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From Incident Narratives to Actionable Controls: Insights on the Iron & Steel Industry Using LLM-Assisted Learning From Incident Databases

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ABSTRACT

Learning from incidents is a cornerstone of occupational safety risk management, especially in high-risk industrial sectors. Incident databases support this process by collecting records that describe the causes, dynamics, and consequences of adverse events. However, these databases largely rely on unstructured textual narratives, which limit systematic analysis and the translation of learned lessons into effective preventive actions. This paper focuses on the iron and steel industry and presents an analysis pipeline supported by Large Language Models (LLMs) for extracting, synthesising, and structuring information from two major incident databases: the U.S. OSHA database and the French ARIA database. Relevant records were selected using industry classification codes and pre-processed to harmonise terminology, normalise information fields, remove duplicates, and manage multilingual content. Within a human-in-the-loop framework, LLMs were used to identify critical occupational risk scenarios, characterise them in terms of frequency and severity, and derive prevention and risk mitigation measures structured according to the ISO 45001 hierarchy of controls. Eight critical scenarios were identified and subsequently validated and refined by safety experts from the steel industry. Quantitative analysis identified point-of-operation machinery and load handling as the most frequent scenarios, while confined spaces and high-energy events exhibited disproportionate severity and lethality. The results demonstrated how LLM-supported approaches can enhance learning from incidents by transforming large volumes of heterogeneous narrative data into a traceable, expert-validated knowledge base that supports hazard identification, risk assessment and management, and continuous improvement in high-risk industrial environments.

Keywords: Occupational safety, Risk management, Learning from incidents, Artificial intelligence, OSHA database, ARIA database

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INTRODUCTION

Learning from Incidents (LFI) can be defined as a structured process through which organisations examine accidents and near misses to uncover underlying causes and prevent the occurrence of similar events in the future (Lindberg et al., 2010; Lukic, 2012). LFI is widely recognised as a fundamental element of contemporary safety management, and recent approaches can benefit from diverse artificial intelligence techniques along with subject-matter expert evaluations to improve the robustness of the insights generated. This is particularly relevant in high-hazard environments, where adverse events provide critical opportunities to strengthen safety performance and organisational learning (Pasman, 2009; Stefana et al., 2024; Cocca et al., 2025). The iron and steel industry exemplifies a high-hazard environment. Its technologically advanced yet labour-intensive processes expose workers to diverse risks, including extreme heat from molten metal, heavy equipment, airborne contaminants, confined spaces, and ergonomic strain (ILO, 2005; Pickvance, 2011; Verma et al., 2014). In this setting, systematic LFI is essential to detect root causes, disseminate lessons learned, and reinforce both occupational and process safety (Cooke and Rohleder, 2006). Incident databases constitute a key resource for such learning, as they collect records describing the causes, dynamics, and consequences of adverse events that occurred in diverse occupational settings. However, transforming incident data into actionable knowledge is far from straightforward. Incident reports are typically recorded as unstructured and heterogeneous narratives, often characterised by inconsistent language, uneven detail, and multilingual content (Bene et al., 2024; Verma et al., 2023). Large Language Models (LLMs) appear to have the potential to deal effectively and efficiently with that kind of data (Zhao et al., 2023). The objective of this study is to propose a human-in-the-loop methodology supported by LLMs to extract, organise, and validate knowledge from major incident databases in the iron and steel sector. The paper is structured as follows: first, the data sources and methodological approach are described; second, the identified risk scenarios and associated preventive measures are presented; finally, the implications for occupational safety management and continuous improvement are discussed.

MATERIALS AND METHODS

To identify recurring critical scenarios from an occupational safety perspective, two public incident databases were used as primary data sources: the U.S. Occupational Safety and Health Administration (OSHA) incident database (OSHA, 2025) and the French Analysis, Research and Information on Accidents (ARIA) database (BARPI, 2025). Both databases were filtered to retain only records related to the iron and steel sector. This was done by combining Standard Industrial Classification (SIC), the North American Industry Classification System (NAICS), and the Nomenclature d'Activités Française (NAF) codes with database-specific descriptors and keywords referring to steelmaking, rolling, casting, and related activities. The extracted records were then cleaned, standardised and merged into a

single harmonised database. The harmonised database was provided to the ChatGPT-5.1 Thinking model (OpenAI, 2025). The model was prompted as follows:

You are an occupational health and safety expert. You will be given a file containing records describing injuries that occurred in the iron and steel industry. Analyse all the records included. Identify and describe the most relevant scenarios from an occupational safety perspective. To this end, assess the relevance of these scenarios based on the severity of their potential consequences and how frequently they have occurred. Do not list or describe individual cases. Base your analysis exclusively on the information contained in the file being examined.

The same LLM was then used to quantitatively characterise the identified scenarios. In particular, the prompt used in this case was:

Produce a table indicating, for each scenario, the total number of records that belong to it, the number of records with fatal cases, the number of records with non-fatal amputation cases, the number of records with non-fatal hospitalisation cases, and the number of remaining records with non-fatal cases that are neither amputations nor hospitalised. Hospitalised cases may overlap with those involving amputations. The other categories are mutually exclusive.

The table returned by the model was checked for internal consistency (e.g., total numbers and admissible overlaps) and compared with independent counts from the harmonised database. Finally, for each of the critical scenarios, risk-control measures were derived using a third LLM interaction, this time with the ChatGPT-5.1 Pro model (OpenAI, 2025), which is configured to use external knowledge in addition to the incident records. The model was prompted as follows:

For each of the critical scenarios identified, describe measures for eliminating or reducing occupational safety risks. Do not limit yourself to the content of the file; also use external sources. Prioritise legislation, technical standards from recognised standardisation bodies (e.g., ISO, CEN), and guidelines from government bodies and agencies (e.g., INAIL, OSHA, EU-OSHA), as well as relevant bodies and associations in the iron and steel sector (e.g., World Steel Association, Federacciai).

The measures proposed by the LLM were organised according to the 5 levels of the ISO 45001 hierarchy of controls (ISO, 2018): elimination or substitution of hazards (levels 1 and 2), engineering controls (level 3), administrative controls (level 4), and Personal Protective Equipment (PPE) and residual risk (level 5). Throughout this process, LLM outputs were embedded in a human-in-the-loop workflow. The definition of the critical scenarios, their quantitative characterisation and the associated sets of safety measures were reviewed by occupational safety specialists and experts from the iron and steel industry. These experts assessed the plausibility, feasibility and completeness of the scenarios and measures, checked their consistency with applicable regulations, technical standards and sectoral guidelines, and proposed additions, clarifications or reclassifications where needed. The final scenario descriptions and risk-control recommendations presented in the following section incorporate such feedback.

RESULTS AND DISCUSSION

Eight macroscopic scenarios were identified by the LLM using a harmonised database of 4,552 records describing incidents obtained by integrating the iron and steel records of OSHA and ARIA databases. The scenarios are listed in Table 1.

Table 1: Identified critical scenarios.

#	Critical Scenario
1	Heavy loads moved with cranes, forklifts and rigging
2	Presses, press brakes, shears, saws and drills (point-of-operation)
3	Rollers, rotating shafts, conveyors and strip/coil lines
4	Falls from height and elevated positions
5	Furnaces, molten metal, galvanising baths and hot fluids
6	Chemical and respiratory exposures (solvents, gases, dust, COVID-19)
7	Confined spaces, tanks and oxygen-deficient atmospheres
8	Electrical contact and other high-energy events

Table 2 characterises and analyses the critical scenarios in terms of causes and dynamics, and consequences with their severity and frequency. Refer to Table 1 for the critical scenario number (#).

Table 2: Characterisation of critical scenarios.

#	Causes and Dynamics	Consequences
1	Handling coils, plates, beams, bundles and large components with overhead cranes, hoists, coil cars and forklifts. Events: loads slip from slings or forks, stacks collapse, workers pinched between load and fixed structures. Causes: inadequate rigging practices, unstable loads, missing exclusion zones, and poor signalling	A sixth of the records, often severe: many crush injuries to legs, torso and head, multiple fractures and a substantial number of fatalities when workers are pinned or struck by large masses
2	Hands enter the point of operation of mechanical/hydraulic presses, press brakes, shears, saws, drills and small bench presses during feeding, aligning, removing jams or checking parts. Often guards, light curtains or two-hand controls are absent, bypassed or misadjusted; operators use hands instead of push-sticks or fixtures	The single most common pattern: almost half of records in incident databases involve these machines. Consequences are dominated by amputations of fingers and hands (over a thousand cases), crushing injuries and long-term disability, with occasional fatalities when larger body parts are caught
3	Workers drawn into in-running nips of rollers, coilers, threading and cut-off equipment, or caught on rotating shafts and conveyors - while threading strip, wiping with rags, clearing jams or working on moving coil cars and line components. Guards and interlocks overridden or missing; loose clothing/tools enter the nip	About 7% of the database involves some form of rotating/continuous line equipment. Consequences range from finger amputations to whole-arm entanglements and fatal crush injuries when the torso is caught between moving and fixed parts

(Continued)

Table 2: Continued.

#	Causes and Dynamics	Consequences
4	Falls from roofs, ladders, scaffolds, mezzanines, platforms, on top of loads or vehicles, and through floor/roof openings. Often there is no fall protection, inadequate anchorage, improvised access (standing on pallets, coils or pipes), deteriorated walkways or missing guardrails	About 9% of the records include falls; one of the deadliest scenarios: a large share of the fatalities is due to falls from significant height, with skull fractures, spinal injuries and multiple traumas. Non-fatal falls frequently lead to serious fractures and long absences
5	Work around melting, casting and galvanising operations: furnaces, ladles, pots, kettles, hot pipes and vessels. Typical events: molten metal splashes during pouring or when contacting moisture/ contaminants, leaks from furnaces or zinc baths, failures of plugs or tap holes, and contact with very hot surfaces or liquids	Present in a significant share of the dataset (about 7%) and extremely severe. Cases frequently involve deep burns, sometimes over large body surface areas, often with hospitalisation and not infrequently death. Even when non-fatal, these injuries cause long rehabilitation and permanent impairment
6	Exposure to acids, solvents, cleaning agents, paint vapours, dust (e.g., sandblasting, foundry dust) and process gases, as well as COVID-19, shared transport and poorly ventilated spaces. Often controls are inadequate: limited ventilation, insufficient respiratory protection, no monitoring, and long-term or repeated exposure	Just over 2% of records show chemical or respiratory involvement. Outcomes range from acute burns and respiratory distress to chronic lung disease and numerous fatal pneumonias and COVID-19 cases. Several records (COVID-19 and respiratory disease) contain mainly fatalities
7	Entry into tanks, pits, stickwater or process vessels, or work in enclosed areas (e.g., cleaning, maintenance or welding). Hazards: low oxygen, toxic atmospheres, and inert gases introduced into breathing zone. No formal confined space assessment, testing or rescue planning	Confined-space-type situations appear in 3% of records with very high lethality: loss of consciousness and death are common outcomes once a worker is exposed, and multiple fatalities are possible if rescuers enter unprotected
8	Contact with live conductors during troubleshooting, wiring or testing; arc flash during switching or working inside energised panels; and sudden releases of energy (bursting hoses, exploding motors or pressure components). Causes: work on energised systems, inadequate lockout, mistaken connections and missing barriers	This scenario appears in almost 8% of records, often with catastrophic outcomes: severe burns, cardiac arrest and fatalities in electrocution or mis-connection cases, plus traumatic injuries from flying parts when components explode under pressure

In order to quantitatively characterise the consequences of critical scenarios, in terms of frequency and severity, the percentages of incident records analysed for each of the scenarios are shown in Table 3. For each scenario, the percentages of fatal cases, non-fatal cases with the amputation of body parts, non-fatal cases with hospitalisation of the injured person(s), and remaining cases are also reported. Percentages for amputations and hospitalisations can overlap, so they

do not sum to 100. Refer to Table 1 for the scenario number (#) Table 4 lists the actionable controls for each scenario, including safety measures and good management practices structured according to the ISO 45001 hierarchy of controls.

Table 3: Critical scenarios: severity and frequency.

#	Records (% of Dataset)	Fatalities (% of Scenario)	Amputations (% of Scenario)	Hospitalisations (% of Scenario)	Other Non-Fatal Cases (% of Scenario)
1	13.1	29.6	19.9	41.1	20.1
2	52.4	17.6	48.9	47.5	13.2
3	8.6	10.3	56.7	50.8	13.1
4	10.4	31.4	10.9	41.7	21.9
5	7.5	22.6	13.2	44.7	27.9
6	2.8	25.2	3.9	40.2	33.1
7	2.4	51.8	0.0	16.4	31.8
8	2.8	27.8	22.2	38.9	27.0

The results shown in Table 3 highlight a marked imbalance between frequency and severity across scenarios. Scenario #2 (point-of-operation machinery) accounts for more than half of the database (52.4%) and concentrates on disabling outcomes, with high shares of amputations (48.9%) and hospitalisations (47.5%). Although less frequent, scenario #3 (rotating/continuous line equipment; 8.6%) shows even higher levels of amputations (56.7%) and hospitalisations (50.8%). Conversely, scenario #7 (confined spaces) is rare (2.4%), but exhibits the highest lethality (51.8%), pointing to a "high-consequence" risk profile. Priority setting should therefore integrate both exposure and severity, noting that amputation and hospitalisation categories may overlap.

In terms of safety measures, Table 4 converges on a strategy aligned with the hierarchy of controls proposed by ISO 45001: (i) elimination/redesign and automation to minimise direct worker–equipment interactions (e.g., automatic coil/bundle handling, automated feeding/ejection, redesigned threading and jam management); (ii) engineering controls to physically prevent access to danger zones and manage hazardous energy (fixed/interlocked guarding, presence-sensing devices and two-hand controls, reliable emergency stops, segregation of routes and exclusion zones, ventilation and continuous monitoring for chemicals and gases); (iii) organisational/procedural measures to manage non-routine tasks and maintenance (lifting plans, pedestrian–vehicle separation, task-based risk assessments, lockout/tagout, and permit-to-work systems with defined roles and rescue arrangements for confined spaces); and (iv) PPE for residual risk, including fall-arrest with documented rescue planning, molten-metal/heat protection, fit-tested respiratory protection, and arc-flash-rated PPE where electrical exposure remains.

Table 4: Safety measures and good management practices.

#	Elimination and Substitution of Hazards	Engineering Controls	Administrative Controls	PPE and Residual Risks
1	• Automate charging and transfers; avoid workers near suspended loads • Use automatic coil/bundle handling; eliminate manual slinging • Design loads with built-in lifting points and plan routes	• Segregate crane/vehicle routes; barriers and marked exclusion zones • Crane/forklift safety features: overload limits, indicators, cameras, emergency brakes, magnet status & backup power • Engineered storage (saddles, spacers, anti-roll) to prevent collapse	• Written lifting plans for complex/unusual lifts; define route and exclusion zones • Train/authorise operators, riggers and signallers; routine pre-use inspections and tagging of gear • Strict rules: no one under suspended loads; pedestrian–vehicle separations	• Safety helmet, high-visibility clothing, safety footwear (toe/metatarsal) • Cut-resistant/dexterous gloves for slings, bands and sharp edges
2	• Automate feeding/ejection (feeders, roller feeds, ejectors) to keep hands away • Reduce manual set-ups (batch work, pre-assembled kits) and use alternative processes where possible (e.g., laser cutting)	• Fixed/interlocked guards at point of operation; enclosed shear/saw areas • Presence-sensing devices for manual feed; two-hand controls and anti-repeat devices • Reliable emergency stops and safe electrical/mechanical stopping functions	• Task-based risk assessments for setup, adjustment, cleaning and maintenance with safe modes (reduced speed/inching) • Lockout/tagout for jams, tool changes and cleaning; remove stored energy • Train and routinely test guarding, sensors and emergency stops	• Eye/face protection; hearing protection where noise is high • Gloves for handling cut metal - select carefully near rotating parts to avoid entanglement
3	• Redesign threading with automatic devices or controlled slow-speed modes • Redesign conveyors to reduce jams; use automatic roll/roller cleaning instead of manual cleaning	• Guard all in-running nips; use distance/barriers to keep body parts out of reach • Pull-cord emergency stops along conveyors; fenced/interlocked zones for coilers/uncoilers • Fully guard drive shafts/couplings; remove snag points	• No access to moving parts except in designed safe modes; apply lockout/tagout and blocking • Written procedures for threading/tailing out (positions, tools, speed, accessible e-stops) • Training and supervision to prevent bypassing guards and unsafe shortcuts	• Control loose clothing, jewellery and long hair in rotating-equipment areas • Eye/respiratory protection for dust and fumes; hearing protection in rolling areas

(Continued)

Table 4: Continued.

#	Elimination and Substitution of Hazards	Engineering Controls	Administrative Controls	PPE and Residual Risks
4	• Use remote inspections at height (cameras, drones, sensors) and relocate routine maintenance points to safer levels • Install fixed platforms or automation to avoid climbing on products/vehicles	• Permanent stairs/platforms with guardrails, toe boards and anti-slip surfaces • Edge protection on roofs; mark fragile surfaces (e.g., skylights) • Anchorage points/lifelines where guardrails are not feasible; inspect and secure scaffolds/MEWPs	• Permit-to-work for high-risk work at height; plan method and rescue before starting • Rules on ladder use; choose safer access equipment when needed • Train on unstable surfaces; maintain good housekeeping to prevent trips and slips	• Competent use of fall-arrest/restraint systems (harness, lanyard/devices) with adequate fall clearance • Documented rescue plans and drills for prompt recovery of a suspended worker
5	• Keep wet/contaminated scrap out of furnaces (dry storage, drying/preheating, supplier rules) • Select layouts/equipment that reduce consequences of leaks/breakouts (containment, diversion channels, breakout detection)	• Operate from protected pulpits/ control rooms • Shields/barriers near tapping and casting; multiple clear escape routes • Reliable combustion controls (burners, flame monitoring); guarding to prevent falls into hot baths	• Written operating instructions, training and drills for tapping, additions and slag handling • Permits for maintenance (cooling time, isolation, residual-heat controls) • Train to recognise warning signs; treat and investigate near misses as high priority	• Heat- and molten-metal-resistant PPE: helmet/face shield, neck protection, gloves, leggings and suitable footwear • Wear PPE correctly and dry; manage heat stress (rest areas, hydration, task rotation)
6	• Substitute less hazardous chemicals or use mechanical methods where feasible • Move high-exposure processes to dedicated controlled areas; reduce dust/fume generation via process improvements	• Local exhaust ventilation at key sources (pickling, blasting, cutting, tapping/casting) • Enclose acid/degreasing/paint operations with air extraction • General ventilation and continuous gas monitoring	• Maintain chemical inventories and communicate hazards and handling requirements • Conduct exposure assessments and prioritise improvements; train workers on mixing/transfer/ storage and hazard labels	• Respiratory protection matched to contaminant; fit testing and user training • Chemical-resistant gloves/ aprons and eye/ face protection for liquid chemicals

(Continued)

Table 4: Continued.

#	Elimination and Substitution of Hazards	Engineering Controls	Administrative Controls	PPE and Residual Risks
7	• Design out entry: external cleaning access, removable parts and drains for "no-entry" maintenance • Use cameras/robots for inspections; prefer open-top/surface-mounted designs where possible	• Positive isolation of plant connections to avoid gas leaks • Atmosphere testing (O_2, flammables, toxics) before entry and continuous monitoring; forced ventilation • Prevent inert-gas hazards by design (no misconnection to breathing air; avoid accumulation)	• Identify and classify confined spaces; permit-to-work specifying tests, ventilation, occupancy, communications and rescue • Define entrant/attendant/supervisor roles; attendants do not enter for rescue without proper protection • Provide rescue equipment and conduct drills in representative spaces	• Respiratory PPE as required (filtering to supplied air/SCBA), based on oxygen/toxic risks • Harness and lifelines for non-entry rescue; safe lighting/tools (low voltage/ intrinsically safe where needed)
8	• Design for remote switching/diagnostics and adequate clearance to minimise exposure to live parts • Design high-pressure systems to reduce uncontrolled releases; automate/monitor remotely to reduce manual interventions	• Enclosed/interlocked electrical equipment with clear labelling; coordinated protection (breakers/fuses/relays) to clear faults quickly • Pressure relief devices (PRVs, bursting discs) and robust supports to contain overpressure events • Guard rotating/high-energy components that could fail violently; inspection regimes for stressed parts	• Hazardous energy control programme (lockout/tagout) covering electrical, mechanical, hydraulic, pneumatic and thermal energy • Rules for de-energised wo¸rk and verification; controlled authorisation for exceptional live work • Competence/training for electrical workers; written procedures for pre-/de-pressurising and maintenance; investigate high-energy near misses	• Arc-flash-rated clothing plus face/hand protection and insulated tools where exposure remains

CONCLUSION

This study presented a human-in-the-loop, LLM-assisted methodology to support LFI in the iron and steel industry through the structured analysis of two international incident databases. The findings show that LLM-assisted analysis can effectively and efficiently translate narrative data into actionable, technically grounded recommendations. However, embedding LLM outputs within a structured human expert validation process is essential to ensure contextual relevance, regulatory consistency, and practical feasibility, mitigating the limitations associated with purely automated analyses. The proposed approach can support hazard identification, evidence-based risk assessment, and continuous safety improvement in high-risk industrial environments. Future research should explore scalability to other industrial sectors and the possible integration with real-time safety reporting systems.

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