

Hira-Based Assessment of Fire and Explosion Risks in Manufacturing Plants

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Abstract

Fire and explosion are major industrial hazards that can result in fatalities, property damage, production losses, and environmental consequences. Hazard Identification and Risk Assessment (HIRA) provides a systematic method for identifying hazardous activities, evaluating their likelihood and severity, and establishing appropriate control measures. HIRA commonly uses a risk matrix based on severity and likelihood to prioritize hazards. National Safety Council of India+1 This paper presents a structured HIRA methodology for assessing fire and explosion risks in manufacturing plants, focusing on fuel sources, ignition sources, combustible dust, electrical systems, flammable-material storage, hot work, process equipment, and emergency conditions. The study proposes a 5×5 risk matrix and the hierarchy of controls to identify high-risk activities and recommend engineering, administrative, and emergency controls. The approach can support proactive fire and explosion prevention and continuous improvement of industrial safety performance.

Keywords: HIRA, fire risk, explosion risk, manufacturing plant, hazard identification, risk assessment, safety management, risk matrix, industrial safety.

1. Introduction

Manufacturing plants contain numerous potential sources of fire and explosion, including combustible raw materials, flammable liquids and gases, electrical equipment, hot surfaces, pressure systems, welding operations, and combustible dust. Industrial risk assessments therefore need to consider both routine and abnormal operating conditions.

HIRA is a systematic process for identifying hazards, assessing associated risks, evaluating existing safeguards, and determining additional controls. The National Safety Council of India describes HIRA as a method for addressing foreseeable significant health and safety hazards and notes that 3×3 or 5×5 matrices can be used to combine severity and frequency. National Safety Council of India

Previous industrial studies demonstrate that HIRA can identify process-specific hazards and provide a basis for selecting engineering and administrative controls. PubMed Central (PMC) Indian environmental-risk assessments for manufacturing facilities similarly identify fire, explosion, electrical hazards, fuel storage, and equipment-related events as important accident scenarios. Environment Clearance+1

2. Objectives

The main objectives of this study are:

- To identify potential fire and explosion hazards in manufacturing operations.
- To assess the likelihood and severity of identified hazards.

- To determine risk ratings using a HIRA matrix.izing fire and explosion hazards in manufacturing plants. By combining hazard identification, likelihood assessment, consequence analysis, existing safeguards, and additional controls, organizations can develop a structured approach to reducing industrial risk. The method is particularly useful when integrated with preventive maintenance, process safety, emergency preparedness, and continuous improvement. For complex or high-hazard processes, HIRA should complement rather than replace detailed process-safety and quantitative risk
- To evaluate existing preventive and protective measures.
- To recommend additional risk-control measures.
- To develop a risk register for continuous monitoring and improvement.
- To provide a systematic framework that can be adapted to different manufacturing industries.

3. Methodology

The proposed methodology consists of five major stages:

3.1 Hazard Identification

Plant operations are divided into areas and activities, such as:

- Raw-material storage
- Production/process areas
- Chemical and flammable-liquid storage
- LPG or other fuel-gas systems
- Electrical rooms and transformers
- Boilers and furnaces
- Welding and hot-work activities
- Maintenance operations
- Warehouses
- Waste-storage areas
- Material handling and transfer operations

For each activity, possible sources of fuel, oxygen, and ignition are identified.

3.2 Consequence Identification

Potential consequences include:

- Minor or major fire
- Flash fire
- Pool fire
- Vapour-cloud explosion
- Dust explosion
- Pressure-vessel explosion
- Toxic smoke exposure
- Burns and fatalities
- Equipment and structural damage
- Production interruption
- Environmental damage

Fire and explosion scenarios can involve initiating events, intermediate conditions, safeguards, and eventual loss events; this scenario-based approach is also reflected in formal risk-assessment methodologies. ISO

3.3 Risk Assessment

A 5×5 matrix can be used:

$$\text{Risk Score} = \text{Likelihood} \times \text{Severity}$$

Severity	Description	Score
Negligible	No significant injury/damage	1
Minor	First-aid injury or minor damage	2
Moderate	Serious injury or significant damage	3
Major	Major injury/fatality or major property loss	4
Catastrophic	Multiple fatalities/major disaster	5

Likelihood	Description	Score
Rare	Highly unlikely	1
Unlikely	Could occur occasionally	2
Possible	Could occur periodically	3
Likely	Expected under some conditions	4
Almost certain	Frequent/expected occurrence	5

The resulting risk score ranges from **1 to 25**. The organization's predefined risk-acceptance criteria should determine the categories for low, medium, high, and critical risks.

4. Typical Fire and Explosion HIRA

Activity/Hazard	Possible Consequence	Existing/Typical Controls	Risk
Flammable-liquid storage	Fire/flash fire	Bunding, ventilation, fire protection	High
LPG/fuel-gas leakage	Explosion/fire	Leak detection, isolation valves	High
Welding/hot work	Ignition of combustible material	Hot-work permit, fire watch	High
Electrical short circuit	Electrical fire	Protection devices, inspection	Medium–High
Combustible dust accumulation	Dust explosion/fire	Housekeeping, dust extraction	High
Fuel transfer	Spill and ignition	Bonding/grounding, containment	High
Boiler/furnace operation	Fire/explosion	Interlocks, inspection, controls	High
Chemical incompatibility	Fire/exothermic reaction	Segregated storage, procedures	High

Activity/Hazard	Possible Consequence	Existing/Typical Controls	Risk
Static electricity	Ignition	Earthing/bonding	Medium–High
Improper waste storage	Fire	Segregation and housekeeping	Medium

These are illustrative ratings; an actual plant HIRA must use site-specific operating conditions, inventories, safeguards, incident history, and competent professional judgment.

5. Major Fire and Explosion Hazards

5.1 Flammable Materials

Flammable liquids and gases represent significant fire hazards because leakage or spills can generate combustible atmospheres. Controls should include suitable storage, segregation, ventilation, leak prevention, ignition-source control, and appropriate detection and suppression systems.

5.2 Electrical Hazards

Electrical faults, overloaded circuits, damaged cables, unsuitable equipment, and poor maintenance can provide ignition sources. Electrical installations should therefore be inspected and maintained according to applicable standards and hazardous-area requirements.

5.3 Hot Work

Welding, cutting, grinding, and similar activities can produce sparks and hot surfaces. A hot-work permit system, removal or protection of combustibles, gas testing where applicable, fire extinguishers, and post-work fire monitoring are important controls.

5.4 Combustible Dust

Dust generated by manufacturing processes can accumulate on surfaces or become suspended in air. Under appropriate conditions, ignition can produce rapidly developing fires or explosions. Dust control, housekeeping, extraction, and appropriate equipment selection are therefore important.

5.5 Process Equipment

Boilers, furnaces, reactors, pressure vessels, pipelines, and fuel systems may generate fire or explosion scenarios if containment, pressure control, combustion control, or safety instrumentation fails.

6. Hierarchy of Risk Controls

Risk reduction should prioritize controls rather than relying primarily on PPE. Recommended measures include:

1. **Elimination** – remove the hazardous activity or material where practicable.
2. **Substitution** – replace hazardous materials/processes with safer alternatives.
3. **Engineering controls** – detection, automatic shutdown, ventilation, isolation, explosion protection, fire suppression, guarding, and containment.
4. **Administrative controls** – SOPs, permits, training, inspections, preventive maintenance, emergency drills, and access controls.
5. **Personal protective equipment** – appropriate PPE as the final layer of protection.

7. Emergency Preparedness

A manufacturing plant's HIRA should connect identified scenarios with emergency-response arrangements. These should include:

- Fire detection and alarm systems.
- Suitable fire extinguishing systems.
- Emergency shutdown and isolation.
- Clearly identified evacuation routes.
- Emergency lighting and signage.
- Assembly/muster points.
- Emergency response teams.
- Communication procedures.
- Fire and emergency drills.
- Coordination with external emergency services.

Indian building and fire-safety requirements include industrial occupancies and specific hazardous manufacturing/storage categories; the National Building Code of India provides fire and life-safety provisions relevant to industrial facilities. Fire Department

8. Discussion

HIRA provides a practical semi-quantitative approach for prioritizing fire and explosion hazards. Its major advantage is that it converts a large number of identified hazards into a structured risk register that can be used for corrective-action planning.

However, HIRA should not be treated as a substitute for specialized process-safety studies where the complexity of the process requires them. For major chemical or process facilities, HAZOP, quantitative risk assessment (QRA), consequence modelling, or other specialized studies may be appropriate. QRA, for example, can incorporate initiating-event frequencies, consequence analysis, and risk calculations. National Safety Council of India

The effectiveness of HIRA also depends on accurate plant information, competent assessment teams, appropriate risk criteria, and periodic review. Changes in materials, production processes, equipment, plant layout, or operating procedures should trigger reassessment.

9. Recommendations

Based on the HIRA framework, manufacturing plants should:

Activity/Hazard	Possible Consequence	Existing/Typical Controls	Risk
Flammable-liquid storage	Fire/flash fire	Bunding, ventilation, fire protection	High
LPG/fuel-gas leakage	Explosion/fire	Leak detection, isolation valves	High
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Electrical short circuit	Electrical fire	Protection devices, inspection	Medium–High
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Static electricity	Ignition	Earthing/bonding	Medium–High
Improper waste storage	Fire	Segregation and housekeeping	Medium

- Maintain an updated fire and explosion risk register.
- Conduct periodic HIRA reviews.
- Control ignition sources systematically.
- Implement preventive maintenance for electrical and process equipment.
- Establish effective hot-work permit systems.
- Maintain good housekeeping and control combustible dust.
- Provide appropriate fire detection and suppression systems.
- Inspect emergency exits and evacuation routes.
- Train employees in fire prevention and emergency response.
- Conduct periodic emergency drills.
- Investigate incidents and near misses.
- Verify the effectiveness of corrective actions.
- Apply specialized HAZOP/QRA studies where the process hazard warrants them.

10. Conclusion

HIRA is an effective systematic framework for identifying and prioritizing fire and explosion hazards in manufacturing plants. By combining hazard identification, likelihood assessment, consequence analysis, existing safeguards, and additional controls, organizations can develop a structured approach to reducing industrial risk. The method is particularly useful when integrated with preventive maintenance, process safety, emergency preparedness, and continuous improvement. For complex or high-hazard processes, HIRA should complement rather than replace detailed process-safety and quantitative risk studies.

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