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Potentially fatal incidents: identification, classification and human factor analysis

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Introduction. Potentially fatal incidents (PFIs) are increasingly used as leading indicators in high-risk industries, yet their definitions, classification criteria, and investigative depth vary widely across organisations, limiting. their preventive value and comparability. Human factors (HF) play a critical role in determining whether incidents escalate into PFIs and must be considered together with technical and organisational barrier performance. This research aims to examine the role of human and organisational factors in PFI identification, analyse misclassification patterns, and propose a human-factors-based model to improve PFI classification consistency and learning value. A retrospective document analysis was conducted using incident reports from a heavy-industry organisation covering the period from 2020 to 2024. The dataset was systematically reviewed and PFI classifications were re-evaluated using a structured framework integrating hazardous energy and exposure assessment, barrier performance evaluation based on Bow-Tie logic, and human and organisational factor coding using an HFACS-based structure. Analysis revealed inconsistency in PFI classification, including overclassification and under-classification linked to limited recognition of human and organisational factors. Number of incidents were labelled as PFIs despite lacking credible fatal energy exposure, while other events with systemic and human-factor contributors associated with fatal risk were not recognised as PFIs. The HF-PFI Model demonstrated improved classification reliability by integrating energy exposure, barrier status, human factor categories, and systemic indicators. Integrating human-factors analysis into PFI identification can strengthen serious injury and fatality prevention in high-risk industrial environments.

Key words: potentially fatal incidents, human factors, accident investigation, safety culture, heavy industry, systemic safety, risk assessment.

INTRODUCTION

Historically, manufacturing has functioned as the main engine of economic growth and development (Szirmai & Verspagen, 2015). Within the European Union, industrial production continues to contribute substantially to economic output, reflecting sustained growth and supporting competitiveness at the national and regional level (Eurostat, 2026). At the same time, industry continues to be associated with higher occupational risk. According to Eurostat data, 3,298 fatal occupational accidents were recorded in the EU in 2023, moreover, data reveal that the number of fatal workplace accidents has remained broadly stable over the period from 2018 to 2023, with only minor annual fluctuations (Eurostat, 2025). Although organisations and regulators have introduced numerous preventive measures, including technological controls, safety management systems, training programmes, and regulatory enforcement, these efforts have not led to a substantial reduction in occupational fatalities (Fa et al., 2021).

Across the Atlantic, safety professionals are increasingly adopting risk focused and system-based approaches to safety analysis. In this perspective, severity of an injury depends on circumstances, while potential for a fatal outcome is a property of the work system itself. As a result, prevention efforts increasingly focus on the identification and analysis of PFIs - events in which a fatal outcome was realistically possible, regardless of the actual injury sustained (ISN, 2025; NSC, 2024). Research shows that fatal accidents and minor injuries are driven by fundamentally different contributing factors (Manuele, 2014; Zhang et al., 2025), and that traditional safety management approaches are insufficient for addressing serious injuries and fatalities (Cooper, 2019; Busch et al., 2021; Bayona et al., 2024).

Moreover, contemporary risk-reduction research in occupational safety and ergonomics emphasise the need to shift from outcome-based measurement toward analytical approaches that identify and reduce systemic risk (Jensen & Gilkey, 2023).

Consistent with this, industry guidance indicates that the early warning signs of serious injuries and fatalities differ from those associated with minor accidents, supporting the use of PFIs as leading indicators (Interstate Natural Gas Association of America, 2021; Campbell Institute, 2024; Edison Electric Institute, 2024).

Despite their value, PFIs remain difficult to identify and classify consistently in practice. Variability in definitions, reliance on simplified severity-based criteria, and limited integration of human and organisational factors frequently lead to misclassification (Manuele, 2014; Cooper, 2019; Naghavi et al., 2019; Bayona et al., 2024). As a result, some events are labelled as PFIs despite lacking credible fatal potential, while others, involving substantial fatal risk, remain classified as minor accidents or near misses. This weakens the reliability of PFIs as leading indicators and reduces their value for organisational learning and prevention (Busch et al., 2021; Campbell Institute, 2024).

Misclassification is particularly problematic in complex, high-hazard industrial environments, where fatal outcomes typically result from the interaction of human performance, organisational conditions, and barrier degradation rather than from a single failure (Aliabadi et al., 2018; Naghavi et al., 2019). In such contexts, organisations may continue investing in controls that reduce minor injury frequency while leaving systemic fatal risk insufficiently addressed. Prior research has shown that unstructured expert judgment can produce inconsistent assessments of fatal potential even among experienced practitioners (Alexander et al., 2017), emphasizing the need for structured, evidence-based PFI classification approaches.

The aim of this study is to examine how human and organisational factors influence the identification and classification of PFIs in industrial incident investigations and to develop a HF-based analytical framework to improve classification consistency. Therefore, the following research questions were stated:

1. What human and organisational factors influence identification and classification of PFIs in industrial incident investigations?

2. How can these factors be systematically integrated into an analytical framework to improve PFI classification consistency?

METHODS

To address the research questions, this study adopts a retrospective, document-based analytical approach applied to industrial incident investigation reports. To achieve the aim and answer first question, full obtained incident dataset was systematically reviewed to examine how human and organisational factors are reflected in PFI identification and classification decisions. To address second question, these factors were integrated into a structured human-factors-based analytical framework designed to support more consistent PFI classification. The following sections describe the study design, data sources, and development of the analytical framework.

The design was selected to enable systematic re-evaluation of incident classification decisions and to examine how PFIs are identified and interpreted within organisational investigation practice, particularly for studying low-frequency, high-consequence events such as serious injuries and fatalities. Qualitative analysis was used to identify human, organisational, and contextual factors described in investigation reports, while quantitative elements were applied to assess classification outcomes, misclassification frequencies, and patterns.

The dataset consisted of 62 formally reported workplace incident investigation reports recorded workplace incidents recorded in a single heavy-industry organisation operating in high-hazard industrial environments between 2020 and 2024 was selected to capture recent incident investigation practices within the organisation and to ensure consistency with the current reporting procedures used in the digital incident management system.

Incidents were extracted from the organisation's digital incident reporting and investigation system, which is used across operational sites to document occupational safety related incidents. The dataset included incident descriptions, investigation narratives, initial severity classifications, assigned root causes, identified contributing factors, and documented corrective actions.

The final dataset consisted total of 62 incident investigation reports that contained sufficient information regarding the incident circumstances, exposure conditions, and investigation findings to allow re-evaluation using the HF-PFI framework. Reports lacking sufficient detail regarding exposure conditions or barrier performance were excluded from the analytical phase.

To ensure coverage, no pre-filtering was applied based on original incident severity or classification. This allowed the analysis to capture both events initially classified as PFIs and those recorded as minor accidents or near misses but potentially involving exposure to fatal risk. As the analysis relied on documented investigation reports, the assessment was limited to the information recorded within the reports, and no additional incident reconstruction or external data sources were used. All data were anonymised prior to analysis, and no personal identifiers were retained neither initially stored in the system. Access to the dataset was granted for research purposes, and data handling complied with organisational confidentiality requirements and institutional ethical guidelines for document-based research. The HF-PFI reclassification analysis was conducted by the author using the structured analytical framework described in this study.

The HF-PFI analytical framework was developed by integrating evidence from scientific sources with empirically grounded industry practices, with the aim of strengthening the consistency and practical applicability of PFI identification and classification. Framework was structured around three identified analytical dimensions, followed by an integrated determination of fatal potential.

Energy and exposure assessment, to determine the presence of fatal potential. It evaluated whether incident involved hazardous energy sources, such as mechanical, gravitational, electrical, chemical, or thermal energy, and the extent of worker exposure. The analysis focused on whether a fatal outcome would have been possible under slightly altered circumstances, independent of the actual injury sustained. Exposure severity, proximity, duration, and the presence or absence of physical separation from energy sources were considered.

Barrier performance evaluation, applying Bow-Tie logic, which conceptualises accident development as a progression from hazards to consequences mediated by preventive and mitigative barriers (de Ruijter & Guldenmund, 2016), to distinguish between preventive and corrective controls; For each incident, barriers were classified as effective, degraded, bypassed, absent, or not applicable at the time of the event. Particular attention was given to barriers influenced by human action, including procedural compliance, supervision, permit systems, and situational decision-making.

Human and organisational factor analysis, using structured classification based on the Human Factors Analysis and Classification System (HFACS), which has been widely applied in high-hazard industries, including mining and heavy industry, to identify systemic contributors to accidents and near misses (Reason, 1990; Patterson & Shappell, 2010; Fa et al., 2021), to capture individual, team, supervisory, and organisational influences. Factors were analysed across multiple levels, including unsafe acts (e.g., decision errors, skill-based errors, perceptual errors), preconditions for unsafe acts (e.g., cognitive workload, communication failures, environmental conditions), supervisory factors (e.g., inadequate supervision, inappropriate planning, failure to correct known problems), and organisational influences (e.g., resource management, operational processes, and safety culture).

Then, these three dimensions were applied in combination for each incident to enable assessment of fatal potential and to support consistent differentiation between PFIs and non-PFI events. The application process followed sequential procedure. First, all incidents were screened using the energy and exposure assessment to determine the presence of credible fatal potential, independent of the actual injury outcome. Incidents that did not involve hazardous energy or credible exposure scenarios were excluded from further PFI analysis and classified as non-PFI events.

For incidents meeting the fatal potential criteria, barrier performance evaluation was conducted using Bow-Tie logic. Subsequently, human and organisational factors were analysed using an HFACS-based classification. Where discrepancies were identified between the original organisational classification and the HF-PFI assessment, incidents were categorised as over-classified PFIs or under-classified PFIs.

Reclassification outcomes were compared with the original organisational classification assigned at the time of investigation. Incidents were categorised as:

- correctly classified PFIs,
- over-classified PFIs (labelled as PFIs despite lacking credible fatal potential),
- under-classified PFIs (not labelled as PFIs despite credible fatal potential).

RESULTS

Determinants of fatal risk identified from safety science literature and industry practice

Focused review of safety science literature and industry-led guidance documents identified a set of determinants associated with fatal risk escalation, independent of realised injury severity. Across both academic and practice-oriented sources, fatal outcomes were not explained by isolated unsafe acts or single technical failures, but by the interaction of hazardous energy, exposure conditions, barrier performance, and human-organisational context.

Safety science literature consistently distinguishes fatal accidents from minor injury events, emphasising that severity outcomes are not linearly related to accident frequency or injury rates. Seminal research highlights that fatalities and serious injuries are driven by different combinations of exposure, system conditions, and barrier failures, rather than by an accumulation of minor unsafe acts alone (Manuele, 2014; Cooper, 2019; Bayona et al., 2024).

A central factor repeatedly identified in the literature is the presence and uncontrolled release of hazardous energy. Studies across industry demonstrate that fatal risk is closely associated with exposure to high-energy sources, such as gravitational, mechanical, electrical, chemical, or thermal energy, combined with insufficient separation between workers and the hazard (Manuele, 2014; Alexander, 2017; Cooper, 2019; Erkal, 2021; Bayona et al., 2024). The literature emphasises that fatal potential exists even when no injury occurs, provided that energy transfer was fatal under slightly altered conditions.

Another dominant theme is barrier performance and integrity. Systems safety research shows that fatal accidents typically emerge from multiple barrier failures, including degraded, bypassed, or absent controls, rather than from the absence of controls alone (Reason, 1990; Hollnagel, 2014; Manuele, 2014). Importantly, barriers are frequently human-dependent, relying on correct procedural execution, supervision, or decision-making.

Industry-led safety guidance closely aligns with findings from safety science literature, transferring these principles into practical classification frameworks. A consistent message across industry sources is that injury severity is a circumstantial outcome, whereas fatal potential can be assessed more reliably by examining energy exposure and barrier status. PFIs are defined in industry practice as events in which a fatal outcome was realistically possible, regardless of whether injury occurred. Industry documents further stress that misclassification of PFIs commonly arises when investigations rely on outcome severity or intuition, rather than structured assessment of fatal potential. Several guidance models explicitly warn that events without injury are frequently under-classified, while incidents with visible consequences may be over-classified despite lacking credible fatal energy. Notably, industry sources increasingly recognise the role of organisational context, including production pressure, informal work practices, and normalised deviations, as contributors to fatal risk. (Busch et al., 2021; Interstate Natural Gas Association of America, 2021; Erkal et al., 2021; Edison Electric Institute, 2024; Campbell Institute, 2024, ISN, 2025).

Then, findings from identified across safety science literature and industry practice, were translated into a structured a structure of HF-PFI classification matrix, consistent with research showing that risk assessment tools must balance analytical rigor with practical clarity to support reliable decision-making in operational contexts (Jensen & Gilkey, 2023). Table 1 illustrates how identified factors are embedded within HF-PFI analytical framework.

Table 1. HF-PFI classification matrix

Analytical dimension	Assessment criteria	Indicator	Implication for fatal potential
1. Hazardous Energy & Exposure	Presence of energy sources with credible fatal capacity (e.g. gravitational, mechanical, electrical, chemical, thermal) and degree of worker exposure	• High-energy source present / absent • Direct, indirect, or no exposure	Fatal potential exists when uncontrolled energy release could plausibly result in death under slightly altered conditions
2. Barrier Performance (Bow-Tie Logic)	Effectiveness of preventive and mitigative barriers at the time of the incident	• Effective • Degraded • Bypassed • Absent	Fatal potential increases with degraded, bypassed, or absent barriers, particularly where barriers are human-dependent
3. Human & Organisational Factors (HFACS-based)	Human and organisational contributors influencing exposure or barrier performance	• Unsafe acts (decision or skill-based errors) • Preconditions (fatigue, workload, communication) • Organisational influences (supervision, resources, safety climate)	Presence of HF factors indicates increased likelihood of escalation and reduced barrier reliability
Integrated HF-PFI Determination	Combined evaluation of all four dimensions	• Credible fatal potential present • Credible fatal potential absent	PFI when credible fatal potential is present, regardless of injury outcome

PFI misclassification identified using HF-PFI matrix

Application of the HF-PFI classification matrix to the dataset of 62 incident investigation reports revealed substantial inconsistencies between original organisational classifications and matrix-based determinations of credible fatal potential. Each case was re-evaluated through assessment of hazardous energy and exposure severity, preventive and mitigative barrier performance, human and organisational factors. Reclassification decisions were based on whether a fatal outcome would have been realistically possible under slightly altered circumstances, independent of the injury outcome that actually occurred, in line with the analytical procedure described within this article.

Of the 62 analysed cases, 39 incidents (63%) were identified as misclassified when compared with the HF-PFI determination. Among these, 25 incidents (40%) were classified as under-classified PFIs, having been originally recorded as minor accidents or near misses despite involving credible fatal potential. In contrast, 14 incidents (23%) were identified as over-classified PFIs, where events were labelled as PFIs despite lacking sufficient hazardous energy exposure or escalation when assessed using the matrix. The remaining 23 incidents (37%) were consistently classified under both the original organisational system and the HF-PFI framework.

Under-classification occurred nearly twice as frequently as over-classification, indicating a tendency to under-recognise fatal potential in events without severe or visible injury consequences. These findings demonstrate that current PFI identification practices do not consistently reflect fatal-risk factors, which aligns with HFACS applications in other high-risk industries, where organisational and supervisory factors were found to play a dominant role in high-consequence events rather than isolated operator error (Theophilus et al., 2017; Yildiz et al., 2021).

HFACS associated with PFI misclassification

Further analysis of the 39 misclassified incidents revealed clear patterns in the presence and treatment of human and organisational factors during investigation and classification. Under-classified PFIs were associated with human and organisational contributors that were documented descriptively but not operationalised in classification decisions.

Table 2. HFACS-based human and organisational factors identified in under-classified PFIs

HFACS level	HFACS category	Description (Contextualised for PFI analysis)	Number of cases (n)	% of under-classified PFIs
Level 1: Unsafe acts	Decision errors	Risky or suboptimal decisions under time pressure or incomplete information	10	40%
	Skill-based errors	Slips, lapses, or execution errors during routine tasks	6	24%
	Total unsafe acts	At least one unsafe act identified	16	64%
Level 2: Preconditions for unsafe acts	Workload / time pressure	High task demand, production urgency, or staffing constraints	12	48%
	Communication breakdowns	Incomplete, unclear, or absent communication	9	36%
	Fatigue / attention limitations	Reduced alertness or cognitive capacity	5	20%
	Total preconditions	At least one precondition identified	18	72%
Level 3: Organisational influences	Inadequate supervision	Insufficient oversight, coordination, or enforcement	8	32%
	Work planning deficiencies	Inadequate task planning or sequencing	6	24%
	Resource constraints	Insufficient time, personnel, or equipment	5	20%
	Total organisational influences	At least one organisational factor identified	14	56%

Among the 25 under-classified PFIs, unsafe acts were identified in 16 cases (64%), most commonly involving decision errors under time pressure or skill-based execution errors during routine tasks. Preconditions for unsafe acts, including workload, production pressure, communication breakdowns, and fatigue, were identified in 18 cases (72%), while organisational influences, such as inadequate supervision, deficient work planning, and resource constraints, were evident in 14 cases (56%). Because multiple human and organisational factors could be present within a single incident, one case could contribute to more than one HFACS category and level. Table 2 shows the distribution of HFACS levels identified in under-classified PFIs. Although these factors were often mentioned descriptively in investigation reports, they were rarely linked to fatal-risk escalation in the original PFI classification.

In contrast, over-classified PFIs showed substantially lower prevalence of HFACS-coded contributors, with unsafe acts identified in 4 cases (29%) and organisational influences in 3 cases (21%), suggesting that classification decisions in these cases were driven primarily by injury visibility or perceived severity rather than systemic risk assessment.

The findings are consistent with empirical evidence from construction safety research showing that predictors of serious injuries and fatalities differ substantially from those associated with minor injury outcomes.

DISCUSSION

This study examined how human and organisational factors influence the identification and classification of PFIs and developed a structured HF-PFI framework to improve classification consistency. The results demonstrate that PFI misclassification is substantial in industrial incident investigations and is not random; rather, it reflects systematic reliance on severity and inconsistent integration of fatal-risk determinants into classification decisions. Across 62 analysed incident reports, nearly two-thirds were classified differently when evaluated against the HF-PFI criteria, with under-classification occurring more frequently than over-classification. This indicates that fatal potential is most missed in events with minor or absent injury consequences, supporting the argument that realised severity does not reliably reflect escalation potential.

The findings extend both safety science and industry practice perspectives by showing that PFIs can be operationalised more consistently when classification explicitly integrates hazardous energy and exposure, barrier performance, and HFACS-based human and organisational contributors. In this sense, HF-PFI matrix does not introduce completely new approach, but it advances an applied contribution.

Key empirical outcome of the study is predominance of under-classification relative to over-classification. This aligns with existing near miss definition in high-hazard work: near misses with low injury consequence are often treated as low severity events, even when the hazard exposure and barrier state indicate credible fatal potential. When injury is minor or absent, investigators may downgrade event significance, even where exposure conditions and barrier integrity indicate clear possibility of the fatal outcome. Contrary, visible injury consequences trigger classification as a PFI. The study's findings support the need to treat fatal potential as a system property.

HFACS-based results show that human and organisational factors were common in under-classified PFIs, with preconditions and organisational influences occurring at high levels. Importantly, these factors were frequently documented descriptively, but were rarely linked to fatal-risk escalation, which may indicate that presence of human and organisational contributors in investigations does not automatically translate into escalation. In practice, incident investigations may record workload, communication issues, supervision, or planning weaknesses as contextual information without using these elements analytically. HF-PFI framework addresses this gap by placing HFACS categories within a classification that connects human and organisational factors to barrier performance and exposure conditions.

Barrier performance emerged as a central factor between under- and over-classified cases. Under-classified PFIs were characterised by degraded, bypassed, or human-dependent preventive controls and frequent procedure–practice gaps. Human and organisational factors affect barrier integrity, and barrier integrity determines whether high-energy exposure can escalate into a fatal event. Procedure vs. practice gaps, informal workarounds, and production-driven deviations were frequently present in under-classified PFIs but seldom framed as escalation factors in original investigations.

From a broader risk science perspective, these findings align with recent work on risk assessment in modern industry, which emphasises that high-consequence events emerge from complex interactions between technical systems, human performance, and organisational conditions rather than from isolated component failures (Pinciroli et al., 2026). The results, therefore, have direct implications for organisations using PFIs as leading indicators. First, realised injury severity should be separated from fatal potential in PFIs. Classification guidance and investigator training should emphasise that events with no injury may still represent high fatal risk if energy exposure and barrier degradation are present. Second, structured barrier evaluation should be embedded into classification decisions, ensuring that both preventive and mitigative controls are assessed and that human-dependent barriers are clearly identified. Third, investigation systems should require consistent documentation of HFACS-relevant factors to ensure these elements are linked to escalation thinking rather than recorded as background or supporting information.

From theoretical perspective, the findings support the growing critique that frequency-based indicators are insufficient for fatality prevention, as they do not capture the mechanisms through which low-probability, high-consequence events develop. Traditional indicators, such as injury rates or accident frequencies, are outcome-focused and therefore poorly suited to identifying hidden escalation that only become visible when specific technical, human, and organisational conditions align.

This study has limitations that should be considered when interpreting the findings. First, the analysis is based on incident reports from a single heavy-industry organisation, which may limit transferability to other sectors or organisational contexts. Second, the study relies on the quality and completeness of investigation documentation. Therefore, future work should validate the model through multi-organisation testing, and cross-industry comparison.

Future research should evaluate whether integrating HF-PFI matrix into investigation systems leads to measurable improvements in classification consistency over time and whether reclassified PFIs correlate with independent indicators of serious risk exposure.

CONCLUSIONS

This study examined how human and organisational factors influence identification and classification of PFIs in industrial incident investigations and developed a structured human-factors-based analytical framework to improve classification consistency and preventive value. The findings demonstrate that PFI misclassification is widespread and systematic rather than incidental, with under-classification occurring substantially more often than over-classification. This indicates a tendency within organisational investigation practice to interpret low or absent injury severity as evidence of low fatal risk, even when conditions indicate credible escalation potential. As a result, opportunities for organisational learning are reduced, and preventive actions are less likely to target the system conditions that contribute to fatal risk escalation.

HF-PFI classification matrix addresses this gap by operationalising fatal-risk factors identified in safety science literature and industry practice into an applicable structure. Rather than introducing new concepts, the framework integrates established elements of energy and exposure assessment, Bow-Tie based barrier evaluation, and HFACS-informed human factor analysis into single classification system. Application of the matrix demonstrated improved classification consistency, and enhanced differentiation between events with and without credible fatal potential.

From a practical perspective, the findings highlight the need for organisations to separate realised injury severity from actual fatal potential. Integrating structured barrier evaluation and human-factor analysis into classification decisions can improve learning quality and improve prevention of occupational fatalities.

Moreover, organisations can embed the HF-PFI framework into existing incident investigation and reporting systems by incorporating structured assessment of hazardous energy exposure, barrier performance, and human and organisational factors into investigation checklists and classification procedures, wich can support more consistent identification of credible fatal potential and strengthen organisational learning from incidents.

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