. Analysis of objective scoring



Key to Table 11 (next pages)

Phase	1= chronology	2=causal causes	3= root cause	TSE = to some extent

Scope	1=the work and technological system	2=the staff level	3=the management level
	4=the company level	5=the regulators and associations	6=the Government level

According to the team evaluations, as shown in **Figure 29**, less than half of the methods were self-supporting, including Organizational Analysis of Safety, ETBA, CAST and AcciMap. Teams disagreed on whether STEP, FTA and ETA were self-supporting. The graphical output was notably high for most methods, with the exception of ETBA, the Chronology Description method, and Organisational Analysis of Safety. Two methods (Barrier analysis and Tiered Root-Cause) were not rated in this aspect. Where accessibility was rated as was largely considered positive but mixed in regard to ease of learning. Most methods were applicable to up to the 4th level of the socio-technological system, with a few methods also achieving analyses for regulators and policymakers. Nearly half of the methods needed only a few days to apply to the selected cases, while results were achieved with six methods in a matter of weeks, and three methods were indicated as taking a few months to complete. A good portion of the methods seemed fairly easy to learn even if application was more complicated in some cases, and therefore, took more time to achieve results.

Table 13. Methods as evaluated by different teams

Method	Team	Phase	Self-supporting?	Graphical Output?	Accessibility?	Learning easiness?	Scope of investigation	Duration	Replication?
AcciMap	7	3	Yes	Yes	Yes	Yes	1►6	Weeks	Yes
	8	3	Yes	Yes	Yes	Yes	1►6	Weeks	Yes
ARIA 3 (BARPI method)	3	1,2,3	No	Yes	TSE	Yes	1►4	Days	Yes
Barrier Analysis	6	1,2,3					1►6		
Bow Tie	8	2	No	Yes	No	Yes	1►4	Days	Yes
CAST	7	3	Yes	Yes	TSE	TSE	2►4	Days	
Chronology Description	6	1	No	No	Yes		1►6	Weeks	TSE
ECFA	4	1	No	Yes	Yes	Yes	1	Days	
ECFC	6	2,3	No	Yes			1►6		
ESReDA Cube	4			Yes	Yes	No	1►6	Weeks, Months	TSE□No
ETBA	4	2	Yes	No	Yes	Yes	1	Days	
Event Tree	6	3	Yes	Yes	TSE	No	1►2	Months	Yes
	6	2,3	No	Yes			1►6		
Fault Tree	6	3	Yes	Yes	TSE	No	1►2	Months	Yes
	6	2,3	No	Yes			1►6		
MORT	4	3	No	Yes	Yes	TSE	1►4	Weeks	
MTO	6	2,3	No	Yes			1►6		
Organizational Analysis of Safety	4	1	Yes	No	Yes	TSE	NA	Weeks	TSE
		2	Yes	No	Yes	TSE	1►2/3	Weeks	TSE
		3	Yes	No	Yes	TSE	3►6	Weeks	TSE
Root cause on tiered sorting basis	6	2,3					1►6		
STEP	6	1,3	No	Yes			1►6		
	7	1	Yes	Yes	Yes	Yes	1►4	Days	Yes
Storybuilder	1	1,2,3	No	Yes	Yes	Yes	1►4	Days	TSE
Tripod Beta	7	2,3	No	Yes	No	No	1►4	Days	

Table 14. SWOT analysis of methodologies used (p. 1 of 4)

Method	Strengths (Positive aspects of any kind, e.g., ease of use, results, logic used, etc.)	Weaknesses (Negative aspects of any kind, e.g., ease of use, results, logic used, etc.)	Opportunities (What kind of positive outcomes may result from the strengths?)	Threats (What kind of negative outcomes may result from the weaknesses?)
AcciMap	Easy to understand the principles Does not require commercial software. The output can be adapted to suit the case in question.	Requires intensive work on tracing information and mapping it to the correct level of the system. Does not have a graphical tool, so the analysis is conducted by hand. Not formally standardised.	Opportunity to discover the relationships between actions within the system. Makes very clear that technological failures have causes within the organizational and management system (and possibly also external influences and drivers.	The work involved and lack of formalised "boxed version" means that the principles must be learnt first and then the information sorted before developing the final AcciMap. This is a lot of work, which may lead to the approach being rejected as it is not seen as being standardised.
ARIA3 (BARPI)	Concrete and rational output Emphasize the distinction between disturbances and organisational causes	Does not allow to underline positive actions. Focused on the causal understanding (no element on consequences)	Communication tool between inspection body and operators Supposed blocks allow to raise questions and missing information => force deeper analysis	Focused on plant operator responsibility only
Barrier analysis	Sufficient from the point of digging into root causes and handling the facts.	Listing approaches may cause confusion if the accident Contains many simultaneous events, using of charting Methodologies can be much more convenient in such case. It does not force the analyst to consider a further domain of the accident.		

Table 14. SWOT analysis of methodologies used (p. 2 of 4)

Method	Strengths (Positive aspects of any kind, e.g., ease of use, results, logic used, etc.)	Weaknesses (Negative aspects of any kind, e.g., ease of use, results, logic used, etc.)	Opportunities (What kind of positive outcomes may result from the strengths?)	Threats (What kind of negative outcomes may result from the weaknesses?)
Cause and Events Analysis	Good technique for simple and straight-forward events	Listing approaches may cause confusion if the accident contains many simultaneous events, using of charting methodologies can be much more convenient in such cases.		
ESReDA Cube	Emphasises learning. What may be learned from the individual facts of the event and who could benefit from the learning? A communication tool. Facilitates discussions amongst stakeholders on identified topics. It assists the user to use a systematic approach to look at an accident and discuss about it. Integrated and systematic way of looking at an event (near miss, incident, accident), taking stock of the organisational context, level of stakeholder responsibility and depth of learning required.	Results depend on the scope of the analyst(s). Analyst(s) need to be clear, both on the viewpoint and goal, of the analysis. If a team of analysts is formed, convergence is needed in understanding chronology of events and related causes. Should not be used as a stand-alone method, but as a supporting method, as it is more like a model, rather than a method. Does not include timeline of events or causality.	Model may be used before the investigation as a planning tool. Model may be used during the investigation to identify what has been missed in the investigation so far. Model may be used at the end of the investigation to pinpoint recommendations to specific stakeholders. Model may be used after the event to analyse the event or to analyze the investigation process itself.	When planning resources, use of the Cube will also require another method for chronology and causality to be used beforehand. This must be catered into the decision on whether to use the Cube.

Table 14. SWOT analysis of methodologies used (p. 3 of 4)

Method	Strengths (Positive aspects of any kind, e.g., ease of use, results, logic used, etc.)	Weaknesses (Negative aspects of any kind, e.g., ease of use, results, logic used, etc.)	Opportunities (What kind of positive outcomes may result from the strengths?)	Threats (What kind of negative outcomes may result from the weaknesses?)
Fault Tree Analysis • Event Tree Analysis	Root cause analysis Flow and Sequence are clear	Only one accident (not suitable for multiple accidents)	Should be used in combination with other methods	
MTO	• Root cause analysis • Barrier analysis • Change analysis	Only one accident Actors are not clear	Should be used in combination with other methods	
Organisational Analysis of Safety	Easy to use. Goes beyond the “human” error paradigm. Provides with a global vision of the situation	Time (and therefore money) consuming method. Definition of efficient improvement can call for questioning. It’s easier to find out organisation pathological factors rather than resilient factors Organisational paradigm is not yet fully stabilized. Lack of ability to "reflexivity" for the managers	Possibility to make fundamental improvements in safety	Results of analysis not acknowledged not to say denied or refused

Table 14. SWOT analysis of methodologies used (p. 4 of 4)

Method	Strengths (Positive aspects of any kind, e.g., ease of use, results, logic used, etc.)	Weaknesses (Negative aspects of any kind, e.g., ease of use, results, logic used, etc.)	Opportunities (What kind of positive outcomes may result from the strengths?)	Threats (What kind of negative outcomes may result from the weaknesses?)
STEP	Very easy to use with just pencil and paper. Simple and transparent output. Time sequence is described. Actors and subjects are clear. STEP is modified as new information surfaces and thus it is also useful in pointing out the grey areas where more information is necessary	Very simplistic. Only provides a timeline and list of actors No Barrier analysis. Relation among actors is not clear	Easy choice for any safety expert no training needed. Provides a timeline of events as a starting point for analysis	Another method is required to analyse what caused each event on the timeline
Tripod Beta	Detailed barrier analysis provides strong foundation for many types of indirect analysis. With software, the output is very user friendly. Without software, it is not possible.	Requires purchase of software. May require some training to use, but if one has already worked through a bow-tie analysis, self-training may be possible. Becomes difficult to work with in complex cases because the graphic presentation becomes too large for a computer screen Does not really work well for indirect causes, partly because of the challenges with graphic representation but also because the method does not give a satisfying way to describe complex causality of indirect causes	Excellent for understanding direct causes, especially in complex situations. It provides a solid foundation for further analyses of different types, e.g., human and organisational factors, the role of regulation, etc.	The cost of software and the need for training may make this method inaccessible to many inspectors.

Annex 2. Methodologies and other reference materials from the JRC Accident Analysis Benchmarking Exercise (AABE)

*This list of references is a copy of a list that is available on the JRC Minerva website, here, compiled for the Accident Analysis Benchmarking Exercise described in **Annex 1.** The references and links were updated in April 2025. It is not an exhaustive list, by any means, of accident analysis guidance and modelling support that is available in open sources online. There are many, many other excellent references out there, including documents and websites published for analyzing and investigation accidents in the aviation, nuclear energy, and rail transport industries. However, this list can be used for anyone who needs a starting point for their research in this area.*

The references and links were updated in April 2025. At that time, all links were functioning properly.

General information

- A mini guide to root cause analysis (Vorley)
- A review of accident modelling approaches for complex critical cociotechnical systems (Qureshi)
- Accident investigation (RSSB)
- Accident investigation: From searching direct causes to finding in-depth causes – Problem of analysis or/and of analyst? (Dien et al.)
- Accident investigation techniques (Oshwiki)
- Barriers to learning from incidents and accidents (ESReDA)
- Bow Ties in Risk Management (CCPS)
- Can we examine safety culture in accident investigations, or should we? (Strauch)
- Comparison of some selected methods for accident investigation (Sklet)
- Engineering a Safer World (Leveson)
- Guidance for safety investigation of accidents (ESReDA)
- Guidance on investigating and analysing human and organisational factors aspects of incidents and accidents (The Energy Institute)
- Guidelines for investigation of logistics incidents and identifying root causes (CEFIC, ECTA, FECC)
- Investigation of barriers and safety functions related to accidents (Ringdahl)
- Investigation tools in context (Frei et al.)
- Results and lessons learned from the ESReDA's Accident Investigation Working Group: Introducing article to "Safety Science" special issue on "Industrial Events Investigation" (Dechy et al.)
- Risk analysis active learning through the investigation of real cases (Darbra et al.)
- Selection of Accident Investigation Methods (Pranger)
- Standardization of Barrier Definitions (International Organisation of Oil and Gas Producers)
- Storybuilder at https://www.rivm.nl/en/storybuilder
- Study on Developments in Accident Investigation Methods: A Survey of the "State-of-the-Art (Hollnagel and Speziali)
- Systemic view on safety culture (Oedewals)
- Towards an evaluation of accident investigation methods in terms of their alignment with accident causation models (Katsakioros et al.)
- Understanding Human Behaviour and Error (Embrey)
- Investigating accidents and incidents: A workbook for employers, unions, safety representatives and safety professionals (UK Health and Safety Executive)

Models

- AcciMap
  Risk management in a dynamic society: A modelling problem (Rasmussen)
  Accimap approach (Wikipedia)
  A case study to compare the advantages and limits of two accident analysis methods (Vacher et al.)
  Integration of organisational aspects into learning from experience : illustration with a case study (LeCoze and Lim)
- AEB (Accident Evolution and Barrier Function)
  Accident Evolution and Barrier Function (Svenson)
- Barrier analysis
  Barrier analysis (Wikipedia)
- Bow Tie
  The bow tie is a widely used method and there are many guidances available on the web. For a general overview (with references), the Wikipedia web reference page is recommended.
  The CCPS / Energy Institute book *Bow Ties in Risk Management* (Wiley, 2018) is particularly useful (**Link inserted**)
  Bow tie diagramme (Wikipedia)
- Causal tree analysis
  Use of Causal tree method for investigation of incidents and accidents involving radioactive materials (de Vasconcelos et al.)
- Change analysis
  See Root Cause Analysis below
- Disc Framework Model
  System modeling with the DISC framework: Evidence from safety-critical domains (Reiman et al.)
- DREAM (CREAM) - Driving Reliability and Error Analysis Method (Cognitive Reliability and Error Analysis Method)
  A methodological study of the Driving Reliability and Error Analysis Method (DREAM) (Norwegian Centre for Transport Research)
  CREAM Analysis of the Glenbrook Train Accident and Comparison with WBA (Parikh and Campbell)
- ESREDA Cube
  Evaluation of the ESReDA Cube Method for the Aviation Sector First analysis of the method's applicability by applying it on 3 aviation cases (Martens)
- Event and causal factor analysis
  Event and causal factor charting/analysis (ECFA)
  Event and causal factor analysis (NERC)
- Event and conditional factor analysis (ECFA+)
  Events and conditional factors analysis (NRI)
- Event tree analysis
  Event tree analysis (Wikipedia)
- Fault tree analysis
  Fault tree analysis (Wikipedia)
- FRAM (Functional Analysis Resonance Model)
  FRAM Module I
  Comparing a multi-linear (STEP) and systemic (FRAM) method for accident analysis (Herrera and Woltjer)

Analysis of Comair 5191 with the FRAM Model (Hollnagel et al.)
FRAM Guidance

- GEMS (Generic Error Modelling System)
  Generic error modeling analysis (Skybrary)
- MORT (Management Oversight and Risk Tree)
  MORT User's Manual
  Integration of organisational aspects into learning from experience : illustration with a case study (LeCoze and Lim)
- MTO (Man, Technology and Organisation)
  Investigation methodology: Man – technology – organization (Excerpt from the SINTEF report)
- Quantitative Comparative Analysis (QCA)
  https://www.betterevaluation.org/methods-approaches/approaches/qualitative-comparative-analysis
- Root cause analysis
  Root cause analysis (Wikipedia)
- Safety function analysis
  Analysing Safety Functions and Barriers - Experiences from Different Industrial Sectors (Ringdahl)
- SCAT (Systematic Cause Analysis Technique)
  This approach has been developed and is marketed by DNV
- SHELL (Software, Hardware, Environment and Liveware)
  SHELL Model (Aviation Knowledge)
  A human factors approach for the analysis and the encoding of aviation accidents and incidents: a validation study (Poliquen et al.)
  SHELL Model (Wikipedia)
- STAMP (Systems Theoretic Accident Modeling and Processes
  Applying STAMP in Accident Analysis
  STAMP/CAST Case Study - Sewol-Ho Ferry Accident in South Korea *Other case studies using STAMP/CAST can be found under Fukushima and Macondo Case Studies on the Case Study References page*
- STEP (Sequential Timed Events Plotting)
  Comparing a multi-linear (STEP) and systemic (FRAM) method for accident analysis (Herrera and Woltjer)
- Swiss cheese model
  Swiss cheese model (Wikipedia)
  Revisiting the Swiss Cheese Model of Accidents (EUROCONTROL
- TapRoot
  About TapRoot
  Example application of TapRoot (Skompski)
- TRIPOD (Based on Tripod Theory of Hazard, Target and Event)
  The home of the tripod beta accident investigation and analysis methodology
  Optimizing fact-finding in incident investigation and analysis using Tripod TRACK (Verhoeve et al.
  Tripod Beta User Guide

Annex 3. List of Online Open Source Chemical Incident Databases

This list of references is a copy of a list that is available on the JRC Minerva website, *here*, The list of references was updated in April 2025.

The references and links were updated in April 2025. At that time, all links were functioning properly.

ARIA (France) http://www.aria.developpement-durable.gouv.fr/
A database operated by the French Ministry of Ecology, Energy, Sustainable Development listing the accidental events which have, or could have damaged health or public safety, agriculture, nature or the environment. Chemical accidents are reported that meet established criteria.
Number of events: >10,000 **Time span:** > 1970 **Geographic coverage**: France and some major disasters in other countries
Purpose: Lessons learned **Format:** Free text only
Description of content: Concise, and sometimes, comprehensive technical summaries of serious accidents from all hazard sources. Reports are verified by technical experts. Impacts are reported in free text. All accidents associated with sources classified as high hazards and meeting a certain impact criteria are recorded in this database in accordance with French legislation.
Data on impacts: Each incident is classified according to the EU Gravity Scale based on human health, environment, community and economic impacts

CAPRI https://minerva.jrc.ec.europa.eu/en/shorturl/capri/caprihome
CAPRI collects and aggregates publicly available data and information about specific worldwide chemical disasters occurring mainly in the second half of the 20th century and beyond. These events reach across a spectrum of industries, from fixed chemical installation, through transport to pipelines and offshore.
Number of events: > 1,000 (different datasets) **Time span:** >1950 **Geographic coverage:** Global
Purpose: Comprehensive resource for research, history, policy, trend analysis and lessons learning
Format: Three online databases
Description of content. World Disasters database (searchable database of short summaries), Historic Accidents (searchable database with a summary of the incident and links to resources), and Chemical Incidents in the Global Media (Interactive database) since 2019.
Data on impacts Each database provides information on impacts

CSC (Korea) Chemistry Safety Clearinghouse https://icis.me.go.kr
Chemical accident and near miss data notified to authorities according to Korean law
Number of events: > 400 **Time span:** >2014 **Geographic coverage:** Korea
Purpose: Lessons learned and causal and impact statistics **Format:** Classified by technical cause
Description of content: Short summaries of chemical accidents on fixed sites and in transportation, reported in accordance with Korean legislation. For each accident there are statistics on human health impacts, and a mix of qualitative and quantitative information on other impacts.
Data on impacts: Quantitative data on human health impacts. Inconsistent data in all other categories. Economic impacts not collected

eMARS https://emars.jrc.ec.europa.eu
Accidents reported to the European Commission in compliance with Seveso Directive Annex VI criteria.
Number of events: >1,000 **Time span:** > 1984 **Geographic coverage:** EU/OECD countries
Purpose: Lessons learned and causal and impact statistics **Format**: Free text and classification of events by various filters (substance, industry type, impact, etc.)
Description of content: Completeness and precision of descriptions varies considerably. For each accident there is a free text description of the incident, statistics on human health impacts, and a mix of qualitative and quantitative information on other impacts. All EU accidents on high-hazard (Seveso) fixed sites meeting a certain impact criteria are recorded in this database in accordance with the EU Seveso Directive.
Data on impacts: Quantitative data on human health impacts. Inconsistent data in all other categories. Economic impacts not collected

eNatech Database https://enatech.jrc.ec.europa.eu/
Technological accidents triggered by a natural hazard or disaster which result in consequences involving hazardous substances (e.g. fire, explosion, toxic release) are commonly referred to as Natech accidents.
Number of events: >100 **Time span:** >1980 **Geographic coverage:** Global
Purpose: The aim of this database is to systematically collect information on Natech accidents that occured worldwide and allow the searching and analysis of Natech accident reports for lessons-learning purpose
Description of content: Online searchable database of chemical incidents triggered by natural hazards
Data on impacts: Detail is provided as is available from information sources

Energy Institute Toolbox https://toolbox.energyinst.org/home
Number of events: > 500 (process safety events) **Time span:** Not given but likely > 2000 **Geographic coverage:** Global
Purpose: To share lessons learned and causal analysis
Description of content: Database of accidents in upstream and downstream petroleum sectors. Provides analysis of sequence of events, response, causes and lessons learned.
Data on impacts: Information on human health impacts

Failure Knowledge Database www.sozogaku.com/fkd/en/
Number of events: > 200 (process safety events) **Time span:** > 1970 **Geographic coverage:** Japan
Purpose: To share lessons learned and causal analysis
Description of content: Database of accidents in several industries including chemical and petroleum sectors. Provides detailed structured analysis of sequence of events, response, causes and lessons learned. The contributor factors are also mapped in a scenarios diagramme.
Data on impacts: Information on human health impacts, physical damage and costs incurred.

High Pressure Gas Safety Institute https://www.khk.or.jp
Number of events: >20,000 **Time span:** >1965 **Geographic coverage:** Japan
Purpose: Preventing chemical incidents **Format:** Excel file
Description of content: The accident case database consists of chemical incidents including location, substance, industry, and descriptive information about the incident (in Japanese).
Data on impacts: Provided as part of the accident summary

Hydrogen Incident and Accident Database (HIAD)
https://minerva.jrc.ec.europa.eu/en/shorturl/capri/hiadpt
Number of events: ~800 **Time span:** >1970 **Geographic coverage:** Global
Purpose: Prevention of hydrogen-related incidents and analysis of trends
Description of content: It is a repository of past hydrogen incidents in an Excel file including descriptive information on each incident and lessons learned when available.
Data on impacts: Consequences are provided and, as information is available, elaborated in considerable detail..

IChemE Safety Centre www.icheme.org
Number of events: 100 - 200 **Time span:** >1960 **Geographic coverage:** Global
Purpose: Lessons learned from historical chemical disasters **Format:** Classified by industry type
Description of content: Summaries of well-known chemical accidents on fixed sites. For each incident, there is a description, incident analysis and lessons learned.
Data on impacts: Quantitative data on human health impacts and property damage

IOGP Safety Performance Indicators and Process Safety Events (International Association of Oil and Gas Producers-IOGP) www.iogp.org
Accident data reported by IOGP participating member companies
Number of events: >6,000 **Time span:** 2015 **Geographic coverage:** Participating members worldwide
Purpose: Lessons learned and causal and impact statistics **Format:** Classified by technical and underlying causes

Description of content: IOGP is one of the first industry organisations to report disaggregated data on safety events occurring in member company operations. Database of activities that can be sorted by type of activity and impact. Many of the incidents are occupational. They also publish a book of process safety case studies on an annual basis.
Date on impacts: Each incident is classified as Tier 1 or Tier 2 severity based on human health, environment, community and economic impacts

Process Safety Incident Database (PSID) www.aiche.org/ccps/resources/psid-process-safety-incident-database
Process safety incidents reported by member companies of the AICHE Center for Chemical Process Safety

Number of events: ~100 **Time span:** > 2000 **Geographic coverage:** USA
Purpose: To pool process safety incident experience among participating companies so they can learn from the experiences of others without suffering the consequences of failures, while minimizing corporate liability.
Description of content: Concise summaries of serious chemical accidents. Detailed explanation of lessons learned and adequate detail on circumstances.
Data on impacts. Specific numbers provided on deaths and injuries. Limited detail on other types of impacts.

ProcessNet (German industry) https://processnet.org/en/incident_db.html **[en],** https://processnet.org/ereignisdb.html **[de]**
Hazardous incidents in process engineering facilities managed jointly by DECHEMA and VCI

Number of events: ~100 **Time span:** > 2000 **Geographic coverage:** Not available
Purpose: Lessons learned and causal information **Format:** Free text
Description of content: Concise technical summaries of chemical accidents.
Data on impacts: Very limited if available at all

RISCAD (Japan) Relational Information System for Chemical Accidents Database https://riscad.aist-riss.jp/
Operated by the Japanese National Institute of Advanced Industrial Science and Technology
Number of events: >7500 **Time span:** > 1949 **Geographic coverage:** Japan
Purpose: Lessons learned and causal and impact statistics **Format:** Technical causes by keyword
Description of content: Summarises accidents reported by various firefighting, response and safety organisations. For each accident there is a free text description of the incident, statistics on human health impacts, and free text descriptions of other impacts.
Data on impacts: Quantitative data on human health impacts

UEMS (Unplanned Explosions at Munitions Sites) database http://www.smallarmssurvey.org
Uunplanned explosions occurring at munitions sites, including production and storage, since 1979
Number of events: >500 **Time span:** >1979 **Geographic coverage:** Global
Purpose: Motivate improved reduction of risk associated with munitions sites **Format:** Classified by ty technical and underlying causes
Description of content: The Small Arms Survey defines UEMS as the accidental explosion of stockpiles of ammunition and explosives at storage sites, whether the stockpiles are properly stored or are abandoned, damaged, or improperly stored. Its work is intended to highlight a global problem with poor risk management at many these sites.
Data on impacts: Statistics on fatalities and injuries

Work Accident Map (China) China Labour Bulletin http://maps.clb.org.hk/accidents/en#201801/201807/1821
Work accidents collected from the media and other sources by the China Labour Bulletin
Number of events: >1700 **Time span:** >2014 **Geographic coverage:** China
Purpose: Lessons learned and impact statistics **Format:** Mapped by location, location links to short summary with reference to a news report
Description of content: Database and map of workplace accidents including chemical accidents. Short summaries plus a link to a newspaper description are included. Statistics on human health impacts only.
Date on impacts: Quantitative data on human health impacts (onsite only)

ZEMA (Germany) http://www.infosis.uba.de/index.php/de/site/12981/zema/index.html
Database managed by the German Federal Environment Agency of hazardous incidents and incidents in process engineering facilities.
Number of events: >750 **Time span:** > 1980 **Geographic coverage:** Germany
Purpose: Lessons learned and causal and impact statistics **Format:** Free text
Description of content: Concise technical summaries of chemical accidents. All accidents associated with sources classified as high hazards and meeting a certain impact criteria are recorded in this database in accordance with German legislation.
Data on impacts: Quantitative data on human health impacts. Inconsistent data in all other categories. Economic impacts not collected

Annex 4. Selection of sources of investigation reports and analyses of chemical accidents

This list of references is a copy of a list that is available on the JRC Minerva website, *here*, The list of references was updated in April 2025.

ARIA (France) http://www.aria.developpement-durable.gouv.fr/
Hosts the ARIA databases of industrial accidents but also contains many in-depth reports of those accidents including chemical accidents.

Dutch Safety Board https://www.onderzoeksraad.nl/en/
The Dutch Safety Board investigates into the causes of disasters and accidents, including industrial disasters.

EC-JRC Lessons Learned Bulletin https://minerva.jrc.ec.europa.eu/en/shorturl/minerva/publications
A summary of lessons learned from accidents based on a thematic topic.

IChemE Loss Prevention Bulletin
The IChemE Loss Prevention Bulletin (LPB) is a leading source of process safety case studies from 40 years of publication. It is a subscription-based publication but several articles are also available free of charge online: https://www.icheme.org/knowledge/loss-prevention-bulletin/free-downloads/articles/articles/
A few special complete issues of the LPB are also available online: https://www.icheme.org/knowledge/loss-prevention-bulletin/free-downloads/issues/issues/

United Kingdom COMAH Competent Authority http://www.hse.gov.uk/comah/investigation-reports.htm
The COMAH Competent Authority undertakes investigations as a result of an incident or complaint at a COMAH establishment.

U.K. Health and Safety Executive Safety Bulletins http://www.hse.gov.uk/safetybulletins/
The UK HSE issues safety bulletins to communicate major faults that would result in a serious or fatal injury and where immediate remedial action is required. Many of these are derived from a chemical incident occurrence.

UK Health and Safety Executive accident reports https://www.icheme.org/membership/communities/special-interest-groups/safety-and-loss-prevention/resources/hse-accident-reports/
By arrangement with HSE a selection of old or out-of-print accident reports are available through the IChemE.

U.S. Chemical Safety Board https://www.csb.gov/
The CSB is an independent federal agency charged with investigating industrial chemical accidents.

U.S. National Transportation Safety Board https://www.ntsb.gov/investigations
The NTSB investigations include accidents in transportations and pipelines carrying dangerous goods.

UEMS (Unplanned Explosions at Munitions Sites) database http://www.smallarmssurvey.org
Hosts a database of unplanned explosions occurring at munitions sites, including production and storage but also a list of publications associated with munitions explosions, including accident studies, on its website.

The following organizations investigate incidents in transport and their site includes reports from investigations of accidents in transport involving dangerous substances.

Finnish Safety Investigation Authority https://www.turvallisuustutkinta.fi/en/index.html
The Safety Investigation Authority investigates all major accidents regardless of their nature as well as all aviation, maritime and rail accidents and their incidents.

Japanese Failure Knowledge Database http://www.sozogaku.com/fkd/en/
The Japanese Institute for the Advancement of Technology hosts the Failure Knowledge Database, a collection of case studies covering 16 industries, including the Petrochemical and the Chemical industries. There are 100 cases presented for each industry.

Swedish Accident Investigation Authority https://www.havkom.se/en/
The SHK is a government authority which investigates accidents and incidents with the aim of improving safety, including accidents involving dangerous substances.

Swiss Transportation Safety Board https://www.sust.admin.ch/en/stsb-homepage/
The STSB investigates accidents and dangerous incidents involving trains, aircraft, inland navigation ships, and seagoing vessels.

Transportation Safety Board of Canada http://www.tsb.gc.ca/eng/
The Transportation Safety Board of Canada (TSB) is an independent agency that advances transportation safety by investigating occurrences in the marine, pipeline, rail and air modes of transportation, including incidents involving dangerous goods.

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For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex (eur-lex.europa.eu).

EU open data

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

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