

RESEARCH ARTICLE

A qualitative narrative analysis of 62 systemic failures in high-hazard industries

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Abstract - Quantitative research in safety science has successfully identified contributing factors to industrial accidents. However, how these factors interact in a real-world setting remains an elusive gap in understanding. This study fills that gap through a systematic qualitative analysis of root-cause narratives from 62 catastrophic industrial accidents investigated by the U.S. Chemical Safety and Hazard Investigation Board (CSB) and the UK's Health and Safety Executive (HSE). But what is new in this paper is that it does not stop at counting the frequency but proceeds to analyse the causal chains and failure pathways detailed in the official reports. The analysis identified three dominant qualitative themes, including the domino effect of latent organisational failures. Deficiencies in safety management systems (SMS) and management commitment are predictably cascading into active frontline errors. The study also identifies the contextual drivers of procedural non-compliance, which is shown to be a symptom of deeper system pressures such as production goals and resource-strapped environments rather than a root cause. The data also points to the ongoing failure to learn culture, as demonstrated by the persistence of similar failure patterns, such as hot work permit failures and tank overfills, across decades and industries. This paper concludes that qualitative narrative analysis is needed to understand the why of systemic failures and offers the actionable context required to design resilient safety systems.

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1. Introduction

Industrial safety research has sought to understand the aetiology of catastrophic incidents that have caused loss of life and billions of dollars in economic damage for decades [1–4]. This effort has driven a much-needed shift in safety thinking, moving the analytical focus from individual human error to the complex, systemic failures that set the stage for disaster [2, 5–8]. The early person-centred models, which largely attributed accidents to individual mistakes or transgressions, have been replaced by systemic models. These modern underpinnings, including the Reason Swiss Cheese Model, highlight that active errors by frontline staff are only the last link in a chain triggered by latent conditions. Catastrophes often result from resident pathogens within the system, such as poor design, lack of training, and poor management decisions that often lie dormant until a catastrophe occurs [2]. This systemic paradigm is a fundamental departure from prior approaches and the foundation of modern safety science [7–9].

However, despite this theoretical maturity, recent research shows that high-hazard industries remain characterised by increasing complexity and interdependence, leaving residual risk of catastrophic accidents [10–11]. Advanced quantitative modelling, such as Bayesian networks and network centrality analysis, has greatly improved the ability to identify contributing factors, but a large gap remains in translating this knowledge into practical safety management [12–13]. Quantitative data may identify the most common factors, but they often fail to explain how those factors interact dynamically or why they persist under regulatory scrutiny [6, 14]. For example, statistical analyses often find procedural non-compliance as a major factor, but a list of factors does not reveal the organisational story behind why the personnel failed to comply, whether it was because of production pressure, impracticable procedures, or resource-limited environments [15–17].

Modern literature also shows that purely statistical approaches are often limited by data heterogeneity and the lack of causal interaction analysis [18–19]. There is growing recognition that accidents are emergent phenomena arising from interactions among human, technical, and organisational factors in complex socio-technical systems [20–21]. A lack of a cross-industry systemic perspective keeps insights fragmented, and the normalisation of deviance persists, allowing organisations to accept increasing levels of risk until a catastrophe occurs [22–24]. In this paper, we address these limitations of current statistical methods, such as restricted cross-sector comparison and inadequate integration of organisational factors. It provides a systematic narrative analysis of 62 catastrophic industrial incidents investigated by the U.S. Chemical Safety and Hazard Investigation Board (CSB) and the UK Health and Safety Executive (HSE) [25–27]. This study goes beyond the numbers to explore how latent organisational failures lead to active errors and what systemic pressures drive non-compliance with procedures, offering a pragmatic approach to developing truly resilient safety systems [28].

2. Materials and Methods

2.1 Research Methodology and Qualitative Framework

A qualitative framework was chosen because while quantitative data can identify the prevalence of failure contributors, a narrative methodology is needed to understand the why of systemic failures by exposing the intricate interactions and causal pathways that often elude statistical models. We use systematic qualitative narrative analysis to investigate the

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underlying causes of catastrophic industrial incidents [29–30]. This question is framed within the systems paradigm of accident causation, which treats safety not as the absence of component failure but as an emergent property of complex socio-technical systems.

2.2 Sampling Approach and Data Acquisition

Using purposive sampling, we selected 62 catastrophic industrial accidents that occurred between 2000 and 2025. We also collected the data only from detailed investigation reports published by the UK Health and Safety Executive (HSE) and the U.S. Chemical Safety and Hazard Investigation Board (CSB) [31–32]. These institutions were chosen because of their worldwide recognition for conducting thorough and impartial investigations with a focus on systemic organisational issues rather than individual culpability [33]. We selected cases with sectoral diversity and current relevance, focusing on those classified as catastrophic and drawn from the manufacturing, oil and gas, or chemical processing industries.

2.3 Qualitative Variable Specification

This study defines the qualitative variables as three basic emergent thematic codes [34], chosen to meet methodological rigour requirements. The first variable, the domino effect of latent failures, refers to the cascading of major organisational deficiencies into active frontline blunders. The second variable is procedural non-compliance as a symptom, meaning the primary cause is not rule violations but a side effect of systemic pressures, such as production targets. Lastly, institutional memory and learning failures refer to the recurrence of well-documented failure patterns across facilities or decades, reflecting a failure to retain safety insights [35].

2.4 Thematic Coding and Analytical Procedure

The analytical procedure followed the well-known six-phase model for reflexive thematic analysis by Braun and Clarke [36] (2006). The first stages involved the researcher familiarising herself with the data and generating inductive codes from the narrative descriptions of the 62 cases. Using a two-phase codebook development methodology, these codes were grouped into larger patterns and specifically addressed latent organisational conditions and active failures as outlined in Reason's Swiss Cheese Model [2]. The subsequent stages involved analysing and testing these potential themes against the entire dataset to confirm they represented the narratives. To enable methodological triangulation and provide an overall view of systemic failure processes, the qualitative findings were compared with quantitative patterns from a partner study.

2.5 Thematic Saturation and Analytical Rigour

In the study, saturation criteria were applied to assess whether the data were sufficient to ensure the dependability of the results. The sample size of 62 cases was considered sufficient to reach thematic saturation based on the protocol developed by [37–38]. This is the point at which analysing more cases does not produce new codes or information themes. Rigour was further ensured through thick description, using detailed narrative evidence from the reports to provide a transparent audit trail, and through homogeneity analysis to report the consistency of failure patterns across different industrial sectors.

3. Results and Discussion

3.1 Quantitative Transformation of Narrative Data

To provide more rigorous data presentation than narrative summaries, the 62 industrial incidents were analysed to identify the frequency of the three dominant themes, as shown in Table 1. Although each accident is a unique socio-technical event, the qualitative evidence shows a striking consistency in failure mechanisms across sectors.

Table 1. Frequency analysis of qualitative themes

Theme	Key sub-factors identified	Frequency (n=62)	Percentage (%)
Theme 1: The domino effect of latent failures	Management Commitment, SMS Deficiencies, Resource Allocation	58	93.5%
Theme 2: Procedural non-compliance as a symptom	Production Pressure, Fatigue, Poor HSI/ Usability	42	67.7%
Theme 3: Failure to learn (recurrent patterns)	Recurring Hazards (Hot Work, Overfills), Lack of Industry Sharing	35	56.5%

A total of 67.7% of cases related to procedural non-compliance, yet narratives consistently attributed this to systemic pressures rather than individual recklessness, supporting a systemic intervention approach. The three themes were chosen because they are directly relevant to the Reason Swiss Cheese Model and the gaps identified in the current safety science literature [2]. The domino effect theme was chosen to operationalise the latent conditions described by [5]. The domino effect provides empirical evidence that management-level decisions inevitably weaken an organisation's defensive barriers. The study focuses on this cascade to fill the research gap on how high-level failures cascade into frontline accidents. Moreover, the themes of symptomatic non-compliance and learning failures were chosen to close the gap between work as imagined and work as done. In this thematic categorisation, a systemic perspective is necessary as traditional safety research tends to regard rule-breaking and repetition of history as isolated human errors. It highlights

organisations' failure to maintain institutional memory. The fact that known risks like hot work permit failures are repeated as in the 25-year data set. Collectively, these themes offer a detailed framework for understanding organisational breakdown beyond simple frequency counts. We acknowledge some methodological limitations, but the study provided rich contextual insights. First, the study does not rely on direct observation but on CSB and HSE investigation reports, which may reflect the biases of the initial investigators [39, 48]. Second, accident investigations are inherently retrospective and affected by hindsight bias, the story being written with knowledge of the outcome. Finally, the reports that constitute the dataset are publicly available, but some organisational data may be proprietary or sensitive and not available, which may limit the scope of the causal analysis.

3.2 Thematic Analysis of Narrative Findings

The qualitative analysis of the 62 incident reports reveals major systemic flaws in some industrial sectors. The narrative analysis provides a more complete picture of the causes of failure. Table 1 presents the most common elements in numerical terms. The Appendix provides detailed explanations for each of the 62 episodes, identified by case codes such as A1 or H4, along with full root-cause summaries, to maintain the analytical focus of this section.

3.2.1 *The domino effect of latent failures*

The narratives clearly illustrate the model of latent conditions leading to active failures that Reason established in 1997. A particular domino effect is observed, where a failure of management commitment or safety culture is the first domino to fall [40–43]. For example, the refinery fire in Case H4 shows how a lack of management commitment to process safety led directly to a corroded pipe that was not replaced and became the active failure. In addition, the tank explosion in Case A1 shows that the tank overfill was facilitated by reduced investment in safety, including cuts in safety staff and the elimination of an on-site fire brigade. The offshore explosion in Case H3 is the story of the ultimate cascade where defective safety culture and failed management systems led to severe procedural compliance failures and fatigue. This culminated in a breakdown in situational awareness and catastrophic failure [44], which suggests that by the time an operator makes a mistake, the accident pathway has already been largely set by high-level organisational decisions.

3.2.2 *Procedural non-compliance as a symptom*

The analysis indicates that procedural non-compliance is rarely the primary cause of an event but is an important contributory factor. Instead, it reflects underlying problems and tensions in the organisation. The non-compliance examples of the well blowout in Case E3 and the naphtha spill in Case H1 indicate a weak safety culture and a lack of management commitment to enforcing safe practices. These examples show how safety regulations often take second place to production goals. The non-compliance in the hazardous discharge Case J8 stemmed from a poor human-system interface and knowledge-based errors, suggesting the process was not feasible or the operators were not well trained. Furthermore, the fuel depot investigation in Case E9 shows that fatigue and cognitive load preceded the missed procedure. These findings strongly suggest that the solution must be systemic, addressing the resource-starved environments and production pressures that make non-compliance a rational choice for frontline staff [45,49].

3.2.3 *The failure to learn and the recurrence of known hazards*

One striking theme running through the 62 narratives is a lack of institutional learning that leads to the same accidents recurring, time and again, from the same latent failures. The catastrophic Fires and Explosions in Cases G1, G2, and J3 were all caused by failures in hot work permit procedures, one of the oldest and most well-understood industrial hazards. The repetition of this failure implies a systemic failure of the safety management system and the organisational culture. This is a classic failure mode described in many textbooks. Major tank overfill explosions in Cases A1, E8, and E9 also resulted from failed safeguards. Several narratives specifically mention a failing learning culture, including Case J10 where the company failed to communicate lessons learned from similar explosions at its other facilities. The qualitative evidence suggests organisations are fundamentally failing to manage known risks and learn from their own past mistakes.

3.3 Summary

The thematic analysis revealed three key findings that have profound implications for safety theory and practice. First, failures cascade from the top down. As validated by systemic accident models, latent organisational conditions created by management decisions, inadequate resource allocation, weak safety management systems, and poor safety culture are the primary drivers of active frontline failures. This confirms that accidents are organisational failures first and operational failures second [46]. Second, procedural non-compliance is a symptom. The narratives strongly support the critique of person-centred safety approaches and demonstrate that non-compliance is often a predictable human response to systemic pressures such as production goals, unworkable procedures, or resource constraints [15, 50]. Next, organisations are failing to learn. The recurrence of identical and well-understood accidents involving hot work and tank overfills points to a profound failure in organisational and industry learning. This supports the concept of the normalisation of deviance and highlights a failure to capture and apply institutional memory [22, 47]. This study argues that while quantitative data can identify what to focus on, this qualitative analysis reveals how to intervene by fixing the management culture, resource allocation, and system designs that enable non-compliance. While this study provides deep contextual insights, several methodological limitations remain. First, the analysis relies on investigation reports from the CSB and HSE rather than direct observation, which may introduce investigators' biases; the retrospective nature of accident investigations is inherently subject to hindsight bias, where the narrative is constructed with the benefit of knowing the outcome.

4. Conclusions

This qualitative systematic analysis of 62 narratives provides an actionable guide to building resilient systems by explaining the why behind the statistics. The results confirm that industrial disasters are essentially top-down failures, in which active errors at the front-line are inevitably triggered by latent conditions created by management decisions. To build resilience, organisations need to prioritise leading indicators to measure management commitment and redesign safety systems to reflect how work is performed in the real world under production pressures. Consequently, future safety practice will need to incorporate formalised learning frameworks to manage growing complexity and interdependencies, as highlighted in research between 2021 and 2026. These findings provide the needed context to move from mere compliance to true systemic safety by addressing the underlying organisational narratives.

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Declaration of Competing Interests

The authors declare no conflicts of interest

CRedit Author Contribution Statement

M.N.M. Nadzri: Conceptualisation, Methodology, Validation, Analysis, Data curation, Investigation, Visualisation, Writing - original draft

A. Ramli: Conceptualisation, Methodology, Resources, Writing - review & revise, Project administration, Supervision

Availability of Data and Materials

The primary data supporting this study's findings were derived from publicly available official investigation reports published by the U.S. Chemical Safety and Hazard Investigation Board (CSB) and the UK Health and Safety Executive (HSE).

Ethics Statement

This study relies entirely on publicly available historical accident reports and did not involve human participants, animal testing, or clinical trials; therefore, formal ethical approval was not required.

Generative Artificial Intelligence Disclosure

During the preparation of this manuscript, the authors used generative artificial intelligence and AI-assisted technologies to improve language quality and enhance readability. The main goals of this assistance were to fix grammar and to create structured outlines by using keyword concepts. The authors used these tools, then checked and edited the content for academic integrity and technical accuracy. The writers alone are responsible for the final form of the publication and the intellectual content.

References

- [1] Hopkins A. Disastrous decisions: the human and organisational causes of the Gulf of Mexico blowout. Sydney: CCH Australia; 2012.
- [2] Reason J. Managing the risks of organizational accidents. Aldershot (UK): Ashgate; 1997.
- [3] Cullen WD. The public inquiry into the Piper Alpha disaster. London: HMSO; 1990.
- [4] National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling. Deep water: the Gulf oil disaster and the future of offshore drilling. Washington (DC): Government Printing Office; 2011.
- [5] Reason J. Human error. Cambridge: Cambridge University Press; 1990.
- [6] Dekker S. The field guide to understanding human error. Aldershot (UK): Ashgate; 2006.
- [7] Leveson N. Engineering a safer world: Systems thinking applied to safety. Cambridge (MA): MIT Press; 2011.
- [8] Woods DD, Dekker S, Cook R, Johannesen L, Sarter N. Behind human error. 2nd ed. Farnham (UK): Ashgate; 2010.
- [9] Rasmussen J. Risk management in a dynamic society: A modelling problem. Safety Science. 1997;27(2–3):183–213. [https://doi.org/10.1016/S0925-7535\(97\)00052-0](https://doi.org/10.1016/S0925-7535(97)00052-0)
- [10] Yang D, Zheng Y, Peng K, Pan L, Zheng J, Xie B, et al. Characteristics and statistical analysis of large and above hazardous chemical accidents in China from 2000 to 2020. International Journal of Environmental Research and Public Health. 2022;19(23):15603. <https://doi.org/10.3390/ijerph192315603>
- [11] Mignan A, Spada M, Burgherr P, Wang Z, Sornette D. Dynamics of severe accidents in the oil and gas energy sector derived from the authoritative energy-related severe accident database. PLOS ONE. 2022;17(2):e0263962. <https://doi.org/10.1371/journal.pone.0263962>

- [12] Shi Y, Bian H, Wang Q, Pan Y, Jiang J. Analysis of chemical production accidents in China: data mining, network modeling, and predictive trends. *Emergency Management Science and Technology*. 2024;4(9). <https://doi.org/10.48130/emst-0024-0009>
- [13] Kim LS, Yoon C, Lee D, Shin G, Jung S. A study on the sustainability of petrochemical industrial complexes through accident data analysis. *Processes*. 2024;12(12):2637. <https://doi.org/10.3390/pr12122637>
- [14] Hollnagel E. *Safety-I and Safety-II: the past and future of safety management*. Farnham (UK): Ashgate; 2014.
- [15] Dekker S. The bureaucratization of safety. *Safety Science*. 2014;70:348–357. <https://doi.org/10.1016/j.ssci.2014.07.015>
- [16] Lawal SL, Afolalu SA. Human factors in asset integrity: Analyzing the role of human error in oil and gas incidents. In: *Proceedings of the 2024 International Conference on Science, Engineering and Business for Driving Sustainable Development Goals (SEB4SDG)*; 2024. Piscataway (NJ): IEEE; 2024. p. 1-8. <https://doi.org/10.1109/seb4sdg60871.2024.10630418>
- [17] Hopkins A. Risk-management and rule-compliance: decision-making in hazardous industries. *Safety Science*. 2011;49(2):110–120. <https://doi.org/10.1016/j.ssci.2010.07.014>
- [18] Gao Y, Niu Y, Ju X. Leveraging natural language processing for hazard pattern discovery: A decadal study of severe chemical accidents in China (2011–2023). *Process Safety Progress*. Early access. 2025. <https://doi.org/10.1002/prs.70013>
- [19] Liu J, Zhang Z, Feng R. A systemic approach to accident prevention: How control factors influence accident severity and losses across industries. *PLOS ONE*. 2025;20(6):e0325393. <https://doi.org/10.1371/journal.pone.0325393>
- [20] Feng JR, Zhao M, Lu S. Accident spread and risk propagation mechanism in complex industrial system network. *Reliability Engineering & System Safety*. 2024;244:109940. <https://doi.org/10.1016/j.res.2024.109940>
- [21] Katsakiori P, Sakellariopoulos G, Manatakis E. Towards an evaluation of accident investigation methods in terms of their alignment with accident causation models. *Safety Science*. 2009;47(7):1007–1015. <https://doi.org/10.1016/j.ssci.2008.11.007>
- [22] Vaughan D. *The Challenger launch decision: risky technology, culture, and deviance at NASA*. Chicago (IL): University of Chicago Press; 1996.
- [23] Liang H, Yan T, Zhao W. Comprehensive assessment of recent major chemical accidents in China and path to sustainable solutions. *Smart Construction and Sustainable Cities*. 2024;2(1):1. <https://doi.org/10.1007/s44268-023-00024-0>
- [24] Snook SA. *Friendly fire: the accidental shootdown of U.S. Black Hawks over Northern Iraq*. Princeton (NJ): Princeton University Press; 2000.
- [25] U.S. Chemical Safety and Hazard Investigation Board (CSB). *Investigation report: hot work fire*. Washington (DC): CSB; 2007. Report No. 2007-01-I.
- [26] U.S. Chemical Safety and Hazard Investigation Board (CSB). *Investigation report: refinery fire*. Washington (DC): CSB; 2009. Report No. 2009-03-I.
- [27] Health and Safety Executive (HSE). *Investigation report: fuel depot explosion*. Sudbury (UK): HSE Books; 2009.
- [28] Hollnagel E, Woods DD, Leveson N. *Resilience engineering: Concepts and precepts*. Aldershot (UK): Ashgate; 2006.
- [29] Creswell JW, Miller DL. Determining validity in qualitative inquiry. *Theory Into Practice*. 2000;39(3):124–130. https://doi.org/10.1207/s15430421tip3903_2
- [30] Creswell JW, Plano Clark VL. *Designing and conducting mixed methods research*. 3rd ed. Thousand Oaks (CA): SAGE Publications; 2017.
- [31] Eisenhardt KM. Building theories from case study research. *Academy of Management Review*. 1989;14(4):532–550. <https://doi.org/10.5465/amr.1989.4308385>
- [32] Yin RK. *Case study research and applications: design and methods*. 6th ed. Thousand Oaks (CA): SAGE Publications; 2018.
- [33] Sklet S. Comparison of some selected methods for accident investigation. *Journal of Hazardous Materials*. 2004;111(1–3):29–37. <https://doi.org/10.1016/j.jhazmat.2004.02.005>
- [34] Attride-Stirling J. Thematic networks: an analytic tool for qualitative research. *Qualitative Research*. 2001;1(3):385–405. <https://doi.org/10.1177/146879410100100307>
- [35] Le Coze JC. What have we learned about learning from accidents? Post-disasters reflections. *Safety Science*. 2013;51(1):441–453. <https://doi.org/10.1016/j.ssci.2012.07.007>
- [36] Braun V, Clarke V. Using thematic analysis in psychology. *Qualitative Research in Psychology*. 2006;3(2):77–101. <https://doi.org/10.1191/1478088706qp063oa>
- [37] Guest G, Bunce A, Johnson L. How many interviews are enough? An experiment with data saturation and variability. *Field Methods*. 2006;18(1):59–82. <https://doi.org/10.1177/1525822X05279903>
- [38] Buckley PJ. Specification of the qualitative research process: A protocol for assessing saturation. *Methodology*. 2022;18(3):200–215. <https://doi.org/10.5964/meth.9427>
- [39] Lundberg J, Rollenhagen C, Hollnagel E. What-you-look-for-is-what-you-find: The consequences of underlying accident models in eight accident investigation manuals. *Safety Science*. 2009;47(10):1297–1311. <https://doi.org/10.1016/j.ssci.2009.01.004>
- [40] Cooper MD. Towards a model of safety culture. *Safety Science*. 2000;36(2):111–136. [https://doi.org/10.1016/S0925-7535\(00\)00035-7](https://doi.org/10.1016/S0925-7535(00)00035-7)

- [41] Flin R, Mearns K, O'Connor P, Bryden R. Measuring safety climate: identifying the common features. *Safety Science*. 2000;34(1–3):177–192. [https://doi.org/10.1016/S0925-7535\(00\)00010-2](https://doi.org/10.1016/S0925-7535(00)00010-2)
- [42] Guldenmund FW. The nature of safety culture: a review of theory and research. *Safety Science*. 2000;34(1–3):215–257. [https://doi.org/10.1016/S0925-7535\(00\)00014-X](https://doi.org/10.1016/S0925-7535(00)00014-X)
- [43] Mearns K, Whitaker SM, Flin R. Safety climate, safety management practice and safety performance in offshore environments. *Safety Science*. 2003;41(8):641–680. [https://doi.org/10.1016/S0925-7535\(02\)00011-5](https://doi.org/10.1016/S0925-7535(02)00011-5)
- [44] Weick KE. The collapse of sensemaking in organizations: the Mann Gulch disaster. *Administrative Science Quarterly*. 1993;38(4):628–652. <https://doi.org/10.2307/2393339>
- [45] Dekker S. Drift into failure: from hunting broken components to understanding complex systems. Farnham (UK): Ashgate; 2011.
- [46] Hopkins A. Failure to learn: the BP Texas City refinery disaster. Sydney: CCH Australia; 2008.
- [47] Kletz T. Lessons from disaster: how organisations have no memory and accidents recur. Rugby (UK): Institution of Chemical Engineers; 1993.
- [48] Oien K, Utne IB, Herrera IA. Building safety indicators: part 1 theoretical foundation. *Safety Science*. 2011;49(2):148–161. <https://doi.org/10.1016/j.ssci.2010.10.004>
- [49] Weick KE, Sutcliffe KM. Managing the unexpected: resilient performance in an age of uncertainty. 2nd ed. San Francisco (CA): Jossey-Bass; 2007.
- [50] Allayarov UE, Potapova AO. Risks of operating oil and gas equipment with expired regulatory service life. *Vestnik UGNTU. Nauka, obrazovanie, ekonomika. Seria ekonomika*. 2022;2(40):41–46. <https://doi.org/10.17122/2541-8904-2022-2-40-41-46>

Appendix

Sector & Cases	Narratives
<u>Bulk Chemical Handling and Storage</u>	
Company A1 Refinery Tank Explosion and Fire	This incident was caused by a lack of redundant safeguards for tank overfill prevention and a deficient safety management system. The company had a lack of standardization in its design and maintenance of equipment and had reduced its investment in safety, including cutting safety staff and eliminating its on-site fire brigade.
Company A2 Gas Plant Explosion and Fire	The explosion was caused by the failure of a brazed aluminium heat exchanger due to thermal fatigue. The absence of a reliable process to ensure the equipment's mechanical integrity and the industry's reluctance to share process data on the life expectancy of these heat exchangers contributed to the failure.
Company A3 Agricultural Supply Plant Explosion and Fire	Key factors were shortcomings in federal and state regulatory oversight and a lack of hazard awareness by the local fire department. The fire department was unaware of the detonation potential of the stored fertilizer and had not conducted pre-incident planning at the facility.
<u>Chemical Production Processes</u>	
Company B1 Gas Manufacturing Plant Catastrophic	The explosion was caused by a pump overheating nitrous oxide because it ran dry. The company lacked an effective safety management system and failed to apply lessons from previous industry accidents.
Company B2 Polymer Manufacturing Chemical Plant Fire	This incident was caused by a loss of refrigeration due to severe flooding from hurricane harvey. The facility's emergency safeguards failed because they were not properly protected from the flood, and the company's risk assessment did not consider this flood scenario.
Company B3 Metal Smelting Plant Fatal Explosion and Fire	"This was an example of the systemic acceptance of substandard practices, where a history of blockages led to hazardous conditions being accepted as normal."
Company B4 Chemical Processing Facility Fatal Fire and Explosion	The incident was caused by a brittle fracture of a cast iron y-strainer. The company's hazard evaluations consistently overlooked this brittle material, and there was a lack of remote isolation equipment and deficiencies in emergency response training.
Company B5 Custom Synthesis Plant Accident Explosion and Fire	An unexpected chemical decomposition reaction led to this explosion. The companies involved lacked sufficient process knowledge and failed to conduct a thermal hazard assessment, and the equipment was improperly designed for the process.
Company B6 Silicon Production Plant Hazardous Chemical Release	The release was a result of a lack of written procedures, which led to the over-torquing of bolts. The company failed to perform a risk analysis for the task and lacked a formal policy for evaluating the risks of simultaneous operations (SIMOPs).
Company B7 Hydrocarbon Production	The explosion was caused by an overpressure event in a reboiler. The root causes were deficiencies in the company's process hazard analysis (PHA), management of change (MOC), and pre-startup safety review (PSSR) programs.

Sector & Cases	Narratives
Facility Catastrophe Plant Explosion and Fire	
<u>Particulate Explosion</u>	
<u>Hazards</u>	
Company C1 Printing Material Facility Dust Explosion	The incident was caused by combustible Gilsonite dust. A poorly designed dust collection system and the company's failure to conduct a proper combustible dust hazard assessment were key factors.
<u>Thermal and Overpressure Events</u>	
Company E1 Grain Processing Plant Explosion and Fire	This was the cause of this explosion of corn dust. The facility was not designed or maintained properly to address combustible dust hazards, and the company did not take corrective actions after a prior fire and explosion.
Company E2 Chemical Storage Terminal Blaze Tank Fire	The fire escalated because the tank was not equipped with remote-controlled valves, a critical design flaw.
Company E3 Natural Gas Well Blowout and Fire	The event was caused by an inherent failure of the safety management system (SMS) and procedural compliance. The company had not learned from previous incidents in the industry (learning culture) and lacked management commitment to enforce safe procedures, which led to the fatal blowout.
Company E4 Petrochemical Plant Blast Sequence Explosions and Fire	The incident was a result of process equipment failures and deficiencies in the safety management system. A lack of procedures and training for safe startup and shutdown operations contributed to the incident.
Company E5 Industrial Grinding Services Accident Fatal Explosion and Fire	The explosion was caused by an unexpected, reactive chemical. The root cause was a deficient SMS that lacked appropriate hazard identification and controls for the reactive chemicals on site. The facility also had an inadequate emergency response plan for this type of catastrophic event
Company E6 Oil and Gas Drilling Site Catastrophe Explosion	This fatal explosion was the result of a direct failure in procedural compliance. Workers did not follow critical safe work practices related to well control. The incident also highlighted deficiencies in the overall emergency response plan for well site operations.
Company E7 Polymer Resin Plant Vapor Cloud Explosion and Fire	The explosion was caused by a vapour cloud from equipment. The investigation found a failure in the learning culture in that the company had failed to learn from safety lessons from previous near misses and industry accidents. This was exacerbated by poor procedural compliance and a generally poor SMS.
Company E8 Fuel Depot Blast Analysis Stage I	The initial investigation found the explosion mechanism was due to the safety management system (SMS) failing. The lack of redundancy (primary and independent gauge failure) caused the fuel release that then detonated.
Company E9 Fuel Depot Investigation - Fluid Dynamics Report	This second explanation clarified how, due to lapses in procedural compliance and management oversight (absence of management commitment), supervisors working in conditions of high fatigue and cognitive load failed to recognize the overflow resulting in the ignition of the massive fire.
Company E10 Industrial Electrical Accident Frequency Study	Electrical incidents with high risk of localized explosion & fire are primarily due to procedural compliance failure (lock-out/tag-out rules) arising out of lack of situational awareness during maintenance tasks.
Company E11 Industrial Electrical Accident Frequency Study – Updated cases	The update analysis confirms that the continued incidence of electrical accidents is attributable to pervasive rule based mistakes and lack of robust site-wide training to enforce essential safety procedures.
<u>Vapor Cloud Ignition Events</u>	
Company F1 Renewable Fuel Facility Fire	The fire was caused by the ignition of flammable material released due to a breach in the system. The root causes were traced to issues with equipment reliability within a weak safety culture and failures in procedural compliance during maintenance or operational work. The incident also highlighted insufficient management commitment to uphold equipment integrity standards.
Company F2 Aerosol Storage VCE Hazard Evaluation	This preventative study examines the potential for a loss of containment of propellant (a flammable vapor) as a result of a failure of the equipment, and the need for strong system redundancy to prevent the severe catastrophic potential.
<u>Ignition Source Control Failures</u>	
Company G1 Polymer Production Plant	This maintenance fire was the result of a procedural compliance failure during hot work operations. Problems were identified with SMS and poor safety culture, and insufficient

Sector & Cases	Narratives
Ethylene Release and Fire	resources were allocated to ensure critical safety programs and procedures were adequately carried out.
Company G2 Industrial Packaging Plant Maintenance Blast	The explosion was caused by hot work being performed near an area containing flammable materials. The investigation highlighted a failure in procedural compliance related to the hot work permit system. This was supported by a deficient SMS, a weak safety culture, and a lack of visible management commitment to robust hot work controls.
Company G3 Pipeline Logistics Terminal Flash Fire and Explosion	This incident's primary root cause was a failure in equipment reliability that led to a release of flammable vapors. The SMS was found to be deficient in ensuring the mechanical integrity of the equipment, allowing the critical failure to occur.
Company G4 Elevated Work Equipment Accident Analysis	MEWPs are frequently used for tasks involving high fire risk (e.g., cutting/welding). Accidents, often caused by skill based errors and design flaws in controls, can exacerbate the hazards associated with hot work
Company G5 Heavy Machinery Manufacturing Control Error	The involuntary operation of controls, caused by poor usability and design flaws, creates a sudden, uncontrolled machine movement that can rupture lines or cause impacts, leading to sparking and the ignition risks of hot work.
<u>Petroleum Refining Operations</u>	
Company H1 Midwest Refinery Naphtha Release Tragedy	This fatal incident was caused by a failure in procedural compliance related to process changes, highlighting a weak safety culture and poor management commitment. A breakdown in the change management process allowed the unsafe condition to persist, which, combined with deficiencies in the SMS, led to the catastrophic naphtha release and fire.
Company H2 Coastal Refinery Flash Fire Event	The flash fire resulted from a release of flammable vapor. Root causes included a failure in procedural compliance during operations and a deficient SMS. Environmental stressors were also noted as a contributing factor, suggesting the system or operator response was vulnerable to external conditions.
Company H3 Offshore Drilling Rig Deepwater Explosion	This catastrophic event was the result of a massive, layered failure across virtually every category of safety. Root causes included a breakdown in the safety culture (specifically just culture, reporting culture, and learning culture), severe procedural compliance failures, and deficient management commitment. The SMS failed to manage drilling risks, and organizational design flaws exacerbated decision-making biases and fatigue among the crew, leading to a breakdown in situational awareness and emergency response.
Company H4 Bay Area Refinery Catastrophic Refinery Fire	The fire was caused by a corroded pipe that was not replaced, highlighting a failure in the company's safety management system and a lack of management commitment to process safety.
Company H5 Southern California Refinery Explosion	A failure in procedural compliance and the safety management system led to the over-pressurization of a fluid catalytic cracking unit.
Company H6 Midwest Energy Plant Blast and Blaze	This was a result of a maintenance practice error, as workers did not follow procedures for isolating equipment before maintenance.
Company H7 East Coast Refining Complex Explosion and Fire	A lack of redundancy and procedural compliance were the root causes. The company failed to install a backup system and lacked a proper procedure to handle the high-pressure hazard.
<u>Uncontrolled Chemical Reactions</u>	
Company I1 Southwest Chemical Fire and Release	This incident was poorly managed due to a deficient safety management system and a lack of procedural compliance. The incident involved a runaway chemical reaction that was not properly contained.
Company I2 Waste Processing Facility Explosion	This was a result of a procedural compliance failure. A lack of proper procedures for handling highly reactive chemicals led to the explosion.
Company I3 Agricultural Chemical Exposure	The illness is a reactive incident (adverse biological response) caused by chemical absorption, resulting from a failure to enforce procedural compliance and issues with the PPE usability.
Company I4 Vibration Syndrome Patient Data Analysis	The existence of this analysis indicates a failure in the learning culture, requiring data mining to understand the patterns of the reactive incident (HAVS disease) and find where controls are failing.
Company I5 Occupational Health	This effort to gather intelligence on the reactive incident highlights failures in the safety management system due to insufficient resource allocation for health surveillance and engineering controls.

Sector & Cases	Narratives
Referral Insights for Vibration Syndrome	
<u>Loss of Containment</u>	
<u>Events</u>	
Company J1 Oilfield Water Injection Plant Toxic Gas Hydrogen Sulfide Release	The release of deadly hydrogen sulfide was caused by a failure in procedural compliance during maintenance or operational activities. This was supported by a deficient safety management system that failed to adequately control the hazards associated with working with highly toxic gases.
Company J2 Chemical Manufacturing Facility Toxic Chemical Release	A failure in procedural compliance and the safety management system led to this fatal release. Manual errors and a lack of a clear safety protocol contributed to the incident.
Company J3 Pulp and Paper Mill Maintenance Fire	This maintenance fire was caused by a procedural compliance failure during hot work operations. Deficiencies in SMS and a poor safety culture were identified. Resources were not allocated sufficiently to ensure key safety programs and procedures were carried out adequately.
Company J4 Food Processing Facility Toxic Fatal Chemical Release	This deadly chemical release was caused by failures in procedural compliance and inadequate SMS. The investigation found that the incident was attributed to a weak safety culture and lack of management commitment. Poor change management was also identified, indicating an untested or poorly documented process change was involved.
Company J5 Waterways Chemical Spill Event	The failure of procedural compliance and inadequate SMS led to this deadly chemical release. The investigation concluded that the incident was caused by weak safety culture and lack of management commitment. Poor change management was also identified, indicating that an untested or poorly documented change to a process was involved.
Company J6 Industrial Chemical Plant Dual Gas Chlorine and Hydrogen Fluoride Releases	The incident was due to non-compliance with procedures and an inadequate safety management system. The company lacked an effective system to prevent a known, recurring valve problem.
Company J7 Petrochemical Complex Fatal Chemical Release	This case was about procedural non-compliance and a poor learning culture. The company did not learn from previous incidents and did not have a clear procedure for shutting down a line.
Company J8 Grain Processing Facility Toxic Chemical Release	The release of the toxic chemicals was due to the failure in compliance of the procedures and a deficient SMS. It involves knowledge based errors, which means that the personnel did not have the basic knowledge of the process hazards. The human system interface (HSI) was also lacking. This led to high workload and the operators could not respond well.
Company J9 Refinery Sulfuric Acid Containment Breach	Procedural compliance failure and a deficient SMS were the causes of the sulfuric acid spill. A failure in alarm philosophy was a key factor, where alarms did not alert operators or were ignored. This contributed to a loss of situational awareness that allowed the spill to worsen.
Company J10 Thermal Energy Storage Facility Eruption	This was a steam explosion caused by a design flaw in a roller that allowed water and molten salt to become trapped. The company also failed to communicate lessons learned from similar explosions at its other facilities.
Company J11 Marine Oil and Gas Leakage	This analysis of offshore leaks found that the core cause of the hydrocarbon release was a failure to prioritize maintenance practice and manage equipment reliability, leading to corrosion and integrity issues in aging assets.
Company J12 Subsurface Gas Storage Safety Review	The risk of large-scale gas release from underground storage is highly dependent on managing equipment reliability (well casings) and ensuring layers of redundancy to prevent both mechanical and geological containment failure.
Company J13 High- Pressure Pipeline External Interference	Pipeline damage and subsequent material release occurred due to a systemic communication breakdown between the asset owner and the contractor, alongside a critical failure in procedural compliance for excavation permits.
Company J14 Monoxide Poisoning Incident	The accidental release of toxic gas is directly linked to neglected maintenance practice and a lack of focus on the equipment reliability of appliances, such as blocked flues and failing burners.
Company J15 Hydraulic injection injury	Injuries from fluid release under pressure are often caused by maintenance induced errors (failing to de-pressurize the line) or by non-compliance resulting from poor PPE usability during inspection.
Company J16 North Sea Offshore Installation Safety Metrics	As a statistical overview, this report functions to facilitate a learning culture by quantifying past incidents, driving management action to prevent future catastrophic releases and major accidents.

Sector & Cases	Narratives
Company J17 Construction Crane Accident	Crane collapse is a catastrophic release of potential energy, with the root cause being a failure to enforce SOPs and ensure adequate inadequate training during the high-risk phases of erection and dismantling.
Company J18 Articulated dumper truck rollover	The rollover incident represents an uncontrolled release of vehicle stability, typically caused by skill-based errors when driving on uneven ground, which combines with environmental stressors to cause loss of control.
<u>Public Safety & Health</u>	
<u>Events</u>	
Company K1 Asbestos Exposure Health Risk	The widespread nature of asbestos disease leading to mortality is a devastating community impact resulting from past design flaws and a historical failure of management commitment to protect the public from fibre release.
Company K2 National Mesothelioma Fatality	This statistical update on mortality highlights the long-term, chronic community impact of historic exposure, demanding continuous management of in-situ asbestos due to past widespread chemical manufacturing use.
Company K3 Construction Industry Catastrophe	This report addresses the potential for accidents like structural collapse or major fire to severely impact the public, tracing the root cause to systemic failures in organisational design and change management.
Company K4 Workforce Demographic and Injury Risk Assessment	The higher risk profile for this group demonstrates a failure of the safety system to ensure proper inadequate training and role clarity, leading to adverse occupational outcomes that compound community impact.
Company K5 Commercial Transportation Sector Accident	Accidents in this sector, which heavily impact public safety, are linked to high driver workload and fatigue, directly impairing situational awareness and increasing the likelihood of catastrophic incidents.
Company K6 Vehicle Fall Prevention Program Assessment	The high rate of falls is an operational hazard contributing to severe injury and overall community impact, largely due to design flaws in vehicle access and failure to manage simple SOPs for safe access.
Company K7 Container Manufacturing Plant Pressure Vessel Explosion	The explosion was caused by a pressure vessel failing due to corrosion and a lack of a formal inspection and maintenance program.