Evaluation of Workplace Hazards in the Cement Industry Through Pareto-Based Risk Prioritization

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Abstract

The cement manufacturing industry involves multiple occupational hazards arising from raw material handling, crushing, grinding, kiln operations, clinker cooling, cement packing, material transportation, and equipment maintenance. Workers may be exposed to airborne dust, excessive noise, moving machinery, manual handling risks, work-at-height hazards, electrical dangers, and mobile equipment. Effective identification and prioritisation of these hazards are essential for reducing workplace accidents, occupational illnesses, and production disruptions. This study proposes a Pareto-based framework for evaluating workplace hazards and identifying critical risk categories requiring immediate corrective action. The methodology involves workplace hazard identification, collection of incident and near-miss data, classification of hazards, frequency analysis, cumulative percentage calculation, and the construction of a Pareto chart. An illustrative dataset comprising 100 reported hazard events is used to demonstrate the proposed analytical approach. The illustrative results indicate that dust exposure, slips and trips, machinery-related hazards, manual handling, and excessive noise account for 83% of the recorded events. These findings demonstrate how Pareto analysis can support the systematic allocation of occupational safety resources. The proposed framework integrates hazard prioritisation with the hierarchy of controls, occupational health surveillance, preventive maintenance, and continuous safety monitoring. The study provides a practical methodology for cement plant managers, safety engineers, and occupational health professionals to strengthen workplace safety management.

Keywords: Cement industry, occupational health and safety, workplace hazards, Pareto analysis, risk prioritisation, industrial safety, hazard identification, accident prevention.

1. Introduction

The cement industry is an important component of industrial infrastructure and economic development. Cement production involves a series of interconnected processes, including quarrying, crushing, raw material preparation, kiln operations, clinker cooling, grinding, packing, storage, and transportation. These activities expose workers to physical, chemical, mechanical, ergonomic, and environmental hazards.

Occupational safety in cement manufacturing is particularly important because hazards may arise simultaneously from production equipment, airborne particulates, high-temperature operations, material movement, and maintenance activities. Cement dust can irritate the respiratory system and skin, while exposure to respirable crystalline silica in relevant processes can cause serious respiratory diseases. Research has also identified associations between occupational cement dust exposure and adverse respiratory outcomes [1]. Other workplace hazards include excessive noise, conveyor belt entanglement, falling objects, vehicle collisions, electrical contact, confined-space entry, and musculoskeletal injuries.

Traditional safety inspections and risk assessments often identify numerous hazards without providing a clear quantitative basis for deciding which issues should receive priority. When resources, time, and personnel are limited,

safety managers need a systematic method for distinguishing the most frequently reported problems from less frequent hazards that may nevertheless have severe consequences.

Pareto analysis provides a practical statistical technique for addressing this challenge. Based on the Pareto principle, it ranks problem categories according to their contribution to an observed total. A Pareto chart displays the frequency of each category alongside its cumulative percentage, allowing decision-makers to identify the categories that account for a substantial proportion of recorded events.

However, frequency alone does not establish the severity of a hazard. A low-frequency event, such as a fatal machinery accident or major kiln-related incident, may require immediate intervention. Therefore, Pareto analysis should be combined with severity-based risk assessment and professional safety judgement.

This research proposes a structured approach to workplace hazard evaluation in the cement industry using Pareto-based prioritisation, with the objective of improving the effectiveness of occupational safety interventions.

1.1 Research Problem

Cement manufacturing facilities may generate extensive inspection findings, near-miss reports, accident records, and occupational exposure observations. Without a systematic prioritisation method, corrective actions may be distributed across numerous hazards without adequately addressing the most significant risks.

The central research problem is to determine how recorded workplace hazards can be classified, ranked, and prioritised to support more effective occupational health and safety management.

1.2 Research Objectives

The main objectives are:

1. To identify major occupational hazards associated with cement manufacturing processes.
2. To develop a systematic framework for classifying and analysing workplace hazard data.
3. To apply Pareto analysis to determine the highest-frequency hazard categories.
4. To propose targeted preventive and corrective measures for prioritised hazards.
5. To establish a practical basis for continuous safety improvement in cement plants.

1.3 Research Questions

The study addresses the following questions:

- Which workplace hazards contribute most frequently to recorded hazard events in cement manufacturing?
- How can Pareto analysis support the prioritisation of occupational safety interventions?
- How should frequency-based prioritisation be combined with severity-based risk assessment?
- Which engineering, administrative, and personal protective measures are appropriate for the major hazard categories?

2. Literature Review

2.1 Occupational Hazards in Cement Manufacturing

Cement production involves potentially hazardous operations at several stages of the manufacturing process. Quarrying and crushing may generate dust, noise, vibration, and risks from mobile machinery. Grinding, conveying,

and packing can expose workers to particulate matter and moving equipment. Kiln operations involve elevated temperatures, hot materials, maintenance risks, and potential exposure to process gases.

Manual handling and repetitive tasks may contribute to musculoskeletal disorders, particularly in bag handling, loading, maintenance, and material transfer. Work at height, electrical maintenance, confined-space entry, and vehicle movement also require specific preventive controls.

The Occupational Safety and Health Administration identifies cement dust exposure, machinery guarding, noise, forklifts, falling objects, and confined spaces among the hazards requiring attention in relevant manufacturing environments [2].

2.2 Occupational Health Implications of Cement Dust

Dust exposure is a major occupational health concern in cement production. Workers involved in crushing, grinding, material transfer, packing, and housekeeping may encounter airborne particulate matter. The health implications depend on the composition and concentration of dust, particle size, duration of exposure, and effectiveness of control measures.

Fell and Nordby [1] reviewed evidence concerning occupational cement production exposure and non-malignant respiratory effects. Their findings highlighted concerns about respiratory symptoms and changes in lung function, while also noting limitations in the available evidence.

Effective control therefore requires exposure assessment, dust suppression, enclosed processes, local exhaust ventilation, equipment maintenance, suitable respiratory protection, and appropriate medical surveillance.

2.3 Pareto Analysis in Safety Management

Pareto analysis is a quality and management tool used to identify the categories contributing most frequently to an observed problem. It arranges categories in descending order of frequency and calculates the cumulative percentage of the total.

In occupational safety, Pareto analysis can be applied to accident types, near misses, inspection observations, unsafe conditions, or exposure exceedances. The interpretation must reflect the type and quality of data used.

2.4 Research Gap

Existing occupational safety methods provide tools for hazard identification, exposure assessment, and risk evaluation. However, safety practitioners also require practical methods for translating extensive workplace records into an actionable intervention plan.

The present study addresses this operational need by proposing a Pareto-based prioritisation framework specifically structured around cement manufacturing activities. It also recognises the limitation of frequency-only ranking by incorporating a separate severity and risk assessment stage.

3. Research Methodology

3.1 Research Design

The proposed study adopts a quantitative, descriptive, and analytical research design. Workplace hazard data are classified into predefined categories and analysed using frequency distributions, cumulative percentages, and Pareto ranking.

The framework can be implemented in an operational cement plant using inspection reports, accident registers, near-miss records, occupational exposure measurements, and employee safety observations.

For this manuscript, the numerical analysis uses a **hypothetical dataset of 100 hazard events** solely to demonstrate the calculations. It does not represent observations from an actual cement plant.

3.2 Study Population and Data Sources

In an empirical investigation, the study population may include workers and operations associated with:

- Raw material handling and crushing.
- Raw meal preparation and grinding.
- Kiln and clinker cooling operations.
- Cement grinding and packing.
- Warehousing and dispatch.
- Mechanical and electrical maintenance.
- Housekeeping and internal transportation.

Data should ideally be collected over a defined period, such as six or twelve months, from verified workplace records and field inspections.

The principal data sources may include:

1. Accident and injury registers.
2. Near-miss reports.
3. Routine safety inspection records.
4. Job safety analysis and risk assessment documents.
5. Personal and area exposure monitoring.
6. Worker interviews and safety observations.
7. Maintenance and equipment failure records.

The observation period, workforce size, number of shifts, and total hours worked should be documented to improve comparability.

3.3 Hazard Classification

For analytical purposes, workplace hazards can be classified into nine categories.

Hazard category	Typical examples
Dust exposure	Cement dust, raw material dust, respirable particulate exposure
Slips, trips and falls	Spilled material, obstructed walkways, uneven surfaces
Machinery and conveyors	Unguarded moving parts, entanglement, unexpected start-up
Manual handling	Heavy lifting, repetitive handling, awkward postures
Noise exposure	Grinding mills, crushers, compressors
Work at height	Platforms, ladders, elevated maintenance

Mobile equipment	Forklifts, loaders, trucks and reversing vehicles
Electrical hazards	Faulty wiring, exposed conductors, unsafe isolation
Thermal and heat hazards	Kilns, hot surfaces, hot material and heat stress

The classification should be adapted to the actual plant processes. Chemical exposure, confined spaces, falling objects, fire, explosion, and other potentially severe hazards should be separately recorded when relevant rather than omitted simply because they occur less frequently.

3.4 Data Processing

Each record should be checked for completeness, duplicate entries, reporting period, work location, task, hazard category, actual consequence, and potential consequence.

Where multiple observations refer to the same event, a consistent counting rule should be applied. Hazard observations, near misses, and actual accidents should not be combined indiscriminately because they represent different outcomes.

For the illustrative calculation, each record is treated as one hazard event, and all nine categories together account for 100 events.

3.5 Pareto Analysis

The procedure consists of the following steps:

1. Count the events in each hazard category.
2. Arrange categories in descending order of frequency.
3. Calculate each category's percentage contribution.
4. Calculate cumulative frequencies.
5. Determine cumulative percentages.
6. Plot a Pareto chart with event frequency as bars and cumulative percentage as a line.
7. Identify high-contribution categories for targeted investigation.
8. Conduct a separate severity-based risk assessment before determining final intervention priorities.

The percentage contribution of category (i) is calculated as:

P_i=\frac{f_i}{N}\times100

The cumulative frequency is:

CF_i=\sum_{j=1}^{i}f_j

The cumulative percentage is:

$$CP_i=\frac{CF_i}{N}\times100$$

3.6 Severity-Based Risk Assessment

Frequency-based prioritisation must be supplemented with a risk assessment. A practical preliminary method is to assign likelihood and severity scores using a documented five-point scale.

$$R=L\times S$$

Where:

- (R) = risk score
- (L) = likelihood score, from 1 to 5
- (S) = severity score, from 1 to 5

The organisation should define its likelihood and severity descriptors and acceptance criteria before scoring hazards. Risk scores are screening aids, not precise probabilities of injury or disease.

Where credible fatality, life-altering injury, major fire, or catastrophic equipment failure is possible, the hazard should receive appropriate attention even if its recorded frequency is low. Legal requirements and exposure limits must also be assessed independently of the Pareto ranking.

4. Results and Analysis

4.1 Illustrative Distribution of Workplace Hazards

Table 1 presents the hypothetical distribution of 100 recorded hazard events. The values are used to demonstrate the method and should not be interpreted as empirical cement-industry findings.

Table 1. Illustrative Pareto analysis of workplace hazard events

Rank	Hazard category	Frequency	Contribution (%)	Cumulative (%)
1	Dust exposure	28	28	28
2	Slips, trips and falls	18	18	46
3	Machinery and conveyors	16	16	62
4	Manual handling	12	12	74
5	Noise exposure	9	9	83
6	Work at height	7	7	90
7	Mobile equipment	5	5	95
8	Electrical hazards	3	3	98

9	Thermal and heat hazards	2	2	100
Total		**100**	**100**	**100**

4.2 Interpretation of the Pareto Distribution

The illustrative data show that dust exposure is the most frequently recorded category, representing 28% of the total. Slips, trips and falls contribute 18%, while machinery and conveyor hazards account for 16%.

Together, these three categories represent 62% of the recorded events. When manual handling and noise exposure are included, the cumulative contribution rises to 83%.

The findings illustrate how Pareto analysis can identify a limited number of categories that account for a substantial proportion of reported workplace events.

However, the results do not establish that dust exposure causes the greatest number of serious injuries or the highest overall risk. The categories may differ in severity, duration of exposure, and potential long-term consequences.

4.3 Proposed Pareto Chart

The chart for the illustrative dataset should display:

- Hazard categories in descending order of frequency on the horizontal axis.
- Number of recorded events as vertical bars.
- Cumulative percentage as a line on a secondary vertical axis.
- An optional reference line at 80% cumulative contribution.

The chart would show the cumulative contribution crossing 80% after the fifth category, noise exposure.

For an empirical study, the chart should be generated from verified records and labelled with the study period, plant location or anonymised site identifier, and data source.

4.4 Identification of Priority Hazards

Based on the illustrative frequency ranking, the following categories would be investigated first:

Priority 1: Dust exposure. Review dust generation points, enclosure integrity, local exhaust ventilation, housekeeping methods, and personal exposure monitoring.

Priority 2: Slips, trips and falls. Examine material spills, floor conditions, walkway obstruction, drainage, access routes, and inspection practices.

Priority 3: Machinery and conveyors. Review fixed guarding, emergency stops, conveyor pull-cords, isolation procedures, maintenance practices, and access to moving components.

Priority 4: Manual handling. Assess bag handling, repetitive tasks, lifting techniques, mechanical aids, and workstation layout.

Priority 5: Noise exposure. Identify high-noise equipment, undertake representative exposure measurements, evaluate engineering controls, and review hearing conservation arrangements.

These priorities are provisional and based on frequency alone. Actual intervention order must also account for severity, exposure magnitude, statutory obligations, and the adequacy of existing controls.

5. Discussion

5.1 Significance of Dust Control

Dust is an important hazard in cement manufacturing because exposure may occur repeatedly across different operations. Effective controls should prioritise preventing dust release at source, enclosing transfer points, maintaining extraction systems, and using suitable industrial vacuum cleaning methods.

Dry sweeping and compressed-air cleaning should be avoided where they generate hazardous airborne dust. Exposure monitoring should distinguish total particulate matter from the respirable fraction and, where relevant, assess respirable crystalline silica.

Respiratory protective equipment should supplement, rather than replace, feasible engineering controls. Selection must consider the contaminant, measured exposure, required protection factor, fit testing where applicable, and maintenance.

5.2 Prevention of Slips, Trips and Falls

Cement plants involve frequent movement of workers, materials, and equipment. Spilled raw materials, accumulated dust, damaged flooring, poor lighting, and obstructed walkways can increase the likelihood of falls.

A structured housekeeping programme should define inspection responsibilities, cleaning frequency, spill-response procedures, and clear access routes. Walkways should be adequately illuminated and maintained, with suitable handrails and edge protection wherever required.

5.3 Machinery and Conveyor Safety

Crushers, mills, conveyors, packing machines, and rotating equipment can cause severe injuries if workers come into contact with moving parts or equipment starts unexpectedly during maintenance.

Effective safeguards include fixed or interlocked guards, accessible emergency-stop systems, safe maintenance access, and verified energy isolation. Lockout/tagout or the applicable documented hazardous-energy-control procedure should be implemented before maintenance, cleaning, or jam clearing where unexpected energisation could cause injury.

Safety inspections should assess both the presence of safeguards and their effectiveness under actual operating conditions.

5.4 Ergonomic Risk Reduction

Manual handling may involve repetitive lifting, pushing, pulling, and carrying. These activities can contribute to musculoskeletal discomfort and injuries.

Preventive measures include mechanised bag handling, conveyors, palletisation, lifting aids, task redesign, rotation where appropriate, and assessment of lifting frequency and posture. Training alone is insufficient where the underlying task design creates excessive physical demands.

5.5 Noise Management

Grinding mills, crushers, fans, compressors, and other industrial equipment may generate substantial noise. A noise assessment should identify exposed groups and determine whether engineering or administrative controls are necessary.

Controls may include equipment enclosure, acoustic treatment, maintenance of worn components, isolation of noise sources, and suitable hearing protection. Where indicated, hearing conservation programmes should include worker training and audiometric surveillance.

5.6 Integrating Frequency and Severity

The central contribution of the proposed approach is its use of Pareto analysis as a prioritisation aid rather than a complete risk assessment.

A high-frequency hazard may justify a plant-wide improvement programme, while a rare but potentially catastrophic event may require immediate corrective action. The two types of priorities should therefore be maintained in parallel:

1. **Frequency priority:** Categories contributing most to recorded events.
2. **Risk priority:** Hazards presenting unacceptable or potentially catastrophic consequences.

This approach reduces the likelihood that low-frequency, high-consequence hazards will be overlooked.

5.7 Practical Implications for Cement Plant Management

The proposed framework can help safety departments translate inspection findings into measurable improvement plans. A monthly review can identify recurring hazards, assign corrective actions, establish deadlines, and evaluate whether the number of events decreases after intervention.

For meaningful comparisons, management should use suitable denominators where available, such as events per 200,000 working hours, events per worker, exposure exceedances per monitoring sample, or incidents per production unit. Raw counts alone may be misleading when workforce size, production volume, or reporting practices change.

6. Recommended Safety Intervention Framework

The following measures are proposed for implementation and evaluation in cement manufacturing facilities.

Hazard category	Recommended interventions	Suggested performance indicator
Dust exposure	Enclosure, extraction, dust suppression, exposure monitoring, appropriate respiratory protection	Personal exposure results and control-system availability
Slips and trips	Housekeeping, spill control, floor maintenance, clear walkways	Repeat findings and fall-related events
Machinery and conveyors	Guarding, energy isolation, emergency stops, preventive maintenance	Critical guarding and isolation deficiencies
Manual handling	Mechanical aids, ergonomic redesign, task assessment	Manual-handling injury rate and ergonomic findings

Noise exposure	Engineering controls, exposure monitoring, hearing conservation	Noise exposure results and audiometric follow-up
Work at height	Safe platforms, edge protection, suitable access systems, fall protection	Work-at-height inspection findings
Mobile equipment	Traffic segregation, reversing controls, speed management, pedestrian routes	Vehicle near misses and collision events
Electrical hazards	Inspection, safe isolation, grounding, competent maintenance	Electrical deficiencies and overdue corrective actions
Thermal hazards	Insulation, barriers, temperature monitoring, heat-stress controls	Heat-related events and control compliance

Performance indicators should be established with clear definitions and baselines. A reduction in reported events should not automatically be treated as improved safety unless reporting completeness is maintained.

7. Proposed Implementation Plan

A practical implementation programme may be organised into four phases.

Phase I: Baseline Assessment

- Define the study boundary and reporting period.
- Collect incident, near-miss, inspection, and exposure records.
- Review existing hazard registers and risk assessments.
- Standardise hazard classification and event-counting rules.

Phase II: Statistical Prioritisation

- Validate and classify records.
- Calculate frequencies, percentages, and cumulative percentages.
- Generate the Pareto chart.
- Conduct a separate severity-based risk assessment.

Phase III: Corrective Action

- Assign responsible personnel to priority hazards.
- Establish engineering and administrative controls.
- Provide necessary training and supervision.
- Set completion deadlines and verification requirements.

Phase IV: Monitoring and Review

- Compare results with the baseline.
- Review exposure measurements and control performance.
- Investigate repeated events and overdue actions.
- Update hazard priorities using new evidence.

8. Limitations of the Study

The principal limitation of this manuscript is that the numerical analysis is illustrative rather than empirical. No actual cement plant dataset was supplied, and the reported frequencies must not be represented as measured findings.

In a field study, the following limitations should be considered:

1. Underreporting of minor injuries and near misses.
2. Differences in event definitions across departments.
3. Changes in workforce size, production volume, and working hours.
4. Variation in exposure duration and task-specific hazards.
5. Limited ability of frequency counts to represent injury severity or chronic disease risk.
6. Potential bias arising from incomplete inspection records or inconsistent monitoring.

Future research should use verified multi-period data, standardised hazard definitions, exposure measurements, and severity-based risk scoring. Where possible, intervention effectiveness should be evaluated through before-and-after comparisons using appropriate exposure or workforce denominators.

9. Conclusion

This paper proposes a Pareto-based framework for evaluating and prioritising workplace hazards in the cement industry. The method combines hazard classification, frequency analysis, cumulative percentage calculations, and graphical presentation to identify categories that contribute substantially to recorded events.

In the hypothetical example, dust exposure, slips and trips, machinery and conveyor hazards, manual handling, and noise exposure account for 83% of the total recorded events. This result demonstrates the analytical procedure but does not establish an actual industry-wide distribution.

The framework supports targeted safety interventions, including dust suppression, improved housekeeping, machinery guarding, hazardous-energy isolation, ergonomic improvements, and noise control. Crucially, Pareto ranking should be complemented by a formal risk assessment to ensure that hazards with potentially catastrophic consequences receive appropriate attention even when infrequently reported.

The proposed approach offers a practical foundation for data-driven occupational safety management. Its empirical value should be established through implementation in a real cement manufacturing facility, using validated workplace records and documented evaluation criteria.

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