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Targeted Safety Interventions Through Pareto Based Incident Analysis in Cement Manufacturing

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Abstract

This research explores workplace safety in the cement manufacturing industry through the application of Pareto analysis, a quality management tool used to prioritize issues based on their relative impact. Over a five-year period, a total of 379 incidents were recorded and systematically categorized by type, cause, and operational area. The objective was to identify high-risk categories and zones within the plant to enable targeted safety interventions. The analysis revealed that a small number of categories such as Slip/Trip/Falls, Material Handling incidents, PPE violations, and Procedure Violations were responsible for nearly 80% of the total incidents, validating the Pareto Principle (80/20 rule). Similarly, departments like the Packing Plant, Cement Mill, and Kiln were found to be the most incident-prone areas. The results offer clear direction for resource allocation and focused safety improvements. The study demonstrates the value of a data-driven approach in enhancing industrial safety, optimizing risk control, and fostering a proactive safety culture.

Keywords: *Cement Manufacturing, Workplace Safety, Pareto Analysis, Incident Data, Risk Prioritization, Slip/Trip/Fall, PPE Compliance, Material Handling, Safety Intervention, Occupational Hazards*

1. Introduction:

The cement industry is one of the fundamental sectors driving infrastructure development and economic growth across the globe. It provides the essential material cement for the construction of buildings, highways, bridges, dams, and other civil structures. Characterized by high-temperature operations, continuous material handling, and heavy mechanical processes, cement manufacturing is inherently complex and labor-intensive. Key operational areas such as mining, crushing, kiln operation, and milling involve elevated risk levels, exposing workers to physical, chemical, and mechanical hazards.

Contempt the integration of safety standards, automation, and regulatory compliance frameworks, workplace accidents in cement plants remain a persistent concern. Frequent incidents, whether due to equipment malfunction, procedural lapses, or human error, disrupt operations, compromise worker safety, and affect productivity. Traditional approaches to safety management in this industry often focus on reactive measures rather than proactive, data-driven strategies.

To address this challenge, the present study adopts Pareto analysis, a widely recognized quality management tool, to systematically examine incident and accident data within a cement manufacturing environment. The Pareto Principle, commonly known as the 80/20 rule, asserts that a small proportion of causes often account for a large share of the outcomes. By applying this

10.48047/jocaaa.2023.31.04.36

methodology, the study aims to uncover the most significant contributors to safety incidents and guide targeted intervention strategies.

The objectives of the study are as follows:

1. To collect and categorize incident and accident data from cement manufacturing plant operations over a defined period.
2. To identify the most frequent and critical categories of incidents/accidents in cement manufacturing using Pareto analysis.
3. To apply the Pareto principle (80/20 rule) to highlight the key contributors to overall incident occurrence.
4. To derive actionable insights that can assist safety managers and plant supervisors in prioritizing safety measures and preventive strategies.
5. To propose practical recommendations for reducing incidents and improving workplace safety, based on the results of the analysis.

This structured approach not only helps in identifying high-risk zones but also facilitates resource optimization and enhances the overall safety culture in industrial operations. The findings of the study are expected to serve as a decision-support tool for safety professionals and plant management in the cement industry.

2. Materials and Methods:

This study follows a descriptive and analytical research design, utilizing the Pareto Analysis technique to evaluate five years of historical incident data from a large-scale, fully integrated cement manufacturing plant. The objective is to identify the most frequent and critical causes of safety incidents and to assist safety managers in prioritizing risk mitigation strategies using the 80/20 rule.

A. Data Collection and Source

Total of 379 accident and incident records were collected from the plant’s digital safety management system, covering a five-year period (2020–2024). These records represent actual on-site events including minor injuries, property damage, near misses, and major accidents. Each entry was reviewed for completeness and consistency before being included in the analysis. Each record captured the following fields:

- Date and time of incident
- Department and shift
- Incident type and risk level
- Area of occurrence
- Root cause and category
- Short description of the incident

B. Description of Material and Operations

10.48047/jocaaa.2023.31.04.36

The plant handles critical raw materials such as Limestone ($CaCO_3$), Laterite, Bauxite, Gypsum ($CaSO_4 \cdot 2H_2O$), and chemical additives like Grinding Aids and Water-Reducing Admixtures (WRA). The key cement products manufactured include Ordinary Portland Cement (OPC), Portland Pozzolana Cement (PPC), and White Cement.

Operations span across:

- Mining and Raw Material Extraction
- Crushing and Raw Mill Processing
- Preheating and Clinkerization (Rotary Kiln)
- Clinker Cooling
- Cement Grinding and Packaging
- Utilities (Power Plant, WHRS, and Water Systems)

C. Incident Classification and Categorization

The 379 incidents were systematically was classified into a relevant incident category and mapped to a specific plant zone. Categories included:

- Incident Category: Slip/Trip/Fall, Procedure Violation, Dust, PPE.
- Operational Area: Packing Plant, Cement Mill, Kiln.
- Risk Level: Low, Medium, High.
- Injury Type: Minor, Major, Property Damage.

This classification enabled a structured analysis to reveal patterns, trends, and high-risk zones within the facility. The plant area was subdivided into 49 zones (e.g., Cement Mill, Kiln, Packing Plant, Raw Mill, Mines), and incidents were analyzed area-wise to determine critical hotspots.

D. Method of Analysis: Pareto Approach

The Pareto Analysis was used to identify the "vital few" causes contributing to the majority of safety incidents. The following steps were followed:

Frequency Calculation: Count of incidents for each category.

i. Total Frequency (F): $F = \sum_{i=1}^{n} f_i$

ii. Percentage of Total (p_i): $pi = \left(\frac{f_i}{F}\right) X100$

iii. Cumulative Percentage (C_i):

$$C_{\text{i}} = \sum_{j=1}^{i} p_j$$

The calculated values were used to develop Pareto charts, where bar graphs illustrated the frequency of each incident category, and a superimposed line graph showed their cumulative percentage. The point at which this cumulative curve approached 80% was used to identify the 'vital few' categories that contributed most significantly to overall incidents.

Table 2.1 Incident category Pareto analysis

Vital few / Trivial Many	Sr. No.	Incident Category	Frequency	Total Percentage	Cumulative
Vital few	1	Slip/Trip/Fall	78	20.58	20.58
	2	Material Handling	43	11.35	31.93
	3	PPE	40	10.55	42.48

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	4	Procedure Violation	36	9.50	51.98
	5	Dust	32	8.44	60.42
	6	Moving Machine	31	8.18	68.60
	7	Caught In/Between	29	7.65	76.25
	8	Equipment Failure	13	3.43	79.68
Trivial Many	9	Biological Hazard	13	3.43	83.11
	10	Cut Injury Sharp Edge	13	3.43	86.54
	11	Traffic Violation	8	2.11	88.65
	12	Lifting failure	8	2.11	90.76
	13	Electrical	7	1.85	92.61
	14	Hot Material	6	1.58	94.19
	15	Fire/Explosion	4	1.06	95.25
	16	Edge Protection	3	0.79	96.04
	17	Floor Opening	3	0.79	96.83
	18	House Keeping	3	0.79	97.62
	19	Roof and side fall	3	0.79	98.42
	20	Chemical Exposure	2	0.53	98.94
	21	Poor illumination	2	0.53	99.47
	22	Scaffolding	2	0.53	100.00
			379	100	100

The values were computed using analytical tools, and Pareto charts were developed to present the frequency of each incident category through bar graphs, with cumulative percentages illustrated by a superimposed line graph. Categories up to the 80% cumulative threshold were identified as the 'vital few' contributing most significantly to the overall incidents.

3. Results and Discussion:

A total of 379 incidents and accidents were reported over a five-year period (2020–2024) at a large-scale cement manufacturing plant. The aim of the analysis was to identify high-priority incident types and operational areas using the Pareto analysis.

Table 3.1 Incident category-wise distribution of reported cases (2020–2024*)*

Sr. No.	Incident Category	No. of Incidents
1	Slip/Trip/Fall	78
2	Material Handling	43
3	PPE	40
4	Procedure Violation	36
5	Dust	32
6	Moving Machine	31
7	Caught In/Between	29
8	Equipment Failure	13

These eight categories accounted for 302 out of 379 incidents, or approximately 79.7%, validating the Pareto Principle that a small number of causes are responsible for a large share of consequences.

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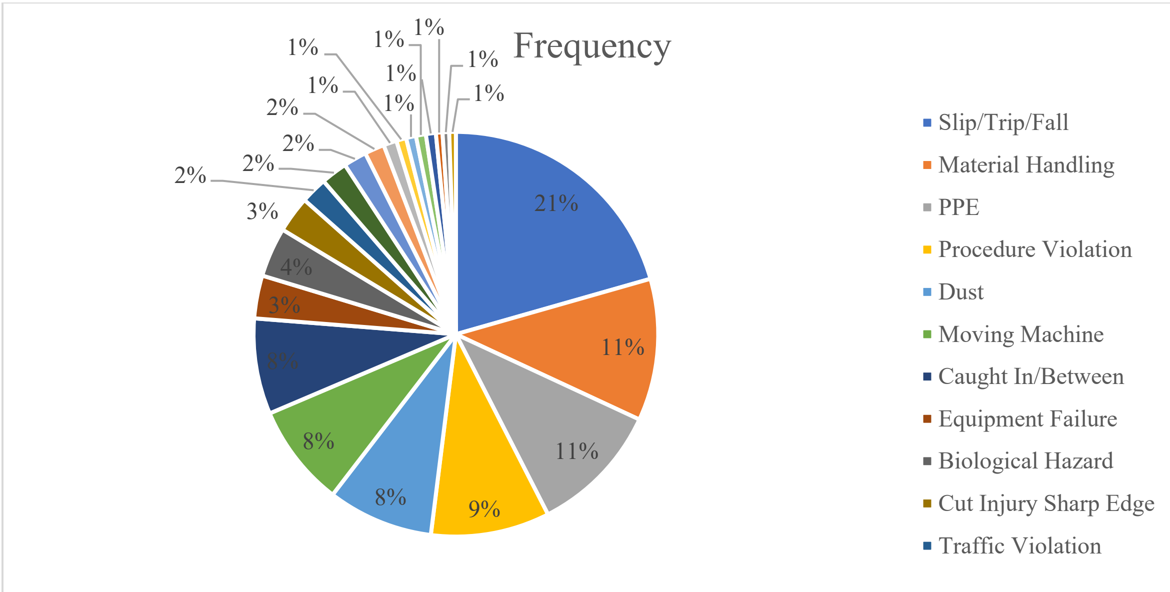

Figure 3.1 Incident category-wise distribution of frequency (in %)

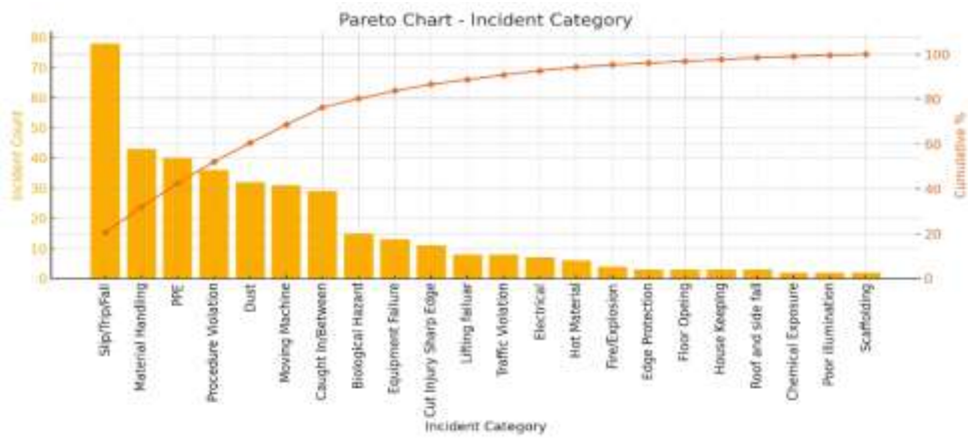

Figure 3.2 Pareto chart representing incident categories with cumulative percentage

Area-Wise Distribution of Incidents

The analysis also revealed the departments where incidents were most concentrated:

Table 3.2 Operational area-wise distribution of safety incidents

Sr. No.	Operational Area	No. of Incidents
1	Packing Plant	36
2	Kiln	29
3	Cement Mill	26
4	Limestone Mine	19
5	Wagon Loading	16
6	Preheater Area	10
7	Fly Ash Silo	9
8	Others (combined)	Remaining cases

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Together, the Packing Plant, Kiln, and Cement Mill accounted for over 24% of total incidents. These areas involve high levels of manual work, rotating equipment, and complex operational processes, contributing to a higher risk profile.

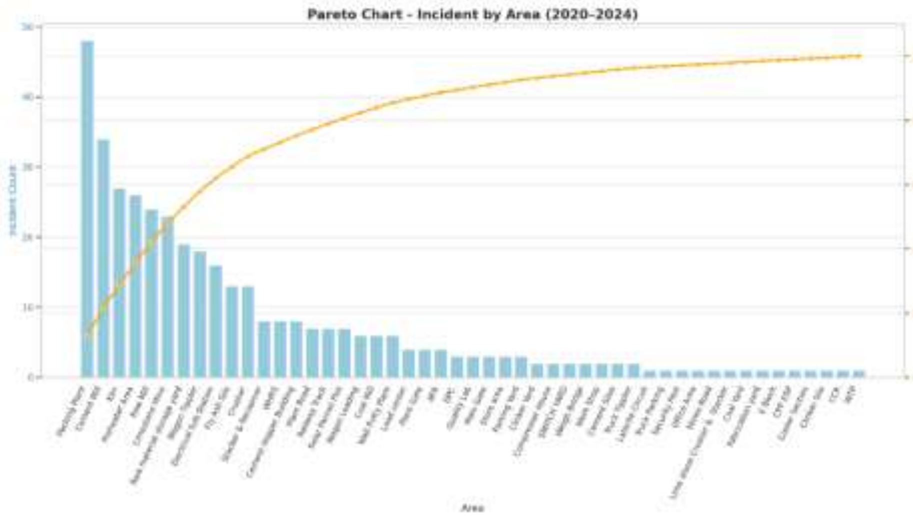

Figure 3.3 Pareto chart of incident distribution by operational area (2020–2024)

Interpretation of Findings

Category-wise Insights:

- Slip/Trip/Fall (21%): Indicates poor floor conditions, lack of warning signs, or inadequate housekeeping.
- Material Handling (11.5%): Linked to improper lifting, unsafe stacking, or lack of handling aids.
- PPE Non-Compliance (11%): Reflects gaps in training, enforcement, or PPE availability.
- Procedure Violations: Suggest operational non-adherence or weak supervision.
- Dust Exposure: Raises concerns about respiratory protection and housekeeping.

Area-wise Insights:

- Packing Plant: High manual involvement, repetitive tasks, and rotating machinery contribute to ergonomic and entrapment hazards.
- Kiln and Preheater: Exposed to thermal and gas-related hazards.
- Cement Mill and Raw Mill: Mechanical hazards and dust risks were prominent

10.48047/jocaaa.2023.31.04.36

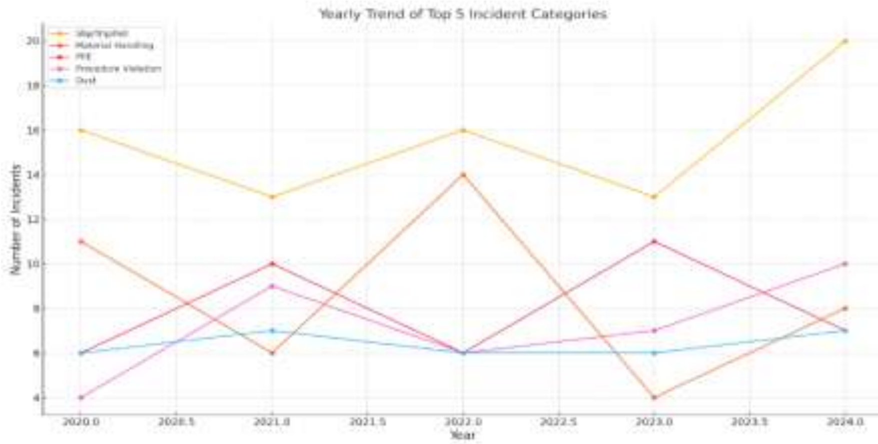

Figure 3.4 Yearly trend of top 5 incident categories in cement manufacturing (2020–2024)

Discussion:

The application of Pareto analysis validated that a limited number of incident categories and operational areas accounted for the majority of workplace safety risks. This finding aligns with global safety benchmarks and supports a focused, data-driven safety strategy.

Root Causes Identified:

- Slip/Trip/Fall: Inadequate flooring, lighting, or footwear.
- Material Handling: Manual processes, fatigue, or poor ergonomics.
- PPE Violations: Behavioral neglect, lack of safety culture, or discomfort.
- Equipment Failure: Maintenance gaps or poor inspection routines.
- Dust Exposure: Inadequate ventilation and control measures.

Systemic Insights:

- Training deficits and absence of proactive safety culture are central issues.
- Repeated incidents suggest that corrective measures were either missing or ineffective.
- Traditional review mechanisms lack the analytical depth offered by this structured approach.

The outcome of this study provides clear evidence that safety efforts should be concentrated on a few critical categories and departments to gain maximum risk reduction with optimal resource allocation.

4. Conclusion:

This research systematically applied the Pareto analysis method to evaluate five years of workplace incident data from a cement manufacturing plant, with the aim of identifying the most frequent and impactful causes of safety breaches. By converting raw incident records into statistically significant insights, the study offers a structured approach for proactive safety management.

- Incident records were systematically gathered and categorized by type, location, and cause for accurate analysis.

10.48047/jocaaa.2023.31.04.36

- Pareto analysis highlighted Slip/Trip/Falls, Material Handling, and PPE violations as the most frequent and severe incidents.
- A few causes were found responsible for most incidents, confirming the relevance of the Pareto Principle in safety management.
- Key risk zones Packing Plant, Kiln, and Preheater were identified for focused safety improvements.
- Practical recommendations include improved training, maintenance, PPE compliance, and housekeeping enhancements.

By focusing on the most critical hazards such as Slip/Trip/Falls, Material Handling issues, and PPE violations and the most incident-prone areas like the Packing Plant, Kiln, and Cement Mill, the study enables safety professionals to make informed decisions and implement targeted control measures. These may include enhanced training, behavior-based safety programs, procedural reinforcement, and equipment or layout modifications.

Importantly, this research highlights the value of data-driven analysis in transforming raw incident records into actionable insights. The approach not only supports regulatory compliance but also contributes to cost-effective risk mitigation, improved operational continuity, and the development of a proactive safety culture. The model presented can be replicated across similar high-risk industries to support long-term safety performance and continuous improvement.

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References:

[1] P. I. Mureșan, M. Ilie, M. Păcurar, C. Oprean, and I. Tănase, "Study of Health and Safety in the Manufacturing Industry Using Pareto Analysis," MATEC Web of Conferences, vol. 290, p. 05008, 2019, doi: 10.1051/matecconf/201929005008.

[2] Marlina, "Combining Pareto Diagram and AHP Method in Cement Bag Quality Control," IOP Conference Series: Materials Science and Engineering, vol. 1088, p. 012064, 2021, doi: 10.1088/1757-899X/1088/1/012064.

[3] I.Maulidya, R. Sunarno, and N. M. Nafi'ah, "Analysis of Human Error in Cement Plant Using SHERPA and HEART Methods," Journal of Physics: Conference Series, vol. 2143, p. 012014, 2022, doi: 10.1088/1742-6596/2143/1/012014.

[4] A. Daba, G. Hordofa, and G. Kebede, "Prevalence of Occupational Injuries and Associated Factors Among Cement Factories Workers in Central Ethiopia," Environmental Health and Preventive Medicine, vol. 27, no. 1, p. 42, 2022, doi: 10.1186/s12199-022-00972-4.

[5] M. R. Rosyidiin, A. A. Rosyid, and M. Nurhasanah, "Cost Integration of Safety Management System at Cement Manufacturing Process," IOP Conference Series: Materials Science and Engineering, vol. 1056, p. 012019, 2021, doi: 10.1088/1757-899X/1056/1/012019.

10.48047/jocaaa.2023.31.04.36

[6] M. Samarasinghe and T. Heenatigala, "A Study of 425 Industrial Accident Cases and Their Prevention Strategies," Proceedings of the International Conference on Industrial Engineering and Operations Management, 2024.

[7] Y. Sun, W. Zhao, and C. Wang, "Research on Imbalanced Safety Data and Its Application in Safety Risk Analysis," Safety Science, vol. 146, p. 105525, 2024, doi: 10.1016/j.ssci.2021.105525.

[8] Z. Ni and Z. Liu, "Causality Extraction of Construction Accidents Based on NLP Technology," Journal of Construction Engineering and Management, vol. 147, no. 2, p. 04020167, 2021, doi: 10.1061/(ASCE)CO.1943-7862.0001968.

[9] Y. Zhong, S. Zhang, and Q. Huang, "Statistical Analysis of Production Safety in China's Construction Industry," Safety Science, vol. 118, pp. 47–56, 2019, doi: 10.1016/j.ssci.2019.05.002.

[10] M. Abbasinia and I. Mohammadfam, "Occupational Accidents Cause Prioritizing Using Fuzzy AHP and TOPSIS," International Journal of Occupational Safety and Ergonomics, vol. 26, no. 1, pp. 144–152, 2020, doi: 10.1080/10803548.2018.1464536.

[11] T. Reddy, R. Kumar, and K. Shankar, "Case Study on Safety Performance of Construction Projects in India Using Safety Audit Elements and AHP-Taguchi Loss Function," International Journal of Construction Management, vol. 20, no. 1, pp. 72–83, 2020, doi: 10.1080/15623599.2018.1457990.

[12] J. Fernández-Muñiz, J. G. Montes-Peón, and M. J. Vázquez-Ordás, "Causes of Occupational Accidents Related to Scaffolding in the Construction Sector: An Exploratory Study," Safety Science, vol. 150, p. 105727, 2022, doi: 10.1016/j.ssci.2021.105727.

[13] M. Soltan Zadeh, A. M. Nikbin, and M. Omidvar, "Structural Equation Modeling of Construction Accidents: A 10-Year Study," Safety Science, vol. 157, p. 105908, 2023, doi: 10.1016/j.ssci.2022.105908.

[14] D. Baker, S. Wang, and X. Lu, "Predicting Construction Safety Outcomes Using AI Based on Universal Attributes," Automation in Construction, vol. 103, pp. 11–22, 2019, doi: 10.1016/j.autcon.2019.02.011.

[15] X. Zhang, H. Li, and Y. Zhang, "Fatal Accident Patterns in China's Building Construction Activities," Safety Science, vol. 110, pp. 139–146, 2018, doi: 10.1016/j.ssci.2018.07.020.

[16] J. Luo and Y. Wang, "Evaluating Accident Analysis Methods Applied to Construction Accidents in China," Safety Science, vol. 103, pp. 81–89, 2018, doi: 10.1016/j.ssci.2017.11.011.

[17] R. Jin, H. Zhang, and Y. Chen, "Bayesian Network Modeling for Construction Safety Risk Assessment," Journal of Construction Engineering and Management, vol. 143, no. 1, p. 04016100, 2017, doi: 10.1061/(ASCE)CO.1943-7862.0001234.

[18] A. Fazel Zarandi, M. Saeedi, and M. Shirazi, "Occupational Health and Safety Risk Assessment Based on Fuzzy Set Theory: A Review," Safety Science, vol. 118, pp. 83–95, 2019, doi: 10.1016/j.ssci.2019.05.006.

[19] M. Ghasemi, R. Niknam, and H. F. Sheikh, "Application of the Bowtie Method in Construction Accident Investigation," Safety Science, vol. 141, p. 105320, 2021, doi: 10.1016/j.ssci.2021.105320.

[20] S. Verma and A. Verma, "Occupational Accident Risk Assessment in the Cement Industry Using Fuzzy Logic," International Journal of Industrial Engineering and Management, vol. 8, no. 2, pp. 89–97, 2017.

[21] C. Han, Z. Wang, and Q. Zhao, "Safety Performance Evaluation in Construction Projects Using Data Envelopment Analysis," Journal of Safety Research, vol. 68, pp. 29–39, 2019, doi: 10.1016/j.jsr.2018.12.002.

10.48047/jocaaa.2023.31.04.36

[22] M. Jafari and M. Sadighzadeh, "Fault Tree Analysis of Occupational Accidents in the Cement Industry," Safety and Health at Work, vol. 11, no. 1, pp. 89–95, 2020, doi: 10.1016/j.shaw.2019.10.001.

[23] R. Sharma and P. Jain, "Occupational Health and Safety Management in the Cement Industry: A Review," International Journal of Occupational Safety and Ergonomics, vol. 27, no. 1, pp. 146–155, 2021, doi: 10.1080/10803548.2020.1740631.

[24] R. Singh and V. Kumar, "Challenges and Opportunities in Safety Management System Implementation in the Cement Industry," International Journal of Safety and Security Engineering, vol. 10, no. 3, pp. 411–420, 2020, doi: 10.18280/ijsse.100304.

[25] N. Patel and P. Desai, "Safety Culture Assessment in the Cement Industry Using Safety Climate Questionnaire," International Journal of Occupational Safety and Ergonomics, vol. 24, no. 1, pp. 122–131, 2018, doi: 10.1080/10803548.2017.1309938.