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Assessment of Emergency Preparedness and Response Capability in High-Risk Industrial Operations

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Abstract—

Emergency preparedness is a critical part of safety management in high-risk industries, where an uncontrolled event can escalate into a fire, explosion, toxic release, equipment failure or multiple-casualty incident. Most industrial organisations maintain emergency plans, response equipment and nominated personnel, but the existence of these arrangements does not itself establish that the organisation can respond effectively under actual emergency conditions. This review examines preparedness from a response-capability perspective. Recognised occupational safety and emergency-management standards, regulatory guidance and recent research were reviewed to identify the elements that influence operational readiness. Seven connected dimensions emerged: risk and emergency scenario identification; emergency planning, command and decision-making; Emergency Response Team capability; emergency equipment and infrastructure; communication, evacuation and accountability; drills and exercises; and external coordination, recovery and organisational learning. The paper proposes an Emergency Preparedness and Response Capability Index (EPRCI), a weighted framework that organisations can use to assess these dimensions together and identify weaknesses that conventional document reviews may miss. The review indicates that a material gap can exist between preparedness recorded on paper and capability demonstrated under pressure. Emergency preparedness should therefore be managed as a measurable, risk-based and continuously tested operational capability rather than as a periodic compliance exercise.

Keywords— emergency preparedness; emergency response; industrial safety; high-risk industry; emergency drills; risk management

I. INTRODUCTION

Industrial operations increasingly combine flammable materials, hazardous chemicals, electrical energy, pressurised systems, heavy machinery and automated processes within the same facility. In oil and gas, petrochemicals, chemical manufacturing, mining, power generation and heavy engineering, a relatively small abnormal event can become severe if the initial controls fail. A process-line leak may lead to fire or toxic exposure; an electrical failure may disable emergency lighting or communication; and a localised fire may spread to adjacent equipment. Prevention remains essential, but it cannot eliminate the need to prepare for control failure.

ISO 45001 places emergency preparedness within the occupational health and safety management system and links it with hazard management, operational control, worker protection and continual improvement [1]. At major-hazard facilities, the UK Control of Major Accident Hazards framework also expects organisations to consider a full range of credible major accidents, including low-probability but high-consequence events [2]. These requirements show that emergency arrangements should form part of normal safety management rather than remain a document prepared mainly for regulatory review.

In practice, preparedness can become document-centred. An organisation may have an approved emergency response plan, marked assembly points, trained fire wardens, current telephone lists and periodic drill records. These arrangements are necessary, but none independently demonstrates that the facility can manage a real emergency. Actual events may occur during a night shift, when the normal incident commander is absent, smoke blocks access, noise disrupts radio communication, contractors do not recognise alarms or an emergency pump fails to start. Supervisors must then act with incomplete information while conditions continue to change.

This creates a distinction between emergency preparedness recorded on paper and emergency capability demonstrated in practice. Recent studies in coal mining and chemical industrial parks have similarly evaluated emergency management as a capability that should match the organisation's risk profile [3]-[5]. The present study extends that direction across high-risk industrial operations and develops a practical integrated assessment framework.

A. Research Problem

Traditional audits commonly verify whether an emergency plan exists, equipment is inspected, employees are trained, assembly points are established,

contact numbers are displayed and mock drills have been conducted. These checks provide evidence of compliance, but they do not show how the components will perform together during an emergency. The research problem is the potential gap between documented preparedness and actual response capability.

B. Aim and Objectives

The study aims to identify the factors that determine emergency preparedness and response capability in high-risk industrial operations and to develop a structured framework for periodic assessment. Its objectives are to examine risk-based scenario identification, emergency planning and command, responder competence, equipment readiness, communication, evacuation, drills, external coordination and organisational learning; to identify common gaps between documented arrangements and practical readiness; and to propose an Emergency Preparedness and Response Capability Index for operational benchmarking.

C. Research Question

The main research question is: To what extent do documented emergency preparedness arrangements represent the actual emergency response capability of high-risk industrial operations? Supporting questions address whether emergency arrangements reflect credible risks, competent responders are available across shifts, equipment is accessible and usable, drills test decision-making, communication and command can be maintained under uncertainty, and lessons are converted into measurable improvements.

II. LITERATURE REVIEW

A. Emergency Preparedness in High-Risk Operations

Emergency preparedness begins before an event occurs. The International Labour Organization identifies alarms, first-aid arrangements and emergency lighting as important workplace controls, while making clear that preparedness extends beyond physical equipment [6]. The required capability depends on the risk profile. A general warehouse may principally need fire protection, evacuation and medical arrangements. A chemical facility may also need toxic-release management, chemical protective clothing, decontamination and spill containment. A mine may require underground

rescue, whereas an oil and gas facility must prepare for hydrocarbon releases, process fires and explosions.

The US Occupational Safety and Health Administration requires emergency action plans to address reporting, evacuation, personnel accountability, critical plant operations, rescue and medical duties, alarm systems and employee training [7]. These elements provide a useful basic structure, although major-hazard installations usually require arrangements extending well beyond evacuation.

B. Risk and Emergency Scenario Identification

An organisation cannot prepare effectively for a scenario it has not reasonably considered. Emergency scenarios should therefore arise from HIRA, HAZID, HAZOP, process-safety studies, fire and environmental risk assessments, incident history and lessons from comparable facilities. A generic scenario labelled 'fire emergency' is insufficient because an office fire, storage-tank fire and pressurised process fire require different resources and decisions.

Xiong et al. linked emergency-management capability in coal mining with the characteristics of organisational risk [3]. Pramayu et al. likewise treated risk and threat identification as a principal component of a capability-based mining model, together with physical capability, human resources, prevention, response, evaluation and recovery [4]. The common principle is that response capability should be built around credible site-specific scenarios.

C. Emergency Planning and Command

A written plan establishes responsibilities, communication channels, escalation requirements, evacuation actions and emergency-team duties, but it is useful only when personnel understand it and can translate it into action. ISO 22320 addresses incident-management roles, resources, structure and cooperation and emphasises unity of command, information sharing, flexibility, human factors and continual improvement [8]. These principles matter when an incident escalates and the response priority changes from control to isolation, evacuation, defensive firefighting or protection of neighbouring equipment.

Command arrangements should provide direction without preventing adaptation. The plan should identify authority, alternates and decision thresholds, but responders must still interpret changing conditions. An assessment should therefore consider whether responsible people can make timely decisions, not merely whether their names appear in the plan.

D. Emergency Response Team Capability

Emergency Response Teams may undertake firefighting, first aid, rescue, hazardous-material control, evacuation support and technical isolation. Listing employees as members does not establish capability. Effective response depends on selection, role-specific training, practical exercises, knowledge of site hazards, familiarity with equipment, physical ability where required, communication, leadership and teamwork. Shift coverage is especially important. A facility may have strong daytime coverage because managers, safety staff and maintenance personnel are present, but significantly fewer competent responders at night or during weekends.

E. Emergency Equipment and Infrastructure

Depending on the hazards, response resources may include detection and alarms, hydrants, pumps, extinguishers, foam systems, breathing apparatus, gas detectors, chemical suits, rescue equipment, spill-control materials, emergency showers, lighting, backup power, communication systems and emergency vehicles. UK HSE guidance for major-hazard operations connects emergency planning with resources, training, spill control, evacuation and external services [9].

Inspection status alone is an incomplete measure. Readiness requires three separate questions: Is the equipment available? Is it operational? Can the intended responder use it correctly under emergency conditions? A serviced breathing apparatus set has limited value if no available responder can wear it safely; a functional hydrant may be unusable if access is obstructed. Equipment, location and user competence must therefore be assessed together.

F. Communication Evacuation and Accountability

Communication can fail despite the availability of radios, public-address systems and telephones because of noise, power loss, poor signal coverage or conflicting information. Emergency messages should establish what happened, where it occurred, the hazards involved, the immediate action required, the person in command and the need for escalation. Backup methods should be available when the primary channel fails.

Evacuation should not be judged only by the time taken to reach an assembly point. Evaluation should also cover alarm recognition, route choice, assistance to people requiring support, behaviour at assembly points and accurate accountability of employees, contractors, visitors and drivers. Incorrectly reporting a person as missing can expose responders to an unnecessary search in a hazardous area.

G. Emergency Drills and Exercises

Drills provide one of the clearest opportunities to test emergency arrangements. ISO 22398 links exercises with the development and confirmation of organisational and personnel competence [10]. Their value, however, depends on design. A repeatedly announced evacuation using the same scenario may improve familiarity but reveal little about decision-making or adaptability.

Exercises can introduce a blocked route, unavailable responder, failed communication method, simulated casualty, missing person, power loss, changing wind direction, unavailable equipment or escalation to a second hazard. Zhuge et al., in a study of 1,859 public-health personnel, found that drill effectiveness was influenced by equipment, training quality, leadership attention, frequency, planning, funding and interdepartmental coordination [11]. Although the operational setting differs, the findings support the view that drill frequency alone does not establish effectiveness. Findings must also lead to assigned corrective actions, target dates and re-testing of significant failures.

H. External Coordination Recovery and Learning

Major incidents may exceed internal resources and require municipal or industrial fire services, hospitals, ambulance services, police, environmental agencies, disaster-management authorities or specialist contractors. External responders should become familiar with important hazards and access restrictions before an emergency. A displayed telephone number is not equivalent to joint preparedness; site familiarisation, shared planning and combined exercises provide stronger evidence.

Emergency management continues after immediate control. Recovery may include medical follow-up, environmental monitoring, structural assessment, equipment isolation, business continuity, safe restart, investigation and support for affected workers. The model proposed by Pramayu et al. includes evaluation, improvement and recovery rather than treating response as the final stage [4]. The resulting improvement cycle is: Plan -> Prepare -> Exercise or Respond -> Review -> Correct -> Re-test.

I. Research Gap

Standards and guidance cover emergency planning, incident management, evacuation, exercises and major-hazard response, and recent research has developed more sophisticated capability models. Jin et al. developed a chemical-industrial-park maturity model using information from 150 chemical accident cases [5], while Pramayu et al. identified gaps between policy and implementation in mining [4]. Nevertheless, industrial reviews frequently assess emergency elements individually: the plan is available, equipment is inspected, the ERT is trained and a drill has been conducted. What may remain untested is how these elements function together as a response system. This study addresses that practical gap through an integrated framework linking risk, planning, people, equipment, communication, exercises, external support and learning.

III. METHODOLOGY

A. Research Design

The study uses a qualitative analytical design based on structured documentary review and conceptual framework development. No field survey was undertaken at this stage. Accordingly, the paper does not present incident statistics or claim to measure performance at facilities that were not studied. Its purpose is to develop a framework suitable for later use in industrial audits, exercises and empirical research.

B. Sources and Review Process

Three source groups were examined: international occupational safety and emergency-management standards, particularly ISO 45001, ISO 22320, ISO 22325 and ISO 22398; regulatory and institutional guidance from OSHA, the UK Health and Safety Executive and the International Labour Organization; and recent research concerning emergency capability and drills in high-risk sectors. ISO 22325 was particularly relevant because it provides guidance for emergency-management capability assessment through planning, information collection, analysis and reporting [12].

C. Analytical Approach

Recurring themes associated with effective emergency response were coded conceptually and grouped into seven dimensions: risk and emergency scenario identification; emergency planning, command and decision-making; Emergency Response Team capability; emergency equipment and infrastructure; communication, evacuation and accountability; emergency drills and exercises; and external coordination, recovery and organisational learning. The

dimensions were then converted into a weighted assessment model. The proposed weights support internal benchmarking and are not statutory or prescribed by ISO.

IV. RESULTS AND DISCUSSION

A. Proposed Emergency Preparedness and Response Capability Index

The Emergency Preparedness and Response Capability Index (EPRCI) assesses whether each emergency-management element is sufficiently developed and demonstrated to support an effective response. It does not merely confirm the element's existence. Table I presents the proposed weighting. Greater weight is assigned to ERT capability because the first minutes of an emergency depend heavily on the people required to interpret information, make decisions and take action.

TABLE I
PROPOSED EPRCI ASSESSMENT STRUCTURE

Assessment dimension	Weight
Risk and emergency scenario identification	15%
Emergency planning, command and decision-making	15%
Emergency Response Team capability	20%
Emergency equipment and infrastructure	15%
Communication, evacuation and accountability	15%
Emergency drills and exercises	10%
External coordination, recovery and organisational learning	10%
Total	100%

B. Rating Method

Each dimension is rated from 1 to 5 using the evidence available from document review, interviews, site inspection, demonstrations and observed exercises. The weighted score is calculated as: EPRCI = SUM [(assessment rating / 5) x dimension weight]. The final result is expressed as a percentage.

TABLE II EPRCI RATING SCALE

Rating	Description
1 - Very Weak	Major arrangements are absent or ineffective
2 - Weak	Basic arrangements exist, but important gaps remain
3 - Adequate	Main requirements are established and generally functional
4 - Strong	Arrangements are well developed, tested and evidenced
5 - Highly Capable	Arrangements are mature, integrated, regularly tested and continually improved

C. Capability Levels

The overall capability bands in Table III are intended for internal comparison and prioritisation. They do not replace regulatory requirements. Organisations should review the total result together with each dimension score because a reasonable overall percentage can conceal a critical weakness in command, responder competence or equipment readiness.

TABLE III
PROPOSED EPRCI CAPABILITY LEVELS

Score	Level	Interpretation
Below 50%	Weak	Significant response gaps exist
50-64%	Developin g	Basic capability exists; major improvement is required
65-79%	Adequate	Preparedness is functional, with improvement opportunities
80-89%	Strong	Capability is well developed and tested
90-100%	Highly Capable	The system is mature, integrated and continually improved

D. Detailed Assessment Criteria

The following criteria translate the seven dimensions into observable evidence. They can be adapted to the facility's hazard profile.

1) Risk and Emergency Scenario Identification

- Major scenarios are identified and linked with current risk assessments.
- Escalation, natural hazards, external events and reduced-manpower conditions are considered where relevant.
- Scenarios are reviewed after process, organisational or legal change and after relevant incidents.

2) Emergency Planning Command and Decision-Making

- The Emergency Response Plan is current, accessible and understood at operational level.
- Roles, authority, escalation levels, backup command and emergency shutdown responsibilities are clear.
- Critical decision points are exercised under changing conditions.

3) Emergency Response Team Capability

- ERT numbers and role-based competence are adequate for every shift.
- Members complete refresher training and practical firefighting, rescue, medical or spill-response exercises as applicable.
- Team leadership, PPE selection, fitness requirements and backup arrangements are demonstrated.

4) Emergency Equipment and Infrastructure

- Resources are available, maintained, accessible, sufficient and suitable for identified scenarios.
- Emergency power, firewater and specialist equipment are reliable where required.
- Available responders can operate the equipment correctly under realistic conditions.

5) Communication Evacuation and Accountability

- Personnel recognise alarms and have primary and alternative communication methods.
- Safe and alternate evacuation routes, assembly points and support for people requiring assistance are established.
- Employees, contractors and visitors can be accounted for accurately, and missing-person reports are controlled.

6) Drills and Exercises

- The programme covers different scenarios and shifts and uses realistic complications.
- Observers assess mobilisation, command, communication, evacuation, accountability and operational response.
- Significant findings undergo root-cause review, assigned corrective action and re-testing.

7) External Coordination Recovery and Learning

- External responders and medical facilities are identified, contacts are current and site hazards are communicated.
- Joint familiarisation or exercises are completed where the risk justifies them.
- Recovery, safe restart, communication of lessons and verification of corrective-action effectiveness are established.

E. Findings from the Review

1) Documentation Does Not Equal Capability

An emergency-management system can be complete on paper and still fail operationally because responsibilities are unclear, the scenario differs from expectations or resources are unavailable. Capability research in mining has similarly identified gaps between policy and implementation [4].

2) Risk Matching Is Essential

Generic plans tend to produce generic responses. High-risk operations require scenario-specific planning and resources. Xiong et al. support this conclusion by connecting capability with the type and nature of organisational risk [3].

3) Human Capability Remains Central

Technology can strengthen emergency management, but people interpret information, decide priorities and operate equipment. Training attendance proves participation, not competence. Practical demonstration and shift-wise availability provide stronger evidence.

4) Drills Can Create False Confidence

A facility may achieve an excellent evacuation time without testing uncertainty, command or technical response. Research on drill effectiveness indicates that training quality, equipment, leadership, coordination and planning matter in addition to frequency [11].

5) Response Depends on Several Functions

Emergency management is not the responsibility of the safety department alone. Operations, maintenance, security, medical personnel, management, contractors and external responders may all be involved. A competent fire team can still be ineffective if an alarm is delayed, process isolation is not completed, responders receive incorrect information, access is blocked or command is unclear.

6) Corrective-Action Closure Indicates Maturity

Repeated findings show that the organisation has not completed the learning cycle. The number of drills is therefore less informative than the timely closure of significant findings, evidence that corrective actions work and successful re-testing.

F. Discussion

The review supports the central argument that emergency preparedness should be judged by demonstrated capability as well as documentation. Consider two hypothetical facilities. Facility A has a detailed plan, extensive equipment and annual drills, but night-shift coverage is weak, contractors are excluded, radio communication is unreliable and corrective actions remain open. Facility B has a simpler plan but conducts scenario-based exercises across shifts, verifies equipment under operating conditions, involves external responders and re-tests important findings. A documentation audit may favour Facility A, while a capability assessment may reach a different conclusion.

Emergency procedures also require a balance between standardisation and flexibility. People need clear roles and initial actions, but no plan can predict every event sequence. ISO 22320's emphasis on roles, resources, cooperation and flexibility is relevant to this balance [8]. The EPRCI integrates these factors through a simple method that can be applied without specialist statistical software. Evidence can be gathered through documents, interviews, site inspection, demonstrations and exercise observations.

The index should not be interpreted only through its final percentage. A facility may score well for planning, equipment and evacuation but poorly for ERT competence. Management should treat a low score in a critical dimension as a priority even when the total lies in an acceptable band.

G. Practical Recommendations

- Link emergency scenarios directly with HAZOP, HIRA, fire, environmental and major-hazard assessments.
- Verify ERT competence through practical demonstration rather than relying only on training records.
- Assess capability separately for day and night shifts, weekends, shutdowns and reduced-manpower periods.

- Introduce realistic complications into drills and periodically test the loss of a normal communication method.
- Monitor alarm activation, ERT mobilisation, command establishment, evacuation, accountability and external-notification times.
- Include contractors in emergency awareness and relevant exercises.
- Arrange site familiarisation or joint exercises with external responders where significant hazards exist.
- Repeat the EPRCI assessment annually and after major incidents, process changes, expansion or exercises revealing serious weaknesses.
- Judge drills by the weaknesses discovered, the quality of corrective actions and successful re-testing, not by a perfect performance alone.

H. Limitations and Future Research

This study is based on documentary review and conceptual analysis rather than direct assessment of industrial facilities. The proposed weights reflect the relative importance identified in the reviewed principles and practical industrial considerations; they have not been statistically validated across sectors. High-risk industries also differ substantially, so the criteria require adaptation to each facility's hazards.

Future research should apply the EPRCI across a diverse sample of facilities and compare its results with observed drill performance, incident records, expert judgement and other safety indicators. Such evidence could test the weighting, examine inter-rater reliability, refine the capability bands and determine whether low scores predict recurring exercise or incident deficiencies.

V. CONCLUSION

Emergency preparedness is a critical defence when preventive controls fail. High-risk industries generally maintain plans, equipment, trained personnel and drill programmes, but the important question is whether these arrangements will work together during an actual emergency. The review shows that capability depends on the interaction of risk identification, planning, competent people, functional equipment, communication, evacuation, command, external coordination and organisational learning.

Preparedness describes what an organisation has arranged; capability describes what it can actually do. The proposed EPRCI offers a practical way to examine that difference across seven connected dimensions. Used with professional judgement and applicable legal requirements, it can help organisations move beyond a compliance-only review and identify weaknesses before an actual emergency exposes them.

Emergency preparedness should therefore be treated as a living operational system. It must be exercised, challenged, reviewed, corrected and re-tested. The quality of an emergency plan is ultimately demonstrated by whether people, systems and resources can work together when conditions no longer follow the expected sequence.

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