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Review of Hazard Identification and Risk Assessment Strategies in the Steel Industry

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Abstract: *The steel industry is one of the most complex and hazardous industrial sectors because its operations involve high temperatures, molten metal, heavy machinery, pressurized systems, hazardous chemicals, combustible materials, electrical installations, and extensive material-handling activities. Workers may be exposed to physical, chemical, mechanical, thermal, ergonomic, and environmental hazards throughout processes such as raw-material handling, coke production, sintering, iron making, steel making, casting, rolling, finishing, maintenance, and transportation. Hazard Identification and Risk Assessment (HIRA) therefore constitutes a fundamental component of occupational health and safety management in steel plants.*

This review examines major hazard identification and risk assessment strategies applicable to the steel industry, including Job Safety Analysis, Preliminary Hazard Analysis, What-If Analysis, Hazard and Operability Study, Failure Mode and Effects Analysis, Fault Tree Analysis, Event Tree Analysis, Bow-Tie Analysis, Checklist Analysis, and quantitative risk assessment.

Keywords: Steel Industry, Hazard Identification, Risk Assessment, HIRA, Occupational Safety, Process Safety, Risk Management, Industrial Hazards, Accident Prevention.

I. INTRODUCTION

The steel industry is an essential component of modern industrial development and contributes substantially to construction, transportation, manufacturing, infrastructure, energy, and other economic sectors. At the same time, steel production represents a high-risk industrial environment in which several hazardous operations occur simultaneously. Steel plants generally involve complex production chains extending from raw-material storage and preparation to coke making, sintering, blast-furnace operations, basic oxygen or electric arc furnace steelmaking, continuous casting, rolling, finishing, maintenance, and transportation.

These activities involve molten metal, extreme temperatures, moving machinery, cranes, conveyors, high-pressure gases, electricity, chemicals, dust, noise, vibration, and confined spaces. Consequently, occupational accidents and process-safety incidents can have severe consequences for workers, equipment, production continuity, and the surrounding environment.

Hazard identification is the systematic process of recognizing hazards associated with workplace activities, equipment, materials, processes, and environmental conditions. Risk assessment subsequently evaluates the likelihood and potential severity of harmful consequences and assists organizations in prioritizing control measures. Within steel manufacturing, HIRA is particularly important because hazards can interact with each other. For example, a mechanical failure may result in an uncontrolled release of energy, while inadequate maintenance or human error can increase the likelihood of a major incident. Effective assessment therefore requires consideration not only of individual hazards but also of interactions between equipment, people, processes, and organizational factors.

Traditional safety management systems frequently rely on inspections, checklists, incident investigation, and compliance-based assessments. Although these approaches remain valuable, the increasing complexity and automation of steel production require more systematic techniques. Modern HIRA methodologies incorporate structured process

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analysis, consequence modelling, reliability analysis, human-factor assessment, and real-time monitoring. The integration of these approaches can enable steel manufacturers to move from reactive accident prevention toward proactive and predictive risk management.

II. MAJOR HAZARDS IN THE STEEL INDUSTRY

Steel manufacturing contains numerous hazard categories. The nature and magnitude of hazards vary according to the production stage, plant design, materials, technology, and work practices.

Table 1. Major Hazards Associated with Steel-Industry Operations

Hazard Category	Typical Sources	Potential Consequences	Examples of Control Measures
Thermal hazards	Molten steel, furnaces, hot surfaces, slag	Burns, heat stress, fatalities	Heat-resistant PPE, barriers, remote operation
Mechanical hazards	Rolling mills, conveyors, presses, cranes	Crushing, entanglement, amputation	Machine guarding, interlocks, isolation
Chemical hazards	CO, benzene, solvents, acids, alkalis	Poisoning, respiratory injury, chemical burns	Gas monitoring, ventilation, substitution
Fire and explosion	Combustible gases, dust, fuels, electrical systems	Fire, explosion, fatalities	Detection, suppression, explosion prevention
Electrical hazards	Furnaces, substations, cables, electrical panels	Electric shock, arc flash, burns	Earthing, isolation, protective devices
Gas hazards	Carbon monoxide, hydrogen, oxygen, fuel gases	Asphyxiation, poisoning, explosion	Fixed and portable gas detectors
Dust and fumes	Coke, sintering, furnace and welding operations	Respiratory disease, reduced visibility	Local exhaust ventilation, filtration
Noise	Rolling mills, compressors, furnaces	Hearing loss, fatigue	Engineering controls, hearing protection
Ergonomic hazards	Manual handling, repetitive tasks, awkward posture	Musculoskeletal disorders	Ergonomic redesign, mechanical handling
Radiation hazards	Some inspection/testing operations	Tissue damage, long-term health effects	Shielding, controlled access, monitoring
Falling-object hazards	Cranes, elevated platforms, material storage	Head injuries, fractures, fatalities	Exclusion zones, lifting procedures
Confined-space hazards	Tanks, furnaces, ducts, pits	Asphyxiation, toxic exposure	Permit systems, atmospheric testing
Environmental hazards	Heat, poor lighting, weather, vibration	Fatigue, accidents, reduced performance	Environmental monitoring and workplace design

III. HAZARD IDENTIFICATION STRATEGIES

Hazard identification is the first major stage of HIRA. The objective is to systematically identify sources of harm before accidents occur.

1. Workplace Inspection

Workplace inspection is one of the simplest and most widely used hazard-identification methods. Safety professionals, supervisors, engineers, and workers inspect production areas to identify unsafe conditions and practices. In steel plants, inspections may focus on furnace areas, crane operations, conveyors, electrical rooms, maintenance locations, storage yards, and chemical-handling areas.

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The main advantage of inspection is its practical nature. It can identify visible hazards such as damaged guards, oil leakage, obstructed emergency exits, defective lifting equipment, poor housekeeping, and inadequate PPE. However, inspection alone may not identify latent process hazards or complex interactions between equipment failures.

2. Job Safety Analysis

Job Safety Analysis (JSA) divides a job into individual steps and identifies hazards associated with each step. The method is particularly useful for non-routine work, maintenance, repair, shutdown, and start-up operations.

For example, maintenance of a rolling mill may be divided into isolation, access, dismantling, component replacement, testing, and restart. Each stage can then be assessed for mechanical, electrical, thermal, and stored-energy hazards.

3. Preliminary Hazard Analysis

Preliminary Hazard Analysis (PHA) is normally conducted during the early stages of system or process development. It identifies potential hazards before detailed plant design or operation. PHA can be particularly useful when new furnaces, automated systems, production lines, or chemical processes are introduced.

4. Checklist Analysis

Checklist analysis uses predefined questions or criteria to evaluate whether required safety conditions exist. Checklists can be developed from regulations, organizational standards, previous incidents, engineering requirements, and industry experience.

The principal benefit is consistency. However, a checklist may become ineffective if it is outdated or treated merely as a compliance exercise.

5. What-If Analysis

What-If Analysis involves asking structured questions such as:

1. What if cooling water is lost?
2. What if furnace pressure increases?
3. What if a crane brake fails?
4. What if a toxic gas detector fails?
5. What if communication is lost during maintenance?

The technique encourages multidisciplinary thinking and can identify scenarios that may not be apparent during routine inspection.

IV. RISK ASSESSMENT METHODOLOGIES

After hazards have been identified, risk assessment determines the significance of those hazards. Risk is commonly conceptualized using likelihood and consequence, although advanced assessments may include exposure frequency, vulnerability, uncertainty, and existing safeguards.

Table 2. Comparison of Major Risk Assessment Techniques

Method	Approach	Main Application	Advantages	Limitations
JSA	Qualitative	Individual jobs/tasks	Simple and worker-oriented	Limited for complex systems
PHA	Qualitative	New systems/processes	Early hazard identification	Preliminary in nature
Checklist	Qualitative	Routine inspection	Simple and standardized	May miss unexpected hazards
What-If	Qualitative	Process/activity review	Flexible and creative	Depends on team expertise
HAZOP	Qualitative/systematic	Process systems	Detailed deviation analysis	Time-consuming
FMEA	Semi-quantitative	Equipment/components	Identifies failure modes	Less effective for complex interactions
FTA	Quantitative/qualitative	Major accident scenarios	Identifies combinations of failures	Requires detailed system knowledge

ETA	Quantitative/qualitative	Consequence pathways	Evaluates protective barriers	Requires reliable event data
Bow-Tie	Semi-quantitative	Major hazards	Clearly links causes, barriers and consequences	Can oversimplify dynamic systems
Risk Matrix	Semi-quantitative	General workplace risks	Easy prioritization	Subjective risk ratings
QRA	Quantitative	Major hazard installations	Numerical risk estimates	Data and expertise intensive

V. HAZARD AND OPERABILITY STUDY

Hazard and Operability Study (HAZOP) is a systematic methodology used to identify deviations from intended process conditions. It uses guidewords such as No, More, Less, Reverse, Other Than, and As Well As to examine process parameters.

In a steel plant, HAZOP may be applied to gas systems, furnace cooling systems, oxygen supply, fuel systems, hydraulic systems, chemical treatment systems, and continuous casting operations. For example, the deviation "No Flow" in a furnace cooling-water system could indicate a potential loss of cooling, resulting in equipment damage or a serious process incident.

HAZOP's principal strength is its systematic and multidisciplinary nature. Its limitation is that comprehensive studies can require considerable time and experienced personnel.

VI. FAILURE MODE AND EFFECTS ANALYSIS

Failure Mode and Effects Analysis (FMEA) examines individual equipment or component failure modes and their potential consequences. In steel manufacturing, FMEA can be applied to pumps, cooling systems, cranes, hydraulic systems, electrical equipment, sensors, conveyors, and automated production systems.

Each failure mode can be assessed according to factors such as severity, occurrence, and detectability. A priority value can then be used to determine which failures require attention.

FMEA is particularly useful for maintenance planning and reliability improvement. However, traditional FMEA may focus heavily on individual component failures and may not adequately represent complex interactions among multiple failures.

VII. FAULT TREE AND EVENT TREE ANALYSIS

Fault Tree Analysis (FTA) begins with an undesired top event, such as a furnace explosion or toxic-gas exposure, and works backward to identify combinations of failures that could produce that event.

Event Tree Analysis (ETA), by contrast, begins with an initiating event and evaluates possible consequences depending on the success or failure of safety barriers.

These techniques can be combined. For example:

Initiating event → Safety-system response → Barrier success/failure → Final consequence

Such approaches are valuable for major accident scenarios because they help engineers understand how technical and organizational failures can combine to produce severe outcomes.

VIII. BOW-TIE RISK ASSESSMENT

Bow-Tie Analysis provides a visual representation of the relationship between hazards, causes, preventive barriers, top events, mitigating barriers, and consequences.

Table 3. Example of a Bow-Tie Structure for a Steel Plant

Element	Example
Hazard	High-pressure combustible gas

Threats	Leakage, pipe failure, incorrect valve operation
Preventive barriers	Inspection, pressure control, isolation systems
Top event	Uncontrolled gas release
Mitigating barriers	Gas detection, emergency shutdown, fire suppression
Consequences	Fire, explosion, injury, equipment damage
Recovery measures	Emergency response, evacuation, medical assistance

Bow-Tie Analysis is particularly useful for communicating complex risks to operators and managers because the relationship between causes and consequences is visually clear.

IX. QUANTITATIVE RISK ASSESSMENT

Quantitative Risk Assessment (QRA) attempts to express risk numerically. It may incorporate accident frequencies, failure probabilities, exposure levels, consequence modelling, and individual or societal risk.

In major steel plants, QRA can be applied to scenarios involving combustible gases, oxygen systems, fuel storage, chemical releases, explosions, and major fires. Quantitative modelling can support decisions regarding plant layout, emergency planning, safety distances, protective systems, and resource allocation.

However, QRA requires reliable data and specialized expertise. Uncertainty in failure rates, human behaviour, environmental conditions, and consequence models should therefore be explicitly considered.

X. RISK MATRIX APPROACH

Risk matrices are commonly used in industrial safety management because they provide a relatively simple mechanism for prioritizing hazards.

A typical risk score can be represented conceptually as:

Risk = Likelihood × Consequence

For example, a hazard with frequent exposure and potentially fatal consequences would receive a higher priority than a hazard with rare exposure and minor consequences.

Table 4. Illustrative Risk Classification Matrix

Likelihood	Minor	Moderate	Major	Severe
Rare	Low	Low	Medium	Medium
Unlikely	Low	Medium	Medium	High
Possible	Medium	Medium	High	High
Likely	Medium	High	High	Very High
Almost certain	High	High	Very High	Very High

Risk matrices are easy to understand and useful for workplace prioritization. Nevertheless, numerical categories can create a false impression of precision when probability and severity ratings are highly subjective.

XI. HIERARCHY OF CONTROLS

Risk assessment should not end with risk ranking. Identified risks must be reduced using appropriate control measures. The hierarchy of controls generally prioritizes measures from most effective to least effective.

Table 5. Hierarchy of Controls Applied to Steel-Industry Hazards

Control Level	Application in Steel Industry
Elimination	Remove unnecessary hazardous maintenance activities
Substitution	Replace hazardous chemicals with less hazardous alternatives
Engineering controls	Guarding, automation, ventilation, interlocks, remote operation

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Administrative controls	SOPs, training, permits, work scheduling, signage
PPE	Helmets, gloves, face shields, respirators, heat-resistant clothing

Engineering controls and elimination are generally preferred over reliance on administrative controls and PPE because they reduce dependence on individual behaviour.

XII. HUMAN FACTORS IN STEEL-INDUSTRY RISK ASSESSMENT

Human factors are an important component of industrial risk. Operators may make errors because of fatigue, inadequate training, poor communication, excessive workload, confusing interfaces, environmental stress, or organizational pressures.

A modern HIRA should therefore consider:

1. Operator competence and training.
2. Fatigue and working hours.
3. Communication between departments.
4. Emergency decision-making.
5. Human-machine interfaces.
6. Maintenance errors.
7. Permit-to-work systems.
8. Contractor management.
9. Shift handover.
10. Safety culture and organizational leadership.

Human-factor analysis is particularly important during non-routine activities such as shutdowns, maintenance, commissioning, and emergency response.

XIII. ROLE OF TECHNOLOGY IN MODERN HIRA

Digital technologies are increasingly transforming industrial safety management. Internet-connected sensors can continuously monitor temperature, pressure, gas concentration, vibration, equipment condition, and environmental parameters. Data analytics can then identify abnormal patterns before they develop into failures.

Artificial intelligence and machine-learning techniques can potentially support predictive safety systems by analyzing historical accident records, near-miss reports, equipment data, environmental measurements, and worker observations. Predictive maintenance can also reduce the likelihood of equipment-related incidents by identifying signs of degradation before catastrophic failure.

Wearable technologies may provide information about worker location, exposure, fatigue indicators, or proximity to hazardous equipment. Digital permit-to-work systems can improve control over high-risk maintenance activities. However, technology should supplement rather than replace established risk-management principles. Poor-quality data, inadequate cybersecurity, inappropriate algorithms, and overreliance on automated warnings can introduce new risks.

Table 6. Proposed Integrated HIRA Framework

Stage	Key Activity	Typical Tools
1. Process mapping	Identify production and support activities	Process flow diagrams
2. Hazard identification	Identify physical, chemical, mechanical and organizational hazards	Checklist, JSA, PHA
3. Scenario development	Identify credible accident scenarios	What-If, HAZOP
4. Risk analysis	Estimate likelihood and consequence	Risk matrix, FMEA
5. Major accident analysis	Evaluate complex failure pathways	FTA, ETA, Bow-Tie
6. Quantification	Estimate numerical risk where necessary	QRA

7. Control selection	Apply hierarchy of controls	Engineering and administrative controls
8. Implementation	Introduce controls	SOPs, training, engineering modifications
9. Verification	Check effectiveness	Audits, inspections, monitoring
10. Continuous improvement	Update assessment	Incident/near-miss data and management review

XIV. DISCUSSION

The review demonstrates that steel-industry HIRA requires a multidimensional approach because hazards arise from both routine and non-routine activities. Simple inspection and checklist methods are valuable for identifying visible workplace hazards, whereas JSA is more suitable for task-level risks. HAZOP provides deeper analysis of process deviations, while FMEA is useful for equipment reliability and maintenance planning. FTA and ETA are particularly useful for major accident scenarios and barrier analysis. Bow-Tie Analysis provides an effective communication framework by connecting causes, preventive barriers, consequences, and mitigation measures.

The choice of methodology should depend on the characteristics of the process and the purpose of the assessment. A small maintenance task does not necessarily require a complex QRA, whereas a major gas, oxygen, furnace, or chemical process may require detailed process hazard analysis and quantitative assessment. Consequently, the most effective approach is not to select one universal method but to establish a layered HIRA system.

Another important finding is that risk assessment should be dynamic. Steel plants continuously change because of new equipment, production targets, automation, maintenance activities, process modifications, and workforce changes. Therefore, HIRA should be reviewed following significant process changes, incidents, near misses, equipment modifications, or changes in legislation and standards.

Worker participation is also essential. Operators and maintenance personnel often possess practical knowledge about abnormal conditions, equipment behaviour, unsafe shortcuts, and recurring near misses that may not appear in formal documentation. Integrating this experiential knowledge with engineering analysis can improve hazard identification.

XV. CONCLUSION

Hazard Identification and Risk Assessment is a fundamental element of safety management in the steel industry. The complexity of steel manufacturing means that workers can simultaneously encounter thermal, mechanical, chemical, electrical, ergonomic, environmental, and process-safety hazards. Traditional inspection and checklist approaches remain useful for routine workplace hazards, but complex steel-production systems require more systematic methods such as HAZOP, FMEA, FTA, ETA, Bow-Tie Analysis, and QRA. The review indicates that each methodology has specific strengths and limitations, and therefore a combination of complementary techniques is more effective than reliance on a single approach.

An integrated HIRA framework should begin with comprehensive hazard identification, followed by structured risk analysis, prioritization, implementation of the hierarchy of controls, and continuous monitoring. Worker involvement, competent safety professionals, reliable incident data, management commitment, and periodic reassessment are essential components of this process. Emerging technologies such as sensors, predictive analytics, artificial intelligence, automation, and digital monitoring offer opportunities to make HIRA more proactive and dynamic. Nevertheless, technological solutions should be integrated with established engineering principles and human-factor considerations.

Ultimately, effective HIRA in the steel industry should move beyond compliance and documentation toward continuous risk reduction, prevention of serious incidents, protection of workers, and improvement of overall operational resilience. A layered approach combining qualitative, semi-quantitative, and quantitative assessment methods provides the strongest foundation for achieving these objectives.

REFERENCES

1. Aven, T. (2016). Risk assessment and risk management: Review of recent advances on their foundation. *European Journal of Operational Research, 253*(1), 1–13.
2. Aven, T., & Zio, E. (2018). Some considerations on the treatment of uncertainties in risk assessment for practical decision making. *Reliability Engineering & System Safety, 172*, 137–145.
3. Badri, A., Nadeau, S., & Gbodossou, A. (2012). A new practical approach to integrate occupational health and safety in risk management. *Safety Science, 50*(5), 1086–1096.
4. Brown, D. F., & Dunn, W. E. (2007). Application of a quantitative risk assessment method to the evaluation of safety in industrial systems. *Process Safety and Environmental Protection, 85*(1), 1–8.
5. Goetsch, D. L. (2015). *Occupational safety and health for technologists, engineers, and managers* (8th ed.). Pearson.
6. Hale, A., & Borys, D. (2013). Working to rule, or working safely? Part 1: A state of the art review. *Safety Science, 55*, 207–221.
7. Hallowell, M. R., & Gambatese, J. A. (2009). Construction safety risk mitigation. *Journal of Construction Engineering and Management, 135*(12), 1316–1323.
8. Harms-Ringdahl, L. (2001). *Safety analysis: Principles and practice in occupational safety*. CRC Press.
9. Khanzode, V. V., Maiti, J., & Ray, P. K. (2012). Occupational injury and accident research: A comprehensive review. *Safety Science, 50*(5), 1355–1367.
10. Leveson, N. (2011). Applying systems thinking to analyze and learn from events. *Safety Science, 49*(1), 55–64.
11. Maiti, J., & Bhattacharjee, A. (1999). Evaluation of risk of occupational injuries among steel plant workers. *Safety Science, 32*(2), 113–129.
12. Maiti, J., & Bhattacharjee, A. (2001). Risk analysis of occupational injuries in steel plant operations. *Safety Science, 38*(2), 121–136.
13. Marhavilas, P. K., Koulouriotis, D., & Gemeni, V. (2011). Risk analysis and assessment methodologies in the work sites: A classification of methods and comparative analysis. *Journal of Loss Prevention in the Process Industries, 24*(5), 477–523.
14. Mohaghegh, Z., & Mosleh, A. (2009). Incorporating organizational factors into probabilistic risk assessment of complex systems. *Reliability Engineering & System Safety, 94*(4), 767–777.
15. Rausand, M. (2013). *Risk assessment: Theory, methods, and applications*. Wiley.
16. Reason, J. (2000). Human error: Models and management. *BMJ, 320*(7237), 768–770.
17. Reiman, T., & Pietikäinen, E. (2012). Leading indicators of system safety—Monitoring and driving the organizational safety potential. *Safety Science, 50*(10), 1993–2000.
18. Sklet, S. (2006). Safety barriers: Definition, classification, and performance. *Journal of Loss Prevention in the Process Industries, 19*(5), 494–506.
19. Tixier, J., Dusserre, G., Salvi, O., & Gaston, D. (2002). Review of 62 risk analysis methodologies of industrial plants. *Journal of Loss Prevention in the Process Industries, 15*(4), 291–303.
20. Zio, E. (2018). The future of risk assessment. *Reliability Engineering & System Safety, 177*, 176–190.