

Hazard Identification and Risk Control Framework for Rolling Mill Manufacturing Processes

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Abstract

Rolling mill manufacturing is one of the most critical operations in the steel industry due to the presence of heavy rotating equipment, high-temperature materials, hydraulic systems, cranes, electrical installations, and continuous production processes. Workers are exposed to hazards such as entanglement, crushing, burns, explosions, falling materials, electrical shock, excessive noise, and ergonomic stress. Traditional safety practices often focus on incident response rather than proactive hazard identification and systematic risk control. This study proposes a **Hazard Identification and Risk Control Framework (HIRCF)** for rolling mill manufacturing processes that integrates Hazard Identification and Risk Assessment (HIRA), Failure Mode and Effects Analysis (FMEA), Bow-Tie Analysis, Job Safety Analysis (JSA), and the Hierarchy of Controls within the ISO 45001 Occupational Health and Safety Management System. The framework identifies major operational hazards, evaluates their associated risks using a risk matrix, prioritizes corrective actions, and establishes engineering, administrative, and behavioral controls. The proposed framework supports continuous monitoring through key safety performance indicators and digital technologies, enabling steel industries to reduce accidents, improve operational reliability, and strengthen regulatory compliance.

Keywords: Rolling mill, Hazard identification, Risk control, HIRA, FMEA, Bow-Tie Analysis, ISO 45001, Occupational safety, Steel manufacturing.

Introduction

The steel industry plays a vital role in economic development by supplying materials for infrastructure, transportation, construction, and manufacturing. Rolling mills convert billets, blooms, slabs, and ingots into finished products such as rails, structural sections, bars, rods, and plates. These operations involve reheating furnaces, rolling stands, shearing machines, cooling beds, conveyors, cranes, hydraulic systems, and material handling equipment operating continuously under demanding conditions.

The complexity of rolling mill operations introduces multiple hazards that may result in severe injuries, production losses, equipment damage, and environmental impacts. Common accident scenarios include:

- Contact with moving rollers and rotating shafts
- Crushing between equipment and materials
- Burns from hot metal and furnace operations
- Hydraulic system failures
- Electrical hazards
- Falling materials during lifting operations
- Slips, trips, and falls
- Noise-induced hearing loss
- Ergonomic disorders due to repetitive tasks

Although industries adopt various safety measures, accident investigations frequently reveal shortcomings in hazard identification, risk assessment, maintenance planning, supervision, and worker competency. Therefore, a structured hazard identification and risk control framework is necessary to systematically identify hazards, evaluate risks, implement preventive controls, and continuously improve safety performance.

Literature Review

Research on industrial safety highlights the importance of proactive risk management in reducing workplace accidents. Heinrich's Domino Theory established the relationship between unsafe acts and accident occurrence, while Bird's Loss Causation Model emphasized management system deficiencies as root causes of incidents. Modern safety management systems advocate integrating engineering controls, administrative procedures, and human factors.

Studies on steel manufacturing identify rolling mills as high-risk environments due to high temperatures, mechanical energy, heavy material movement, and continuous production. Hazard Identification and Risk Assessment (HIRA) has been widely applied to prioritize hazards based on likelihood and severity. Failure Mode and Effects Analysis (FMEA) assists in identifying equipment failures and determining Risk Priority Numbers (RPN), whereas Bow-Tie Analysis illustrates the relationship between causes, preventive barriers, hazardous events, and recovery controls.

Recent research also recommends adopting digital technologies such as Industrial Internet of Things (IIoT), artificial intelligence (AI), predictive maintenance, machine vision, and wearable safety devices to improve hazard detection and operational reliability. However, most studies address individual safety techniques rather than an integrated framework specifically designed for rolling mill manufacturing. This study addresses this gap by combining multiple risk assessment tools within a unified safety management framework.

Research Gap

The literature indicates the following gaps:

- Limited integrated safety frameworks for rolling mill operations.
- Insufficient application of multiple risk assessment tools in a single model.
- Lack of systematic linkage between hazard identification and control implementation.
- Limited use of predictive digital technologies in rolling mill safety.
- Inadequate emphasis on continuous monitoring using measurable safety indicators.

Objectives

The objectives of this study are to:

1. Identify major hazards associated with rolling mill manufacturing.
2. Evaluate risks using HIRA and FMEA.
3. Develop a structured Hazard Identification and Risk Control Framework.
4. Recommend engineering, administrative, and behavioral control measures.
5. Improve occupational safety and operational efficiency.
6. Align the framework with ISO 45001 requirements.

Research Methodology

Research Design

A descriptive and analytical case-study approach is adopted.

Data Collection

Primary Data

- Workplace observations
- Safety inspections
- Employee interviews
- Supervisor interviews
- Safety audit reports
- Incident investigation reports

Secondary Data

- ISO 45001 standards
- OSHA guidelines
- Factory safety manuals
- Published research articles
- Company maintenance records

Sample Distribution

Respondent Category Sample Size

Rolling mill operators 60

Maintenance personnel 30

Safety officers 15

Supervisors 20

Engineers 15

Total 140

Rolling Mill Manufacturing Process

The manufacturing sequence generally includes:

1. Raw material charging
2. Reheating furnace
3. Descaling
4. Roughing mill
5. Intermediate rolling
6. Finishing mill
7. Cooling bed

8. Cutting and shearing
9. Inspection
10. Storage and dispatch

Each stage presents distinct hazards that require systematic assessment.

Hazard Identification

Table 1. Major Hazards in Rolling Mill Operations

Activity	Hazard	Possible Consequence
Reheating furnace	Heat exposure	Burns
Rolling stands	Rotating rollers	Entanglement
Material transfer	Falling steel	Crush injuries
Hydraulic system	High-pressure leakage	Injection injuries
Electrical maintenance	Live conductors	Electric shock
Crane operation	Suspended loads	Fatal injuries
Shearing machine	Blade contact	Amputation
Cooling bed	Hot material	Thermal burns
Grinding	Flying particles	Eye injuries
Maintenance	Unexpected startup	Fatal accidents

Hazard Identification and Risk Assessment (HIRA)

Risk is evaluated using a 5×5 matrix.

Risk Score = Likelihood $\times$ Severity

Table 2. HIRA Results

Hazard	Likelihood	Severity	Risk Score	Risk Level
Roller entanglement	4	5	20	Extreme
Furnace burns	3	5	15	High
Crane load fall	3	5	15	High
Hydraulic failure	3	4	12	High
Electrical shock	2	5	10	Medium

Hazard	Likelihood	Severity	Risk Score	Risk Level
Noise exposure	4	2	8	Medium
Slip and fall	3	2	6	Low

Failure Mode and Effects Analysis (FMEA)

Table 3. FMEA

Failure Mode	Cause	Effect	Severity	Occurrence	Detection	RPN
Roller guard failure	Poor maintenance	Entanglement	10	4	3	120
Hydraulic leakage	Seal damage	Fire/injury	9	5	3	135
Crane brake failure	Mechanical defect	Load fall	10	4	4	160
Emergency stop failure	Electrical fault	Major injury	10	3	5	150
Furnace door malfunction	Equipment failure	Burns	9	3	4	108

Priority should be given to failure modes with the highest Risk Priority Number (RPN).

Bow-Tie Analysis

Hazard: Rotating Rolling Stand

Threats

- Missing guards
- Operator error
- Poor maintenance
- Loose clothing
- Unexpected startup

Preventive Barriers

- Fixed machine guards
- Lockout/Tagout (LOTO)
- Preventive maintenance
- Standard operating procedures
- Operator training

Top Event

Worker entanglement in rolling stand.

Recovery Barriers

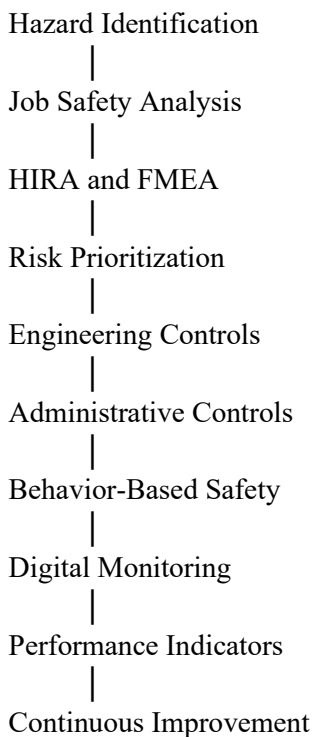
- Emergency stop systems
- Rescue procedures
- First aid
- Medical response
- Incident investigation

Proposed Hazard Identification and Risk Control Framework

The proposed framework consists of eight interconnected stages:

1. Hazard Identification
2. Risk Assessment (HIRA, JSA, FMEA)
3. Risk Prioritization
4. Engineering Controls
5. Administrative Controls
6. Behavioral Safety Programs
7. Digital Monitoring and Predictive Analytics
8. Continuous Improvement

Framework Flow



Risk Control Measures

Engineering Controls

- Machine guarding
- Interlocking systems
- Emergency stop devices
- Light curtains

- Crane anti-collision systems
- Hydraulic pressure monitoring
- Heat shields
- Automated material handling
- Dust extraction systems

Administrative Controls

- Permit-to-work system
- Lockout/Tagout procedures
- Preventive maintenance schedules
- Safety inspections
- Contractor safety management
- Standard operating procedures
- Shift planning

Personal Protective Equipment

- Heat-resistant gloves
- Face shields
- Safety helmets
- Safety shoes
- Cut-resistant clothing
- Hearing protection
- Respiratory protection

Behavioral Safety

- Toolbox talks
- Safety observations
- Near-miss reporting
- Employee participation
- Competency assessments
- Safety leadership programs

Digital Safety Integration

Modern technologies can strengthen the framework through:

- AI-based unsafe act detection using CCTV analytics.
- IoT sensors for temperature, vibration, and hydraulic pressure monitoring.
- Predictive maintenance using machine learning.
- RFID-based worker access control.
- Wearable devices for heat stress and fatigue monitoring.
- Digital dashboards for real-time safety KPIs.
- Mobile applications for hazard reporting and corrective action tracking.

Key Safety Performance Indicators (KPIs)

KPI	Measurement
Lost Time Injury Frequency Rate (LTIFR)	Monthly
Total Recordable Incident Rate (TRIR)	Monthly
Near-miss reports	Number per month
Safety audit compliance	Percentage
Preventive maintenance completion	Percentage
Unsafe acts observed	Number per month
Corrective actions closed	Percentage within target time

Discussion

The integrated framework provides a proactive method for identifying hazards before incidents occur. Combining HIRA, FMEA, and Bow-Tie Analysis enables organizations to evaluate risks from multiple perspectives and prioritize corrective actions effectively. Engineering controls reduce exposure at the source, administrative measures standardize safe work practices, and behavioral interventions strengthen safety culture. The addition of digital technologies supports predictive decision-making, minimizes equipment failures, and enhances real-time monitoring. Organizations implementing this framework can expect reductions in accident frequency, equipment downtime, and operational disruptions while improving regulatory compliance and workforce confidence.

Recommendations

- Conduct comprehensive HIRA reviews annually and after process changes.
- Install advanced machine guarding and interlocking systems.
- Implement AI-enabled video analytics for unsafe behavior detection.
- Introduce predictive maintenance for critical equipment.
- Strengthen Lockout/Tagout compliance during maintenance.
- Improve operator competency through periodic training and simulations.
- Monitor safety performance using digital dashboards and KPIs.
- Encourage reporting of hazards and near misses without fear of reprisal.
- Align all safety procedures with ISO 45001 and relevant national regulations.

Conclusion

Rolling mill manufacturing involves complex mechanical, thermal, electrical, and material handling hazards that require a structured and proactive approach to risk management. The proposed Hazard Identification and Risk Control Framework integrates established risk assessment techniques with engineering controls, behavioral safety, and digital technologies to improve occupational safety and operational performance. By systematically identifying hazards, prioritizing risks, implementing effective controls, and monitoring performance through measurable indicators, steel plants can significantly reduce accident potential and enhance sustainable manufacturing. Future research should validate this framework across multiple rolling mill facilities and explore advanced predictive analytics for dynamic risk assessment.

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