A Systemic Evaluation and Preventive Framework for the Assessment of Human Factors in Workplace Accidents

[1]Baskaran T, [2]Suresh B, [3]Govindarasu R, [4]Ganesh B
[1]Research Scholar, Department of Chemical Engineering Annmalai University, Annamalainagar, India
[2]Professor, Department of Chemical Engineering Annmalai University, Annamalainagar, India
[3]Professor and Head, Department of Chemical Engineering Annmalai University, Annamalainagar, India
[4]Asst.Professor, Department of Chemical Engineering Annmalai University, Annamalainagar, India
doi.org/10.64643/JATIRV2I6-140539

***Abstract*—Globally, there is still an issue with occupational accidents, which causes severe suffering and financial losses. Modern safety science sees these incidents as systemic failures, even though earlier accident investigations frequently identified human mistake as the reason. The basic mechanisms of workplace accidents are investigated using the Human Factors Analysis and Classification System (HFACS) paradigm. The study demonstrates that visible dangerous activities can be linked to latent organizational vulnerabilities through an accident causation process by analysing a representative dataset of 150 industrial events from the manufacturing and construction industries. The results indicate that latent preconditions are the main cause of active operational failures, such as skill-based errors (29.0%) and routine violations (53.1%). The technology environment (37.3%) and inadequate supervision (34.6%) are the two biggest problems. The paper's mapping of interdependencies suggests that minimizing active worker errors requires systemic action. A thorough approach to safety precautions is suggested, with a focus on developing a proactive organizational safety culture, implementing continuous supervisory feedback loops, and designing ergonomic equipment. In the final analysis, this study shifts the safety paradigm from individual fault-finding to systemic resilience, offering practical insights for safety professionals and industrial stakeholders to minimize occupational hazards.**

***Index Terms*—Accident Causation, Human Factors, Human Error, HFACS Framework, Occupational Health and Safety, Safety Culture, Systemic Failure.**

I. INTRODUCTION

From the early emphasis on machine guarding to the current use of integrated management systems, occupational safety has evolved. Workplace accidents continue to occur at a startling pace across the globe despite the implementation of cutting-edge safety measures and stringent adherence to international rules. Conventional investigations often concluded with the finding that "human error" was at fault, thereby concluding in assigning blame to the operator of the frontline. According to modern safety science, human mistake is a symptom of deeper organizational flaws rather than the direct cause of an accident. By examining how people interact with their tools, the workplace, and the overall organizational structure, human factors engineering is committed to resolving these problems. This research employs HFACS to analyse the complex dynamics of accident causation using the Swiss Cheese Model. The study focuses on how environmental preconditions and supervisory levels spread latent organizational failures, leading to active frontline failure.

Investigating bodies are unable to map the overlapped defenses and identify the path to the downstream active error due to the lack of a clear, structured taxonomy. To bridge this operational gap, Shappell and Wiegmann created the HFACS system, which provides standardized hierarchical classification for diagnostic incidents. This framework may distinguish between underlying systemic defects in industrial disaster and active frontline anomalies by breaking down measurable components. In this study, 150 representative datasets of manufacturing and construction mishaps are used to analyze complex dynamics in an industrial setting utilizing the HFACS framework. This study offers a thorough review of accidents and an empirical foundation for designing systemic preventative measures by investigating the influence of latent organizational failures on human behaviors through supervisory levels.

1.1 Problem Statement

Many sectors continue to use a "person-centric" approach to event analysis despite the notion that accidents are multifaceted. This is incoherent. In this perspective, latent circumstances, uncomfortable equipment procurement, unrealistic production schedules and timelines, and a lack of supervisory enforcement are overlooked in favour of immediate active failures (such as a worker failing to wear safety gear). This reactive strategy leads to recurring incidents. Industrial facilities are unable to create effective preventative measures because they do not have a good knowledge of how organizational policies and supervisory actions affect frontline behavior. Therefore, in order to develop effective systemic safety barriers, it is imperative to effectively map and understand the various human elements that lead to workplace accidents.

1.2 Objectives

The human elements that lead to workplace accidents are systematically categorized using the HFACS framework. The main objectives of this research are:

1. To calculate the frequency of latent failure or failures and active failures (unsafe activities) in a historical dataset of occurrences.
2. To determine the connection between underlying organizational problems and active errors or breaches at the frontline
3. To create evidence-based preventive measures that prioritize systemic causes over symptoms.

1.3 Scope of Study

The study focuses on organizational and human factors that lead to workplace accidents in manufacturing and construction. After a five-year tracking period, an empirical study is conducted using a standardized dataset of 150 historical accident investigation reports. All other human-caused force majeure events, such as catastrophic natural disasters or avoidable power grid collapses, are not included and are restricted to the four highest tiers of the normal HFACS framework.

II. LITERATURE

Heinrich (1931) presented the "Domino Theory" as a fundamental theory of safety, asserting that dangerous people were responsible for 88% of workplace mishaps. Despite being at the vanguard of this strategy, safety initiatives were disproportionately focused on regulating employee behavior [4]. Reason's "Swiss Cheese Model" (1990) transformed the field by distinguishing between latent problems entrenched in the system and active failures at the frontline [11].
The Human Factors Analysis and Classification System (HFACS) was created by Shappell and Wiegmann (2001) as a means of bridging the gap between theory and empirical research. Unsafe acts, preconditions for unsafe acts, unsecure monitoring, and organizational effects are the four different levels of failure that the system identifies. Although HFACS was initially created for military aviation, it has been effectively implemented in numerous other high-risk environments [12].
Nwankwo et al. (2021) used a customized HFACS model to analyze global incidents in the oil and gas industry and found that poor contractor environments and subregional staff resource management were major causes of frontline behavior problems [9]. The methodology was also used to historical text data on construction falling incidents by Luo et al. (2022), who noted that inadequate technical settings and the lack of real-time safety inspections and approvals greatly increase cognitive and decision-making errors. These results are consistent with the earlier research [8].

According to Hulme et al. (2019), organizational restrictions are consistently the primary cause of active operational errors, which are easily recorded in common industrial engineering contexts [5]. Li and Harris (2006) showed that accident route forecasting is greatly improved by adding particular technology and physical environmental constraints to the basic HFACS framework [7]. Their findings provided more evidence for this. A hybrid HFACS model was created by Celik and

Cebi (2009) to demonstrate that inadequate organizational structure in the maritime shipping industry [2].

According to Patterson and Shappell's (2010) review of mining safety records, routine operational infractions are typically actively tolerated by direct supervisory targets in certain heavy infrastructure contexts [10]. As noted by Baysari et al. (2011) and applied to this field utilizing HFACS, operators' cognitive states are a contributing factor to poor scheduling and active misjudgments in the train business [1]. Cohen et al. (2018) discovered that when organizational training norms are not followed, personnel frequently employ high-risk heuristic techniques during live-line operations, indicating the important nature of some judgment errors. This aligns with their conclusions [3]. According to Jalali et al. (2023), who summarized the system's cross-industry utility, HFACS offers reliable guidance for sustainable preventative engineering design by transforming individual blame and structural accountability [6].

III. METHODOLOGY.

This study uses mixed techniques and retrospective analysis, with HFACS serving as the main analytical tool. The results of the investigation are shown here. The foundation of this strategy is a three-stage pipeline:

3.1. Data Gathering and Sample Selection

Corporate safety databases, which covered manufacturing facilities and civil construction projects, provided 150 comprehensive accident investigation reports. The selection of reports was based on how well they reconstructed timeline information, recorded physical evidence, and provided witness testimony.

3.2. HFACS Taxonomic Coding

Each accident report was examined by a panel of three safety experts, who then categorized it into the four hierarchical levels of the HFACS framework as identified by the researchers. These standard levels served as the foundation for the code:

1. Organizational Dynamics: Resource planning, organizational dynamics, and operational procedures.
2. Abnormal Control: Misconduct, inadequate management, deliberately inappropriate behavior, and an incapacity to deal with problems that have already been identified.
3. Unsafe acts are influenced by environmental elements, physical and technological conditions, unfavourable mental or physiological states, and personnel considerations. More research is necessary to determine the causes of this phenomena.
4. Dangerous actions: Realistic mistakes categorized as unlawful (routine, skill-based, choice, and perceptual) and illicit (routine, exceptional).

3.3. Statistical Analysis

By doing virtually unbiased analysis with Cohen's kappa (Altogether $\kappa = 0.84$) for an acceptable agreement, the goal of a high inter-rater reliability was accomplished. They computed the frequency and percentage distributions for each category code in order to identify the main causes of the examined occurrences.

IV. RESULTS ND DISCUSSION

There are far less active operational failures, according to an empirical distribution of the human factors in the dataset that exhibits a strong link with particular upstream latent failures.

4.1. Examining Risky Behavior (Active Failures)

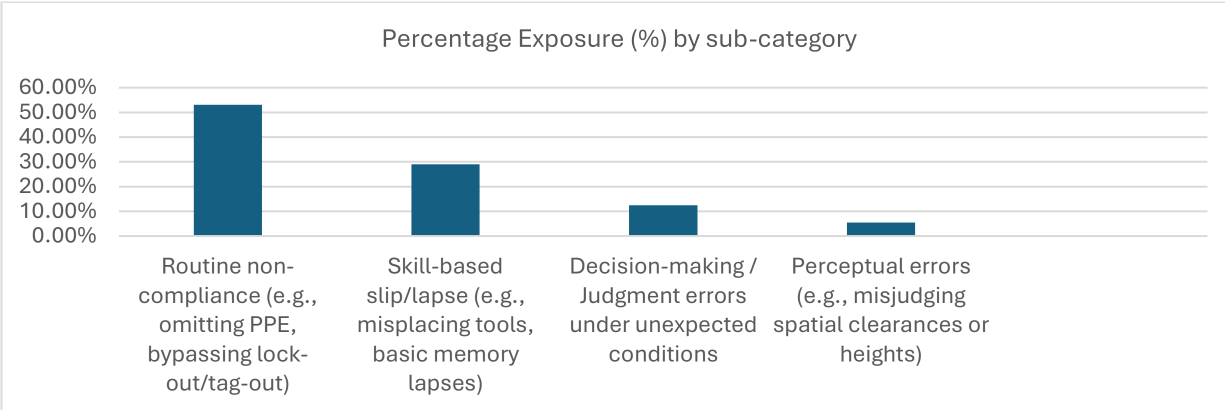
Routine infractions and skill-based mistakes are the primary causes of active failures in the operational frontline. Table 1 displays the Unsafe Acts layer's percentage breakdown and explains exposure classifications in detail including high-level overview of exposure categories: 46.90% of errors and 53.10% of violations

Table 1: Distribution of Causal Factors in the Unsafe Acts Layer

Category	Sub-Category Description	Percentage Exposure (%)
Violations	Routine non-compliance (e.g., omitting PPE, bypassing lock-out/tag-out)	53.10%
Errors	Skill-based slip/lapse (e.g., misplacing tools, basic memory lapses)	29.00%
Errors	Decision-making / Judgment errors under unexpected conditions	12.40%
Errors	Perceptual errors (e.g., misjudging spatial clearances or heights)	5.50%

The data shows that Routine violations are the biggest active contributor, according to data (53.1%). Evidence suggests that non-compliance has become widespread in the workplace, frequently as a result of workers avoiding safety precautions or making up for onerous processes. When performing repetitious duties, an operator's attention is frequently diverted, resulting in skipping or slipping off (29.0%). Based on the data utilized, the visualizations that show the percentage exposure for each category and subcategory are depicted below: highlighting the behaviors that contribute to risk, this bar chart in Table 1. indicates that routine non-compliance is the most significant factor. A high-level pie chart (Figure 1) shows a nearly even distribution between violations and the total number of error types. The exposure subcategories are arranged in a visual pie chart (Figure 2) for quick comprehension.

Table 1. Percentage Exposure by Sub-Category



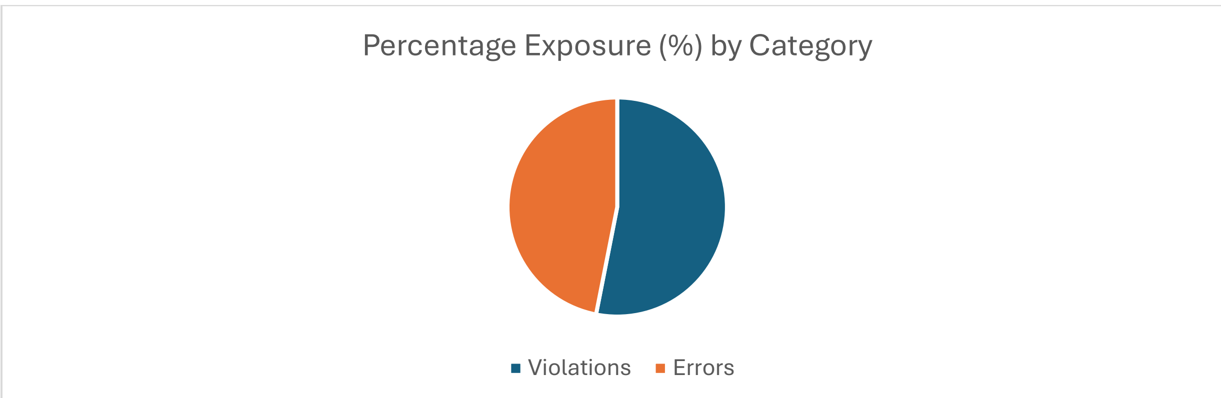


Figure 1. Percentage Exposure by Category

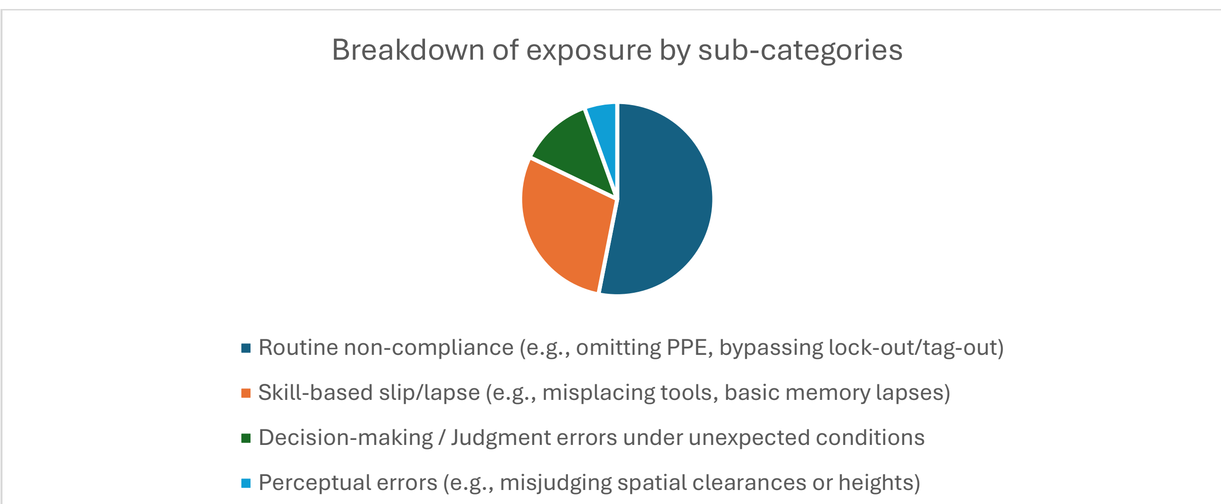


Figure 2. Breakdown of Exposure by sub-categories

The key Findings are:

- Routine infractions, such as failing to wear personal protective equipment (PPE) or adhere to safety precautions, account for 53.1% of all exposures.

- The error breakdown indicates that the overall exposure is 46.9% mistakes, that indicates
- At 29.0%, skill-based mistakes and lapses are the most common.
- 12.4% of decisions and judgments are incorrect.
- Perceptual errors, like missing spatial clearances, account for the remaining 5.5%.

4.2. Investigation of Latent Preconditions and Supervision

The distribution of causal factors in latent layers of preconditions and unsafe supervision is shown in Table 2 and the sector percentage in Figure 3 and Figure 4 below.

Table 2: Distribution of Causal Factors in Latent Layers

HFACS Layer	Dominant Causal Factor	Sector Percentage (%)	Primary Manifestation Observed
Preconditions	Technological Environment	37.30%	Outdated machinery, poorly designed control interfaces, unsuitable tools
Preconditions	Physical Environment	27.80%	Poor illumination, extreme ambient temperatures, congested paths
Unsafe Supervision	Supervisory Violations	34.60%	Infrequent safety briefings, failure to halt known unsafe tasks

By only focusing on the worker's mistake, one cannot fully understand how their work was affected by the error. According to the investigation, the technological environment is the most important latent prerequisite (37.3%). Inadequate controls in maintenance or machinery necessitate flexibility, which raises cognitive strain and causes skill-based mistakes. Furthermore, supervisory infractions account for 34.6% of supervision layer failures. Frontline employees see it as implicit agreement to commit the regular infractions indicated in Table 1 if they only receive briefings once a week and put production pace ahead of safety. The distribution of these elements is shown in the chart (Figure 3 and Figure 4) Dominant Causal elements by Sector Percentage, which emphasizes how supervisory infractions and technological prerequisites stand out as the main areas in need of intervention.

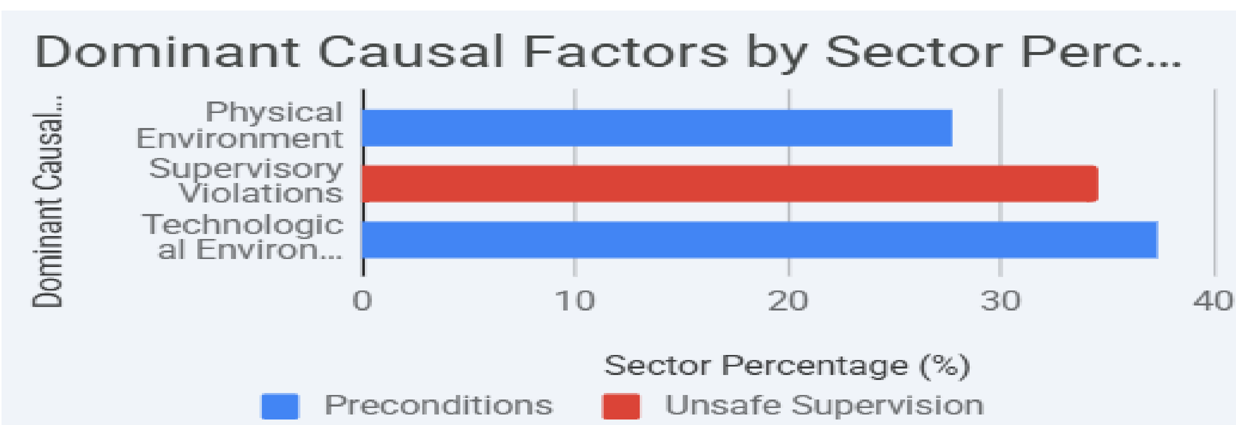


Figure 3. Distribution of dominant causal factors

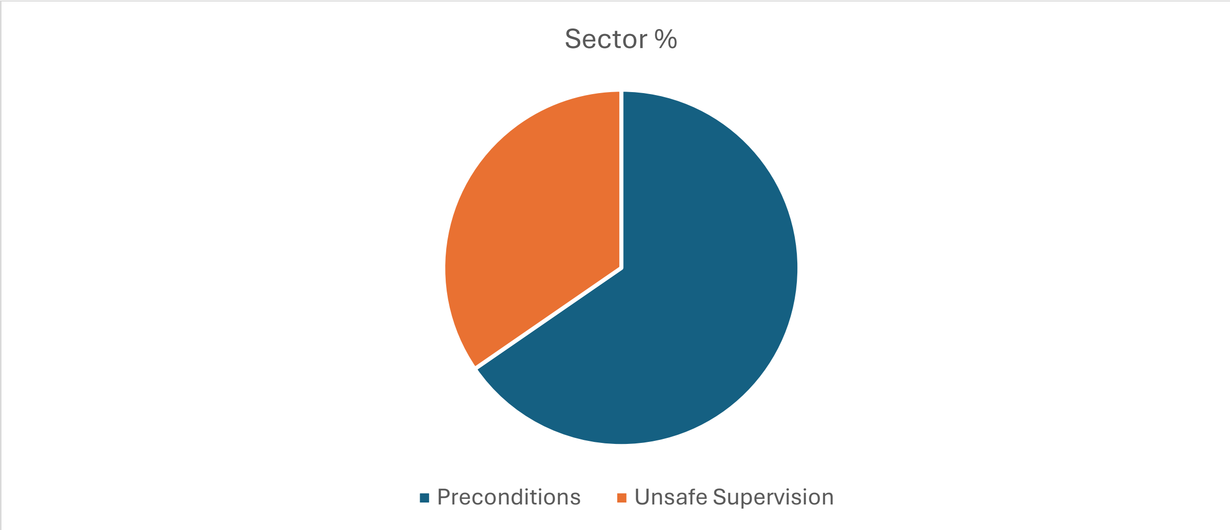


Figure 4. Sector percentage

The following are the main trends and patterns found in the HFACS (Human Factors Analysis and Classification System) layers as a result of the data analysis. There are three distinct records in the dataset:
• Technological Environment (under Preconditions): 37.30%
• Supervisory Violations (under harmful Supervision): 34.60%
• Physical Environment (under Preconditions): 27.80%

Important Lessons:
1.Conditions for Unsafe Behavior Take Control of the Risk Profile
With a combined percentage of 65.10% of the entire sector, environmental and technological preconditions account for the great majority of the identified causal factors.

- Technological Infrastructure is the Leading Vulnerability: The single biggest contributing element, at 37.30%, is the technological environment. This suggests that the most common problems are old equipment, badly designed control interfaces, and inappropriate tools.
- Physical Workplace Hazards Are Important: The physical environment accounts for 27.80% of the causative variables, which are caused by problems including dim lighting, high temperatures, and crowded walkways.
- Actionable Interpretation: Almost two-thirds of the hazards identified can be mitigated by prioritizing capital investments in updating equipment, enhancing user interface designs, and optimizing physical working circumstances (such as lighting and climate control).

2. A Critical Systemic Flaw in Supervisory Oversight
A significant percentage of the cause factors are supervisory infractions, suggesting that organizational and leadership problems are very common.

- High Prevalence of Supervisory Failures: The Unsafe Supervision layer's supervisory violations are the second-largest individual contributor, accounting for 34.60% of the causal variables.
- Lack of Proactive Safety Management: The main signs point to a culture where safety procedures are either ignored or not actively enforced, such as occasional safety briefings and a failure to stop known dangerous tasks.
- Actionable Interpretation: To strengthen the safety culture from the top down, this calls for mandatory, frequent safety briefings, stringent responsibility for supervisors, and focused leadership training.

4.3. Study Limitations

Despite the fact that this study provides useful systemic knowledge, there are a number of constraints to take into account: The only source of retrospective data bias in this analysis is historical inquiry reports. Even if the initial investigator had omitted some organizational elements, such factors could not be recorded during coding. The percentage distributions might not immediately apply to other specialized areas like healthcare or nuclear energy due to the dataset's limited coverage of the manufacturing and construction sectors. Because it makes it possible to distinguish between exceptional violations and decision errors, the classification of human intent through coding is open to qualitative interpretation.

V. CONCLUSIONS

The study shows that institutional flaws are the main cause of workplace accidents rather than human carelessness alone. Active frontline failures, such as skill-based errors (29.0%) and routine violations (53.1%), are strongly associated with upstream latent circumstances in both actual and faulty activities, according to the application of the HFACS framework. Given their frequency, human errors are nearly inevitable due to the lack of supervisory non-compliance (34.6%) and technology environment flaws (37.3%). Therefore, it is not possible to achieve sustainable accident prevention by punishing employees; instead, companies need to concentrate on creating reliable systems that can take into account human limitations.

Future Research:

Real-time prediction indicators should be incorporated into future human factors analysis studies. Researchers can utilize wearable biometric sensors to monitor employee fatigue and cognitive load, which will help develop predictive artificial intelligence. The new HFACS framework should also be expanded to assess the safety implications of remote or hybrid industrial management systems, which will be a crucial area of research in changing workplaces. This will contribute to the creation of more precise models for predicting human error and improving overall system reliability.

By incorporating real-time data from wearable sensors, researchers can gain valuable insights into how different factors impact human performance in various work settings. This will allow for a more comprehensive understanding of how human factors contribute to system reliability and safety. By integrating these advancements, researchers can better identify potential risks and develop strategies to mitigate them effectively. This will enhance system performance overall and assist in identifying potential safety hazards before they escalate. By incorporating these advancements, researchers can better understand how human factors impact system reliability and make informed recommendations for enhancing safety protocols.

VI. ACKNOWLEDGMENT

The authors acknowledge the contributions and commitment of all individuals who supported the successful completion of this study.

Use of Artificial Intelligence (AI)

The authors declare that the generative artificial intelligence (AI) tool, Grammarly, was used exclusively for language editing and / or grammatical improvement. The use of AI did not influence the scientific content, study design, data analysis, data interpretation, results, or conclusions of the manuscript. Full responsibility for the content remains with the authors.

Conflict of Interest

The authors declare no conflicts of interest.

REFERENCES

[1] Baysari, M. T., McIntosh, A. S., & Wilson, J. R. (2011). Understanding the human factors contributing to railway accidents and incidents in Australia: The application of HFACS-RR. Applied Ergonomics, 42(3), 449-457. https://doi.org/10.1016/j.apergo.2010.09.005

[2] Celik, M., & Cebi, S. (2009). Analytical HFACS for investigating human errors in shipping accidents. Safety Science, 47(10), 1419-1431. https://doi.org/10.1016/j.ssci.2009.03.014

[3] Cohen, T. N., Wiegmann, D. A., & Shappell, S. A. (2018). Evaluating the reliability and validity of the Human Factors Analysis and Classification System. Aerospace Medicine and Human Performance, 89(6), 540-548. https://doi.org/10.3357/AMHP.5003.2018

[4] Heinrich, H. W. (1931). Industrial accident prevention: A scientific approach. McGraw-Hill.

[5] Hulme, A., Stanton, N. A., Walker, G. H., Waterson, P., & Salmon, P. M. (2019). Accident analysis in practice: A review of Human Factors Analysis and Classification System (HFACS) applications in peer-reviewed academic literature. Safety Science, 120, 223-233. https://doi.org/10.1016/j.ssci.2019.06.015

[6] Jalali, M., Dehghan, H., Habibi, E., & Khakzad, N. (2023). Application of "Human Factor Analysis and Classification System" (HFACS) Model to the Prevention of Medical Errors and

Adverse Events: A Systematic Review. International Journal of Preventive Medicine, 14(1). https://doi.org/10.4103/ijpvm.ijpvm_123_22

[7] Li, W. C., & Harris, D. (2006). HFACS analysis of ROC Air Force accidents. Aviation, Space, and Environmental Medicine, 77(10), 1056-1061.

[8] Luo, X., Liu, Q., & Qiu, Z. (2022). The Influence of Human-Organizational Factors on Falling Accidents From Historical Text Data. Frontiers in Public Health, 9. https://doi.org/10.3389/fpubh.2021.783537

[9] Nwankwo, C. D., Arewa, A. O., Theophilus, S. C., & Esenowo, V. N. (2021). Analysis of accidents caused by human factors in the oil and gas industry using the HFACS-OGI framework. International Journal of Occupational Safety and Ergonomics, 28(3), 1642-1654. https://doi.org/10.1080/10803548.2021.1916238

[10] Patterson, J. M., & Shappell, S. A. (2010). Operator error and system deficiencies: Analysis of 508 mining incidents and accidents from Queensland, Australia using HFACS. Safety Science, 48(3), 359-361. https://doi.org/10.1016/j.ssci.2009.09.004

[11] Reason, J. (1990). Human error. Cambridge University Press.

[12] Shappell, S. A., & Wiegmann, D. A. (2001). The Human Factors Analysis and Classification System–HFACS. Aviation, Space, and Environmental Medicine, 72(2), 100-107.

BIOGRAPHIES

Baskaran Thirumalai is a Research Scholar in the Department of Chemical Engineering (Industrial Safety) at Annamalai University, Annamalainagar. Based on his academic focus at Annamalai University and his professional background in the oil and gas sector, Baskaran Thirumalai's primary research interests lie in the fields of sustainability, ESG, climate change, industrial safety, hazard control, and risk management. He actively contributes to safety standards and speaks at industry-focused engineering webinars and conferences. Authored and published academic papers in industrial research, including a notable case study in the global refining and petrochemical sector. This paper forms part of his Ph.D research conducted under the supervision of Prof. B. Suresh and Prof. R. Govindarasu.