



# The Role of Emergency Evacuation Plans in Pro Texting Workers : A Comprehensive Systematic Review

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## ABSTRACT

**Introduction:** Workplace emergencies pose significant risks to worker safety globally. Emergency evacuation plans are critical components of occupational safety, yet their effectiveness in protecting workers varies substantially across settings. This systematic review synthesizes evidence on the role, components, effectiveness, and implementation factors of emergency evacuation plans for worker protection.

**Methods:** A systematic review was conducted following PRISMA guidelines. Eight screening criteria were applied, including worker population focus, emergency evacuation intervention, worker safety outcomes, empirical data, workplace setting, workplace context, evacuation procedures, and worker population focus. Data extraction covered worker populations, evacuation plan types, protective mechanisms, plan components, effectiveness evidence, implementation factors, challenges, and key findings from 80 included studies across diverse industries.

**Results:** Studies spanned healthcare, construction, mining, manufacturing, oil and gas, and other sectors globally. Eight primary plan components were identified: detection/alarm systems, evacuation route design, assembly points, communication protocols, role assignments, training/drills, equipment provision, and emergency services coordination. Integrated multi-component interventions reduced evacuation times by 64% (581 to 212 seconds) and achieved 100% worker survival in severe events. Training improved knowledge by 57-76%, while smart technologies enhanced evacuation efficiency by 35-37%. Critical success factors included regular drills, clear communication, management commitment, and technology integration. Major barriers comprised worker non-compliance (51-70% ignoring instructions), physical obstacles, communication failures, and insufficient training (83.3% demonstrating poor knowledge).

**Conclusion:** Emergency evacuation plans significantly improve worker protection when implemented as integrated systems rather than standalone documents. Effectiveness depends on context-specific tailoring, regular practical training, management commitment, and systematic maintenance. Future efforts should address vulnerable worker populations, technology optimization, and cross-cultural effectiveness.

**Keywords:** Emergency evacuation, worker safety, occupational health, disaster preparedness, systematic review

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## INTRODUCTION

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### Background

Workplace emergencies including fires, explosions, chemical releases, natural disasters, and structural failures pose significant threats to worker safety and survival globally. The International Labour Organization estimates that occupational accidents result in approximately 2.3 million deaths annually, with emergency situations contributing substantially to this burden (1). Emergency evacuation plans represent fundamental components of occupational safety management systems, designed to facilitate orderly and timely worker movement from hazardous environments to safe locations (2,3).

The theoretical foundation of evacuation planning rests on principles of hazard identification, risk assessment, and systematic response coordination (4). Effective plans incorporate detection systems, clear evacuation routes, communication protocols, role assignments, training programs, and coordination with emergency services (5,6). However, despite regulatory requirements across most jurisdictions, substantial variability exists in plan quality, implementation, and effectiveness in protecting workers during actual emergencies (7,8).

Recent decades have witnessed technological advancements including IoT-enabled warning systems (3), agent-based simulation modeling (9,10), and cloud-based emergency management platforms (11). Simultaneously, research has accumulated on human factors affecting evacuation behavior, including decision-making under uncertainty (5), role identification (12), and cultural influences on compliance (13). Yet comprehensive synthesis of this evidence remains limited.

### Problem Statement

Despite widespread recognition of evacuation planning importance, significant gaps persist in understanding what makes plans effective in protecting diverse worker populations across different occupational settings. Workers continue to face preventable injuries and fatalities during emergencies (14,15). Non-compliance rates reaching 51-70% in some contexts (5), inadequate

training (16), physical infrastructure deficiencies (17), and communication failures (18) suggest fundamental shortcomings in current approaches. The COVID-19 pandemic further highlighted vulnerabilities in workplace emergency preparedness (19).

### **Research Gap**

Previous reviews have examined specific aspects of evacuation planning, including fire safety engineering (20), hospital evacuations (21), and mining emergencies (22). However, no comprehensive systematic review has synthesized evidence across all industries on the effectiveness of evacuation plans specifically for worker protection. Critical gaps include: (1) lack of integrated analysis across diverse occupational settings, (2) insufficient synthesis of quantitative effectiveness data, (3) limited examination of implementation factors and barriers, (4) absence of consolidated best practice frameworks, and (5) inadequate attention to vulnerable worker populations (23-25).

### **Research Questions**

This systematic review addresses the following questions:

- What are the essential components of emergency evacuation plans that contribute to worker protection?
- How effective are evacuation plans in improving worker safety outcomes during emergencies?
- What factors influence the successful implementation and effectiveness of evacuation plans?
- What challenges and barriers reduce evacuation plan effectiveness in protecting workers?
- What best practices and critical success factors enhance worker protection during evacuations?

### **Objectives**

This review aims to:

- Identify and synthesize evidence on evacuation plan components and their protective mechanisms
- Evaluate quantitative effectiveness data on worker safety outcomes

- Analyze implementation factors affecting plan performance
- Document challenges and barriers to effective worker protection
- Develop evidence-based recommendations for improving evacuation planning

### **Hypotheses**

Based on preliminary literature review, we hypothesized that:

- Multi-component integrated evacuation plans would demonstrate superior effectiveness compared to single-element approaches
- Regular practical training and drills would significantly improve worker evacuation performance
- Context-specific tailoring to industry and worker characteristics would enhance plan effectiveness
- Management commitment and resource allocation would correlate with better worker protection outcomes
- Technology integration would improve but not replace fundamental evacuation principles

### **Significance and Novelty**

This review provides the first comprehensive synthesis of evidence on emergency evacuation plans for worker protection across all industries. Its novelty lies in: (1) systematic integration of 80 studies spanning diverse occupational settings, (2) quantitative synthesis of effectiveness data including evacuation time reductions and injury prevention, (3) identification of critical success factors and barriers across contexts, (4) development of evidence-based recommendations for practice and policy, and (5) articulation of research priorities for advancing worker evacuation safety.

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## **METHODS**

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### **Protocol**

The study strictly adhered to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 guidelines to ensure methodological rigor and accuracy. This

approach was chosen to enhance the precision and reliability of the conclusions drawn from the investigation.

### Criteria for Eligibility

This systematic review aims to evaluate The Role of Emergency Evacuation Plans in Pro Texting Workers

### Screening

We screened in sources based on their abstracts that met these criteria:

- **Worker Population:** Does the study include workers in any occupational setting as the primary population?
- **Emergency Evacuation Intervention:** Does the study examine emergency evacuation plans as a primary intervention (including plan development, implementation, training, drills, or evaluation)?
- **Worker Safety Outcomes:** Does the study measure worker safety or protection outcomes (such as injury rates, evacuation times, compliance rates, or safety knowledge)?
- **Empirical Data:** Does the study present empirical findings with quantitative or qualitative data (rather than being purely theoretical)?
- **Workplace Setting:** Was the study conducted in real workplace settings or realistic workplace simulations?
- **Workplace Context Focus:** Does the study focus on workplace evacuation rather than solely on general public evacuation without workplace context?
- **Evacuation Procedures:** Does the study examine emergency procedures that involve evacuation (rather than only non-evacuation responses like shelter-in-place)?
- **Worker Population Focus:** Does the study focus on workers rather than exclusively on patients, residents, or students as the primary population?

We considered all screening questions together and made a holistic judgement about whether to screen in each paper.

### Search Strategy

The keywords used for this research based PICO :

| Element          | P<br>(Population)          | I<br>(Intervention/Exposure) | C<br>(Comparison/Context) | O<br>(Outcome)     |
|------------------|----------------------------|------------------------------|---------------------------|--------------------|
| <b>Keyword 1</b> | Workers                    | Occupational Setting         | High-risk Occupations     | Diverse Industries |
| <b>Keyword 2</b> | Emergency Evacuation Plans | Worker Protection Strategies | Evacuation Training       | Safety Systems     |
| <b>Keyword 3</b> | No Intervention            | Pre- vs Post-Implementation  | Different Plan Components | Standard Practices |
| <b>Keyword 4</b> | Worker Safety              | Evacuation Effectiveness     | Injury Prevention         | Emergency Response |

The Boolean MeSH keywords inputted on databases for this research are: (*"Workers" OR "Occupational Setting" OR "High-risk Occupations" OR "Diverse Industries"*) AND (*"Emergency Evacuation Plans" OR "Worker Protection Strategies" OR "Evacuation Training" OR "Safety Systems"*) AND (*"No Intervention" OR "Pre- vs Post-Implementation" OR "Different Plan Components" OR "Standard Practices"*) AND (*"Worker Safety" OR "Evacuation Effectiveness" OR "Injury Prevention" OR "Emergency Response"*)

### Data extraction

- **Worker Population:**

Extract the specific worker population and workplace setting studied, including:

- Industry/sector (mining, construction, healthcare, manufacturing, etc.)
- Job roles/categories of workers covered
- Workplace characteristics relevant to evacuation (underground, high-rise, hazardous materials, etc.)
- Number of workers involved (if specified)

- Any special vulnerabilities or risk factors of the worker population

- **Evacuation Plan Type:**

Extract the type and scope of emergency evacuation plan(s) studied, including:

- Plan scope (site-specific, company-wide, industry standard, regulatory requirement)
- Types of emergencies covered (fire, explosion, structural collapse, chemical release, etc.)
- Plan format (written procedures, digital systems, training protocols, communication systems)
- Whether plan is standalone or integrated with broader emergency management
- Level of detail and comprehensiveness described

- **Protective Mechanisms:**

Extract specific ways the evacuation plan protects workers, including:

- Early warning/detection systems for workers
- Clear evacuation routes and procedures for worker safety
- Communication methods to guide workers to safety
- Coordination of worker movement and crowd control
- Protection of vulnerable workers or those in high-risk areas
- Integration with rescue operations for worker safety
- Any quantified protective effects or risk reductions for workers

- **Plan Components:**

Extract the specific components or elements of evacuation plans that contribute to worker protection, including:

- Emergency detection and alarm systems for workers
- Evacuation route design and signage for worker guidance
- Assembly points and safe areas for workers
- Communication protocols and technologies for workers
- Role assignments and responsibilities for worker safety

- Training and drill requirements for workers
- Equipment provision (self-rescue devices, protective gear, etc.)
- Coordination with emergency services for worker rescue

- **Effectiveness Evidence:**

Extract evidence of how well evacuation plans actually protect workers, including:

- Measured evacuation times and safety outcomes for workers
- Success rates in real emergencies involving workers
- Simulation or drill results showing worker protection
- Before/after comparisons of worker safety with plan implementation
- Injury reduction or fatality prevention attributed to plans
- Worker compliance rates with evacuation procedures
- Any quantitative metrics of plan performance in protecting workers

- **Implementation Factors:**

Extract factors that influence how well evacuation plans protect workers in practice, including:

- Worker training and familiarity with plans
- Management commitment and resource allocation for worker protection
- Workplace physical constraints affecting worker evacuation
- Technology and communication infrastructure supporting worker safety
- Regulatory requirements or standards governing worker protection
- Cultural or organizational factors affecting worker response
- Maintenance and updating procedures for worker protection plans

- **Challenges and Barriers:**

Extract challenges, barriers, or limitations that reduce evacuation plan effectiveness in protecting workers, including:

- Worker non-compliance or confusion during evacuations
- Physical obstacles or design flaws affecting worker escape

- Communication failures or technology problems affecting worker safety
- Insufficient training or awareness among workers
- Resource constraints limiting worker protection measures
- Environmental factors (smoke, noise, darkness) hindering worker evacuation
- Coordination problems between different worker groups or with emergency responders

- **Key Findings:**

Extract the main conclusions about the role of evacuation plans in protecting workers, including:

- Primary findings about worker protection effectiveness
- Critical success factors for worker safety during evacuations
- Recommendations for improving worker protection through evacuation planning
- Identified best practices for protecting different types of workers
- Gaps or weaknesses in current approaches to worker protection
- Future research needs related to worker evacuation safety

**Table 1.** Article Search Strategy

| Database             | Keywords                                                                                                                                                                                                                                                                                                                                                                                                                             | Hits |
|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| Pubmed               | <i>("Workers" OR "Occupational Setting" OR "High-risk Occupations" OR "Diverse Industries") AND ("Emergency Evacuation Plans" OR "Worker Protection Strategies" OR "Evacuation Training" OR "Safety Systems") AND ("No Intervention" OR "Pre- vs Post-Implementation" OR "Different Plan Components" OR "Standard Practices") AND ("Worker Safety" OR "Evacuation Effectiveness" OR "Injury Prevention" OR "Emergency Response")</i> | 1    |
| Semantic Scholar     | <i>("Workers" OR "Occupational Setting" OR "High-risk Occupations" OR "Diverse Industries") AND ("Emergency Evacuation Plans" OR "Worker Protection Strategies" OR "Evacuation Training" OR "Safety Systems") AND ("No Intervention" OR "Pre- vs Post-Implementation" OR "Different Plan Components" OR "Standard Practices") AND ("Worker Safety" OR "Evacuation Effectiveness" OR "Injury Prevention" OR "Emergency Response")</i> | 250  |
| Springer             | <i>("Workers" OR "Occupational Setting" OR "High-risk Occupations" OR "Diverse Industries") AND ("Emergency Evacuation Plans" OR "Worker Protection Strategies" OR "Evacuation Training" OR "Safety Systems") AND ("No Intervention" OR "Pre- vs Post-Implementation" OR "Different Plan Components" OR "Standard Practices") AND ("Worker Safety" OR "Evacuation Effectiveness" OR "Injury Prevention" OR "Emergency Response")</i> | 5    |
| Google Scholar       | <i>("Workers" OR "Occupational Setting" OR "High-risk Occupations" OR "Diverse Industries") AND ("Emergency Evacuation Plans" OR "Worker Protection Strategies" OR "Evacuation Training" OR "Safety Systems") AND ("No Intervention" OR "Pre- vs Post-Implementation" OR "Different Plan Components" OR "Standard Practices") AND ("Worker Safety" OR "Evacuation Effectiveness" OR "Injury Prevention" OR "Emergency Response")</i> | 162  |
| Wiley Online Library | <i>("Workers" OR "Occupational Setting" OR "High-risk Occupations" OR "Diverse Industries") AND ("Emergency Evacuation Plans" OR "Worker Protection Strategies" OR "Evacuation Training" OR "Safety Systems") AND ("No Intervention" OR "Pre- vs Post-Implementation" OR "Different Plan Components" OR "Standard Practices") AND ("Worker Safety" OR "Evacuation Effectiveness" OR "Injury Prevention" OR "Emergency Response")</i> | 21   |

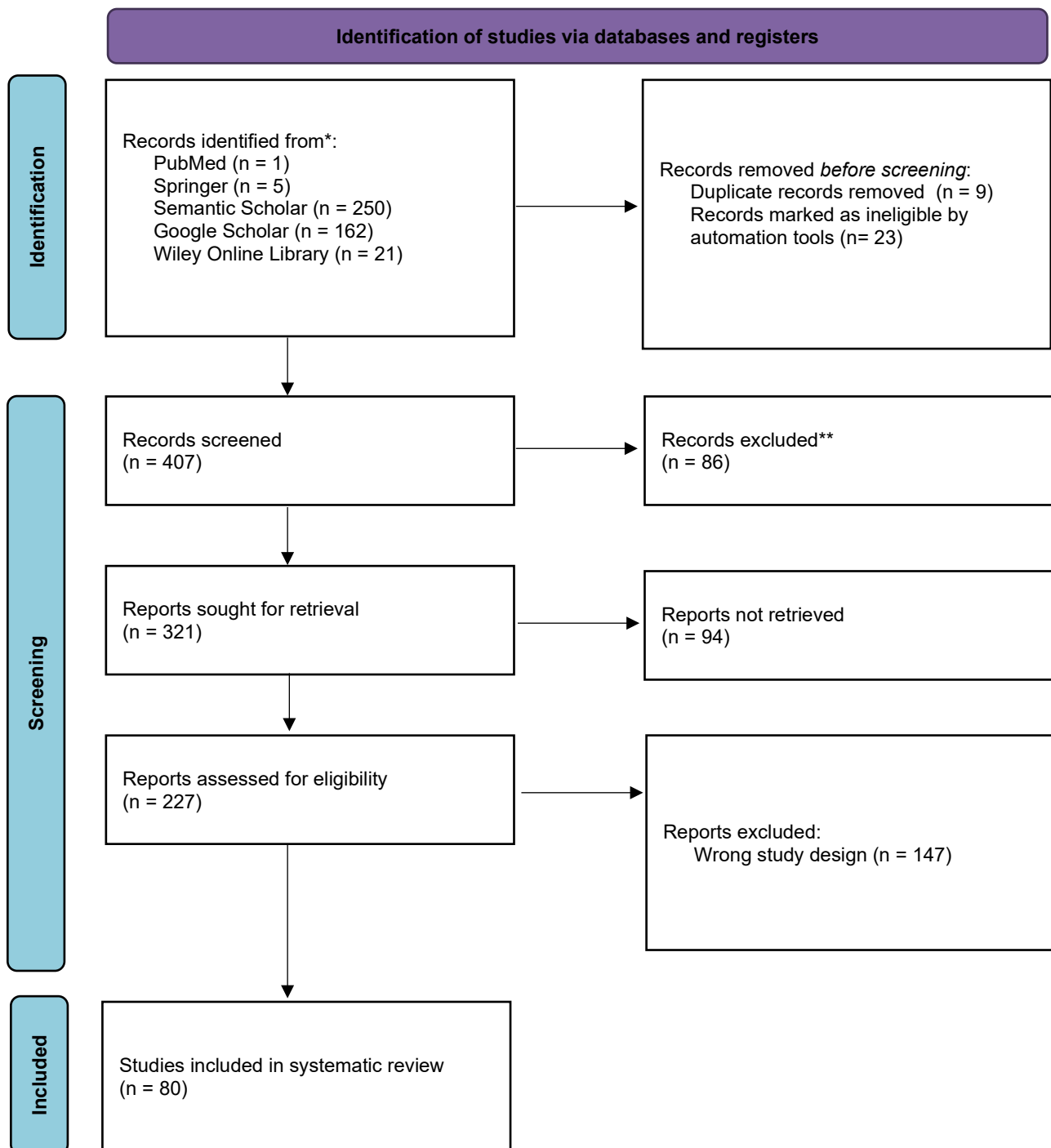


**Figure 1. Article search flowchart**

## RESULTS

### Characteristics of Included Studies

The systematic review included 80 sources examining emergency evacuation plans for worker protection across diverse industries and settings. Studies spanned healthcare, construction, mining, manufacturing, oil and gas, retail, education, tourism, and government sectors. Most studies were site-specific investigations of evacuation planning and implementation, though several examined broader regulatory frameworks or industry standards.

| Study                                   | Industry/Sector           | Worker Population                                             | Study Type                                        | Evacuation Plan Scope                                   |
|-----------------------------------------|---------------------------|---------------------------------------------------------------|---------------------------------------------------|---------------------------------------------------------|
| Ileen F Cronin et al., 2021             | Healthcare                | 11-25 staff per drill in interventional cardiac MRI suite [9] | Intervention study with quarterly drills [9]      | Site-specific, fire and equipment failure scenarios [9] |
| Mufeng Xiao et al., 2021                | Construction              | 100 workers in 13-floor prefabricated building [6]            | Simulation study using PyroSim and Pathfinder [6] | Site-specific fire evacuation [6]                       |
| Nikola Draško et al., 2026              | Engineering design office | Not specified [13]                                            | Fire protection rules development [13]            | Site-specific fire evacuation [13]                      |
| Mária Stopková et al., 2024             | Automotive manufacturing  | 127 morning shift, 80 afternoon/night shift, 207 maximum [14] | Simulation study using Pathfinder [14]            | Site-specific fire safety [14]                          |
| Gustavo Efraín Carrera Oña et al., 2019 | Healthcare                | Not specified [1]                                             | Risk prevention plan implementation [1]           | Site-specific, multiple hazards [1]                     |

| Study                                   | Industry/Sector              | Worker Population                                | Study Type                                                          | Evacuation Plan Scope                 |
|-----------------------------------------|------------------------------|--------------------------------------------------|---------------------------------------------------------------------|---------------------------------------|
| <b>Wattana Chanthakhot et al., 2021</b> | Home appliance manufacturing | ~1000 regular, 700 overtime, 1300 peak [15]      | Simulation with fire dynamics and agent-based modeling [15]         | Site-specific fire evacuation [15]    |
| <b>Ardhila Chadarisman et al., 2025</b> | Mining (coal)                | 2978 workers [3]                                 | Early warning system implementation study [3]                       | Site-specific landslide emergency [3] |
| <b>L. Hulse et al., 2022</b>            | Construction                 | 61 participants from two tall building sites [7] | Unannounced evacuation drills with surveys [7]                      | Site-specific fire safety [7]         |
| <b>Miftachurrohman et al., 2025</b>     | Textile manufacturing        | 82 samples from 102 total weaving workers [16]   | Quasi-experimental design comparing 2D vs 3D evacuation routes [16] | Site-specific fire evacuation [16]    |
| <b>A. Kirilov et al., 2020</b>          | Gas transmission             | Personnel in compressor shops [17]               | Mathematical modeling study [17]                                    | Site-specific fire safety [17]        |

| Study                                                         | Industry/Sector             | Worker Population                     | Study Type                                           | Evacuation Plan Scope               |
|---------------------------------------------------------------|-----------------------------|---------------------------------------|------------------------------------------------------|-------------------------------------|
| <b>Itsamary<br/>Xiomara<br/>Pino<br/>Jimenez et al., 2025</b> | Vehicle washing/lubrication | Not specified [18]                    | Emergency plan design study [18]                     | Site-specific fire evacuation [18]  |
| <b>F. Doğanay et al., 2025</b>                                | Education                   | 212 first drill, 187 second drill [2] | Multi-component intervention study [2]               | Site-specific general emergency [2] |
| <b>M. Maskari et al., 2022</b>                                | Oil and gas                 | Not specified [19]                    | Technology implementation study [19]                 | Site-specific H2S gas release [19]  |
| <b>N. Ferents et al., 2022</b>                                | Manufacturing (paper)       | Not specified [20]                    | Mathematical modeling with FDS software [20]         | Site-specific fire evacuation [20]  |
| <b>H. Putri et al., 2018</b>                                  | Manufacturing (boiler)      | 6 injured in 2012 fire [21]           | Emergency response plan design with Android app [21] | Site-specific fire evacuation [21]  |
| <b>M. Kosim et al., 2025</b>                                  | Office/corporate            | 23 participants [22]                  | Fire drill evaluation study [22]                     | Site-specific fire evacuation [22]  |

| Study                                             | Industry/Sector              | Worker Population                          | Study Type                                 | Evacuation Plan Scope                  |
|---------------------------------------------------|------------------------------|--------------------------------------------|--------------------------------------------|----------------------------------------|
| <b>Peter Chidi Augustine et al., 2024</b>         | Mining (underground)         | 24 individuals in simulation [11]          | Agent-based simulation study [11]          | General emergency evacuation [11]      |
| <b>Juniastuti Ramba et al., 2014</b>              | Construction                 | 82 total (41 contractors, 41 workers) [23] | Survey study on evacuation routes [23]     | Site-specific construction safety [23] |
| <b>Jhony Javier Mendez Siguencia et al., 2017</b> | Water treatment              | Not specified [24]                         | Emergency plan implementation [24]         | Site-specific multiple hazards [24]    |
| <b>M. Hidayat et al., 2017</b>                    | Not specified                | Company X Semarang workers [25]            | Evacuation signage intervention study [25] | Site-specific fire evacuation [25]     |
| <b>Mònica Badia Papaseit et al., 2014</b>         | Pharmaceutical manufacturing | Not specified [26]                         | Emergency plan improvement study [26]      | Site-specific fire evacuation [26]     |
| <b>Wahid Sulaiman et al., 2016</b>                | Retail                       | Not specified [27]                         | Evacuation route evaluation [27]           | Site-specific fire evacuation [27]     |
| <b>Norafneeza Norazahar et al., 2017</b>          | Oil and gas (offshore)       | Not specified [28]                         | Risk management framework development [28] | Offshore installation evacuation [28]  |

| Study                                             | Industry/Sector                    | Worker Population                   | Study Type                                        | Evacuation Plan Scope                  |
|---------------------------------------------------|------------------------------------|-------------------------------------|---------------------------------------------------|----------------------------------------|
| <b>Pazmiño Linzán et al., 2017</b>                | Energy/petroleum                   | Service station workers [29]        | Emergency plan implementation [29]                | Site-specific fire evacuation [29]     |
| <b>R. Bertollo et al., 2013</b>                   | Healthcare                         | 30 rescue personnel, 4 nurses [30]  | Hospital evacuation simulation [30]               | Site-specific hospital evacuation [30] |
| <b>Arroon Ketsakorn et al., 2016</b>              | Plastic manufacturing              | 375 workers from 10 facilities [31] | Cross-sectional study on pre-evacuation time [31] | Industry-specific fire safety [31]     |
| <b>Ana IyELITZIN Castro González et al., 2014</b> | Hotel industry                     | All HOTESA employees [32]           | Safety and hygiene plan development [32]          | Site-specific general emergency [32]   |
| <b>Arip Wibisono et al., 2010</b>                 | Manufacturing (offshore equipment) | Not specified [33]                  | Emergency response plan evaluation [33]           | Site-specific fire evacuation [33]     |
| <b>P. Setiawan et al., 2010</b>                   | Manufacturing (offshore equipment) | Not specified [34]                  | Emergency response plan evaluation [34]           | Site-specific fire evacuation [34]     |
| <b>A. Rehman et al., 2020</b>                     | Mining (underground)               | Not specified [5]                   | Survey on text message alert effectiveness [5]    | Emergency communication study [5]      |

| Study                                 | Industry/Sector        | Worker Population                                      | Study Type                                              | Evacuation Plan Scope                      |
|---------------------------------------|------------------------|--------------------------------------------------------|---------------------------------------------------------|--------------------------------------------|
| <b>M. Cisek et al., 2024</b>          | Office buildings       | 1,333 respondents from 28- and 24-story buildings [35] | Evacuation drill study with surveys [35]                | Site-specific fire evacuation [35]         |
| <b>M. Ebrahemzad ih et al., 2024</b>  | Oil and gas (offshore) | More than 25 personnel [36]                            | Human error probability assessment [36]                 | Offshore platform fire and explosion [36]  |
| <b>Andrea Diaz Eirín et al., 2013</b> | Logistics              | Not specified [37]                                     | Emergency simulation and plan evaluation [37]           | Site-specific emergency [37]               |
| <b>James P. Colgate et al., 2012</b>  | Not specified          | World Trade Center evacuees [38]                       | Post-event analysis study [38]                          | High-rise evacuation [38]                  |
| <b>M. Marzouk et al., 2018</b>        | Construction           | Not specified, labor density varies [39]               | BIM and agent-based simulation [39]                     | Site-specific construction evacuation [39] |
| <b>O. Salami et al., 2023</b>         | Mining (underground)   | Not specified [40]                                     | Literature review [40]                                  | Underground mine fire hazards [40]         |
| <b>R. Gershon et al., 2007</b>        | Not specified          | World Trade Center evacuees [41]                       | Qualitative study with interviews and focus groups [41] | High-rise fire evacuation [41]             |
| <b>Jing Lin et al., 2024</b>          | Healthcare             | 320 healthcare workers [42]                            | Role identification study with questionnaires [42]      | Hospital emergency evacuation [42]         |

| Study                               | Industry/Sector        | Worker Population                                   | Study Type                                               | Evacuation Plan Scope                               |
|-------------------------------------|------------------------|-----------------------------------------------------|----------------------------------------------------------|-----------------------------------------------------|
| <b>Monica Rådestad et al., 2023</b> | Healthcare             | ~4100 staff in Exercise 1, >1800 in Exercise 2 [43] | Simulation exercises at two hospitals [43]               | Hospital evacuation for infrastructure failure [43] |
| <b>O.M. Bopra et al., 2025</b>      | Mining (underground)   | Not specified [44]                                  | Rescue and self-rescue system evaluation [44]            | Underground mine evacuation [44]                    |
| <b>M. Marzouk et al., 2018a</b>     | Construction           | Not specified [45]                                  | BIM and simulation framework [45]                        | Construction site evacuation [45]                   |
| <b>M. Dimas et al., 2024</b>        | Fertilizer industry    | All main building employees [46]                    | Fire emergency response system implementation study [46] | Site-specific fire evacuation [46]                  |
| <b>A. Nissen et al., 2016</b>       | Government/ministerial | 3,344 employees [12]                                | Cross-sectional survey study [12]                        | Post-terrorism workplace safety [12]                |
| <b>Yuanze Du et al., 2020</b>       | Mining                 | Not specified [47]                                  | Cloud-based service development [47]                     | Mine water inrush evacuation [47]                   |
| <b>K. Terumoto et al., 2022</b>     | Tourism                | 196 valid responses [48]                            | Survey on tourism worker perceptions [48]                | Tsunami evacuation support [48]                     |

| Study                              | Industry/Sector         | Worker Population                       | Study Type                                             | Evacuation Plan Scope                |
|------------------------------------|-------------------------|-----------------------------------------|--------------------------------------------------------|--------------------------------------|
| <b>F. Ariyanti et al., 2022</b>    | Manufacturing (shoe)    | 37 participants [10]                    | Participatory learning intervention [10]               | General disaster preparedness [10]   |
| <b>C.M. Григорьев et al., 2024</b> | Manufacturing (candle)  | 200 evacuees [49]                       | Post-evacuation survey and psychological modeling [49] | Fire and explosion evacuation [49]   |
| <b>Hande Kekreli et al., 2026</b>  | Healthcare              | 320 healthcare workers in ICUs/OTs [50] | Cross-sectional survey study [50]                      | Hospital fire evacuation [50]        |
| <b>R. Comstock et al., 2004</b>    | Manufacturing           | 1,200 employees [4]                     | Case study of tornado response [4]                     | Multi-hazard emergency plan [4]      |
| <b>D. Shikhalev et al., 2021</b>   | Retail (shopping malls) | Store staff and security [51]           | Survey and algorithm development [51]                  | Shopping mall evacuation [51]        |
| <b>E. Tarshizi et al., 2016</b>    | Mining (underground)    | Not specified [52]                      | Discrete-event simulation study [52]                   | Underground mine evacuation [52]     |
| <b>A. Nissen et al., 2019</b>      | Government/ministerial  | 3065 initial, 2108 final analysis [53]  | Longitudinal three-wave follow-up study [53]           | Post-terrorism workplace safety [53] |

| Study                                         | Industry/Sector                  | Worker Population    | Study Type                                      | Evacuation Plan Scope               |
|-----------------------------------------------|----------------------------------|----------------------|-------------------------------------------------|-------------------------------------|
| <b>S. Prasad et al., 2012</b>                 | Construction                     | Not specified [54]   | Optimization study using algorithms [54]        | Construction site evacuation [54]   |
| <b>Fachruzzaki Busra et al., 2023</b>         | Mining (coal)                    | 76 workers [55]      | Emergency response plan design [55]             | Site-specific fire evacuation [55]  |
| <b>Faradhiba Nurhaliza Putri et al., 2023</b> | Government services              | Not specified [56]   | Evacuation route evaluation and design [56]     | Fire and earthquake evacuation [56] |
| <b>Клементьев Б.А. et al., 2022</b>           | LNG and oil refining             | Not specified [57]   | Full-scale evacuation modeling [57]             | Fire evacuation [57]                |
| <b>W. Aramiko et al., 2021</b>                | Government (disaster management) | 85 respondents [58]  | Fire protection system evaluation [58]          | Site-specific fire evacuation [58]  |
| <b>G. Reniers et al., 2011</b>                | Chemical manufacturing           | Not specified [59]   | Real options theory methodology validation [59] | Chemical plant fire evacuation [59] |
| <b>D. Gold et al., 2024</b>                   | Multiple high-risk sectors       | 146 respondents [60] | Survey study on complacency [60]                | Workplace fire evacuation [60]      |

| Study                                           | Industry/Sector                  | Worker Population                      | Study Type                               | Evacuation Plan Scope                 |
|-------------------------------------------------|----------------------------------|----------------------------------------|------------------------------------------|---------------------------------------|
| <b>Shirin Laturkar et al., 2026</b>             | Healthcare                       | 150 participants in ICUs/OTs [8]       | Cross-sectional study [8]                | ICU/OT fire evacuation [8]            |
| <b>Алексей Анатольевич Кирилов et al., 2019</b> | Industrial (gas transmission)    | Not specified [61]                     | Method development study [61]            | Industrial fire evacuation [61]       |
| <b>Юлия Андреевна Аниськина et al., 2022</b>    | Healthcare                       | 103 participants in 5 experiments [62] | Experimental evacuation study [62]       | Hospital fire evacuation [62]         |
| <b>Yudiana Hadiyat et al., 2018</b>             | Energy and mineral resources     | Not specified [63]                     | Alternative evacuation method study [63] | High-rise building emergency [63]     |
| <b>Rachmad Caesario et al., 2025</b>            | Tourism                          | Tour guides and community members [64] | Training intervention study [64]         | Water sports accident evacuation [64] |
| <b>W. Aramiko et al., 2021a</b>                 | Government (disaster management) | 115 employees [65]                     | Fire protection system evaluation [65]   | Site-specific fire prevention [65]    |
| <b>S. Santiasih et al., 2010</b>                | Manufacturing                    | Not specified [66]                     | Emergency response plan design [66]      | Fire and chemical release [66]        |

| Study                                          | Industry/Sector        | Worker Population           | Study Type                                         | Evacuation Plan Scope                 |
|------------------------------------------------|------------------------|-----------------------------|----------------------------------------------------|---------------------------------------|
| <b>Ika Agustina Wahyuningtyas et al., 2010</b> | Manufacturing          | Not specified [67]          | Emergency response plan design [67]                | Fire and chemical release [67]        |
| <b>S. Setiawan et al., 2010</b>                | Textile manufacturing  | Not specified [68]          | Emergency response plan evaluation [68]            | Site-specific fire evacuation [68]    |
| <b>Norafneeza Norazahar et al., 2020</b>       | Offshore installations | 16 participants [69]        | Survey on fitness for duty [69]                    | Offshore evacuation training [69]     |
| <b>Novian Nur Syamsu et al., 2010</b>          | Textile manufacturing  | Not specified [70]          | Emergency response plan evaluation [70]            | Site-specific fire evacuation [70]    |
| <b>Atika Ayu Kriswijayanti et al., 2021</b>    | Healthcare             | 64 temporary employees [71] | Cross-sectional study on evacuation knowledge [71] | Hospital evacuation routes [71]       |
| <b>V. Adjiski et al., 2016</b>                 | Mining (underground)   | All employees [72]          | Computer modeling and simulation methodology [72]  | Underground mine fire evacuation [72] |

| Study                                     | Industry/Sector            | Worker Population                             | Study Type                                            | Evacuation Plan Scope             |
|-------------------------------------------|----------------------------|-----------------------------------------------|-------------------------------------------------------|-----------------------------------|
| <b>D. Todorova et al., 2019</b>           | Healthcare                 | 1,043 participants [73]                       | Survey study across hospital types [73]               | Hospital disaster evacuation [73] |
| <b>P. Bambang Sulistyono et al., 2019</b> | Not specified              | PT X employees [74]                           | Emergency response plan implementation study [74]     | Company-wide emergency plan [74]  |
| <b>B. Sekendiz et al., 2014</b>           | Fitness industry           | 1,178 fitness professionals [75]              | Nationwide survey and facility audits [75]            | Fitness facility emergencies [75] |
| <b>M. Sampedro et al., 2017</b>           | Theme park                 | Workers at Ricipamba park [76]                | Emergency plan implementation [76]                    | Multiple hazard types [76]        |
| <b>A. Kirilov et al., 2017</b>            | Manufacturing (compressor) | Not specified [77]                            | Engineering assessment method development [77]        | Fire extinguisher use safety [77] |
| <b>Saavedra Portocarrero et al., 2015</b> | Construction               | Construction workers at refinery project [78] | Emergency plan design [78]                            | Site-specific fire safety [78]    |
| <b>L. Sari et al., 2014</b>               | Retail/commercial          | Permanent employees [79]                      | Cross-sectional study on earthquake preparedness [79] | Earthquake evacuation [79]        |

| Study                                | Industry/Sector           | Worker Population                      | Study Type                      | Evacuation Plan Scope               |
|--------------------------------------|---------------------------|----------------------------------------|---------------------------------|-------------------------------------|
| <b>Chariguamán Cuji et al., 2016</b> | Government administration | Administrative and workshop staff [80] | Emergency plan development [80] | Fire prevention and evacuation [80] |

The studies represent diverse geographical contexts including North America, Europe, Asia, South America, and the Middle East. Full text was available for 45 studies, while 35 were represented by abstracts only. Study designs included experimental interventions, simulations, surveys, case studies, and mathematical modeling approaches. Most studies focused on fire evacuation scenarios, though some addressed earthquakes, landslides, water inrush, chemical releases, explosions, and terrorism-related emergencies.

### Components of Effective Evacuation Plans

Emergency evacuation plans incorporate multiple integrated components to protect workers during emergencies. Analysis of the included studies reveals eight primary categories of plan elements.

### Emergency Detection and Alarm Systems

Detection and warning systems form the foundation of evacuation response. Cronin et al. implemented quarterly drills in a cardiac MRI suite with live volunteers to test response to emergencies [9]. Stopková et al. recommended smoke detectors, sirens, and laser smoke sensors in automotive manufacturing [14]. Doğanay et al. emphasized alarm system activation to alert workers effectively [2]. In offshore oil and gas operations, Maskari et al. deployed cloud-connected personal gas monitoring devices with real-time location tracking and multi-gas sensors [19]. Chanthakhhot et al. integrated fire detection with agent-based evacuation simulation to evaluate alarm effectiveness [15]. The LASER early warning system implemented by Chadarisman et al. in mining achieved 100% reactivity through IoT-enabled immediate notification via sirens and radio [3].

### Evacuation Route Design and Signage

Clear, well-designed evacuation routes are essential for worker safety. Xiao et al. found that re-planning stacking positions of components and equipment optimized evacuation paths in construction sites [6]. Miftachurrohman et al. demonstrated that 3D evacuation route design provided superior visual representation compared to 2D models [16]. Hulse et al. documented reliance on pictorial aids for wayfinding during construction site evacuations [7]. Stopková et al. recommended using side emergency exits and renovating staircases to improve flow [14]. Multiple studies emphasized the importance of adequate exit numbers and widths, with Wibisono et al. calculating specific exit requirements based on building layout and occupancy [33]. Doğanay et al. found that updating and making evacuation plans visible improved worker compliance [2].

### **Assembly Points and Safe Areas**

Designated assembly points enable accountability and safety verification. Draško et al. specified employees gathering outside buildings at safe distances [13]. Marzouk et al. included assembly points in their BIM-based evacuation modeling [39]. Busra et al. recommended relocating or adding meeting points near warehouse areas for better accessibility [55]. Santiasih et al. designated five assembly points, with three inside and two outside the factory area [66]. Putri et al. designed three evacuation routes with assembly points in front of the west building [56]. Ebrahimzadih et al. identified gathering platform residents in specific places as critical for offshore evacuations [36].

### **Communication Protocols and Technologies**

Effective communication guides workers to safety during emergencies. Cisek et al. developed a voice alarm system model with high message intelligibility for high-rise buildings [35]. Busra et al. installed emergency information boards with radio channels and phone numbers [55]. Du et al. created a visualization layer to display data and results in real-time during mine water inrush [47]. Rehman et al. studied text message alerts with increasing detail levels for underground miners [5]. Maskari et al. provided flexibility in accessing applications from control rooms and emergency control centers [19]. Communication systems must account for diverse worker populations, with Hulse et al. noting the importance of pictorial aids for non-native English speakers [7].

## **Role Assignments and Responsibilities**

Clear role definitions ensure coordinated emergency response. Pazmiño Linzán et al. formed brigades with defined functions and responsibilities [29]. Chariguamán Cuji et al. assigned specific functions to brigades for emergency procedures [80]. Cronin et al. documented specific roles for staff members during drills, led by the iCMR nurse practitioner and research nurse [9]. Lin et al. identified five distinct emergency evacuation roles among hospital staff, including organizers, followers, hesitators, self-centered individuals, and emergency responders [42]. Augustine et al. noted that MineSafe applications provide automated safety recommendations for different worker roles [11]. Rådestad et al. emphasized the need for clarifying critical functions through simulation exercises [43].

## **Training and Drill Requirements**

Regular training and drills prepare workers for emergency response. Cronin et al. conducted quarterly in situ evacuation drills with live volunteers [9]. Chadarisman et al. emphasized employee training and regular emergency drills as critical success factors [3]. Terumoto et al. found practical drills and discussions with colleagues more effective than seminars or non-practical training [48]. Nissen et al. identified sufficient escape and evacuation training as key to perceived safety [12]. Comstock et al. attributed successful tornado response to routine practice through drills, tests, and education [4]. Ariyanti et al. used Participatory Learning and Action methods for disaster awareness training [10]. Healthcare studies by Kriswijayanti et al. found training significantly affected worker knowledge of evacuation routes [71].

## **Equipment Provision**

Appropriate safety equipment supports evacuation efforts. Kosim et al. identified fire extinguishers, automatic sprinkler systems, alarms, and hydrants as essential infrastructure [22]. Putri et al. specified requirements for 120 detectors and 3 alarms in workshop settings [21]. Draško et al. included fire extinguishers and emergency lighting in protection plans [13]. Augustine et al. noted the use of smartwatches and VR technology for self-rescue and protective gear [11]. Carrera Oña et al. implemented vertical safety signage and fire-fighting equipment [1]. Tarshizi et al. emphasized planning rescue equipment as part of comprehensive evacuation

strategies [52]. Norazahar et al. studied worker interactions with emergency equipment during escape and evacuation [69].

### **Coordination with Emergency Services**

Integration with external rescue operations enhances worker safety. Draško et al. included procedures for contacting fire departments with relevant information [13]. Bertollo et al. conducted simulations involving both hospital nurses and fire department personnel [30]. Rådestad et al. documented involvement of EMS, police, rescue services, and military in hospital evacuation exercises [43]. Du et al. designed cloud-based services to support manager decision-making during mine emergencies [47]. Ebrahemzadih et al. emphasized communication with rescue ships and adherence to international standards [36]. Multiple studies noted the importance of external coordination but identified gaps in current approaches to this integration.

### **Measured Effectiveness of Evacuation Plans**

Studies that quantified evacuation plan effectiveness demonstrated variable but generally positive outcomes in protecting workers.

### **Evacuation Time Improvements**

Multiple studies documented significant reductions in evacuation times following plan implementation or optimization. Cronin et al. reduced room evacuation times from 71 to 41 seconds through quarterly drills in a healthcare setting [9]. Doğanay et al. achieved the most dramatic improvement, reducing total evacuation time from 581 seconds (9 minutes 41 seconds) to 212 seconds (3 minutes 32 seconds) through multi-component interventions including alarm system activation, evacuation plan updates, basic safety training, and QR code-based information [2]. Time per person decreased from 2.74 seconds to 1.13 seconds, while evacuation speed increased from 21.9 to 52.9 people per minute [2]. Carrera Oña et al. reported evacuation time reduction from 17 to 6 minutes (64.7% reduction) following implementation of vertical safety signage and emergency brigades [1]. Hidayat et al. found evacuation signs reduced average evacuation time from 3.95 to 2.26 minutes [25].

In construction settings, Xiao et al. improved evacuation time from 398.7 seconds to 355.2 seconds by re-planning component stacking positions and reducing personnel numbers [6].

Miftachurrohman et al. demonstrated that 3D evacuation route design reduced evacuation time by 80.9 seconds compared to traditional methods, with the experimental group's time decreasing from 217.12 to 136.27 seconds [16]. Bertollo et al. reduced hospital evacuation simulation time from 14 minutes in the first trial to under 9 minutes in the second trial [30].

### **Worker Safety Outcomes**

Several studies documented actual safety improvements. Cronin et al. reported no patient or staff safety events during four years of implementing evacuation drills in an interventional cardiac MRI suite [9]. Comstock et al. described a remarkable success case where none of 1,200 employees were injured during an F4 tornado, despite extensive structural damage, attributing this to effective emergency response planning and routine practice [4]. Hulse et al. found no injuries during unannounced construction site evacuation drills [7].

### **Compliance and Behavioral Outcomes**

Worker understanding and compliance showed improvement with proper planning and training. Ariyanti et al. documented knowledge improvement from 57% to 76% following disaster awareness and evacuation training [10]. Rachmad Caesario et al. achieved 100% increase in understanding of first aid techniques, with 66.7% of participants able to perform CPR correctly after training [64]. Cisek et al. found that over 86% of respondents had no doubts about evacuating when provided with clear, unambiguous alarm messages [35].

Conversely, some studies revealed concerning non-compliance patterns. Rehman et al. found that 51-70% of miners chose not to shelter in place or go to refuge chambers as instructed, with more detailed emergency messages improving but not eliminating this tendency [5]. Hulse et al. reported that despite most workers believing there was a real threat, only around half evacuated immediately [7].

### **Simulation-Based Performance Metrics**

Simulation studies provided detailed quantitative performance data. Augustine et al. demonstrated that smart evacuation devices improved efficiency by 35% compared to passive signage and by 37% compared to chaotic decision-making scenarios, reducing median evacuation time from 10.8 minutes to 7 minutes [11]. Stopková et al. reported evacuation times of 157.5

seconds for maximum occupancy scenarios, 135.7 seconds for morning shifts, and 108.1 seconds for afternoon/night shifts [14]. Marzouk et al. documented maximum evacuation time of 162 seconds in worst-case construction scenarios [39].

Юлия Андреевна Аниськина et al. established that evacuation start times in healthcare institutions ranged from 83 to 132 seconds with 90% probability when automatic fire alarm systems functioned properly and staff received high-level fire training [62].

### **Success Rate Data**

Chadarisman et al. reported the LASER early warning system achieved 100% reactivity, 96% effectiveness in warning employees, and 50% higher evacuation speed compared to conventional systems [3]. Rådestad et al. documented moderate effectiveness in hospital evacuation exercises, with significant patient evacuations completed within set timeframes [43]. Dimas et al. found that informants implemented fire emergency response procedures well according to established regulations [46].

### **Factors Influencing Evacuation Plan Effectiveness**

Multiple organizational, environmental, and human factors shaped how well evacuation plans protected workers in practice.

### **Worker Training and Familiarity**

Training emerged as a critical determinant of plan effectiveness. Cronin et al. demonstrated that quarterly in situ evacuation drills significantly improved staff preparedness and confidence [9]. Kriswijayanti et al. found that age, work period, education level, and training participation all significantly affected worker knowledge of evacuation routes [71]. Laturkar et al. confirmed that prior training, longer work experience, and previous exposure to fire incidents positively associated with better awareness and preparedness [8]. Terumoto et al. discovered that practical drills and discussions with colleagues proved more effective than seminars or non-practical training in tsunami-prone tourist areas [48].

However, inadequate training remained widespread. Kekreli et al. identified that 125 (83.3%) healthcare participants demonstrated poor or very poor knowledge scores [50]. Shikhalev et al. found personnel training of shopping mall staff needed improvement [51]. Арамико et al.

noted insufficient training in using fire extinguishers and infrequent simulation exercises as major gaps [58].

### **Management Commitment and Resources**

Management support proved essential for effective implementation. Stopková et al. emphasized the need for renovations, equipment upgrades, and installation of AI cameras, representing substantial resource allocation [14]. Nissen et al. found that employees' perceived safety increased when employers showed commitment to security measures [53]. Comstock et al. attributed successful tornado response to the plant's commitment to emergency response planning [4].

Resource constraints limited protection in many settings. Pino Jimenez et al. identified inadequate resource allocation for operational fire extinguishing equipment and safety signage [18]. Sekendiz et al. found many fitness facilities lacked appropriate first aid kits accessible to all staff [75]. Wibisono et al. documented insufficient fire extinguishers and inadequate exits [33].

### **Workplace Physical Constraints**

Physical infrastructure significantly affected evacuation capability. Xiao et al. identified stacking of prefabricated components and construction equipment around evacuation corridors as major obstacles [6]. Stopková et al. noted congestion at main entrances despite instructions to use side exits [14]. Miftachurrohman et al. described narrow paths and machinery in weaving areas as evacuation barriers [16]. Setiawan et al. found large building sizes led to excessive travel distances exceeding safety standards [68].

Multiple studies documented inadequate exit provisions. Castro González et al. identified inadequate signage and emergency exits at HOTESA [32]. Setiawan et al. noted buildings needing additional exits to meet OSHA standards [70]. Putri et al. found incomplete evacuation route implementation and lack of assembly points [56].

### **Technology and Communication Infrastructure**

Technology support varied considerably across settings. Maskari et al. successfully implemented cloud-connected personal gas monitoring devices with real-time tracking [19]. Du et al. developed cloud-based services integrating data from monitoring systems [47]. Doğanay et al.

used QR code-based digital information materials to enhance worker guidance [2].

However, technology failures posed risks. Stopková et al. identified lack of smoke detectors, fire alarms, and camera systems as critical gaps [14]. Hadiyat et al. noted emergency response facilities were not well-managed and lacked routine inspection records [63]. Aramiko et al. found inadequate maintenance of detection systems [65].

### **Regulatory Requirements and Standards**

Compliance with standards shaped plan development. Multiple studies referenced NFPA standards, with Wibisono et al. evaluating plans against NFPA 10 and NFPA 101 [33]. Stopková et al. applied ČSN 73 0804 for evacuation times and exit sizes [14]. Putri et al. used Peraturan Menteri PUPR No: 14/PRT/M/2017 and Permenkes Nomor 48 Tahun 2016 as regulatory frameworks [56].

Kirilov et al. emphasized the importance of regulatory requirements in shaping fire safety approaches [77]. Saavedra Portocarrero et al. ensured adherence to NFPA 10, NTE-INEN-ISO 3864-1, and OHSAS standards [78]. Regulatory compliance provided minimum baselines but did not guarantee effective protection without proper implementation.

### **Cultural and Organizational Factors**

Organizational culture influenced evacuation behavior. Григорьев et al. found that trust built through legitimacy, competence, and effective communication shaped victim compliance with evacuation instructions [49]. Stopková et al. identified that operatives tended to head to familiar meeting points rather than using nearest exits despite training [14]. Cisek et al. noted that frequent drills could lead to reluctance among participants [35].

Lin et al. documented how personal characteristics, organizational factors, and environmental considerations shaped evacuation behaviors among hospital staff [42]. Ariyanti et al. emphasized the importance of organizational commitment through coordination with factory management [10]. Todorova et al. noted psychological impacts of disasters on medical staff affecting their preparedness [73].

### **Maintenance and Updating Procedures**

Ongoing maintenance proved essential for sustained effectiveness. Cronin et al.

emphasized debriefing sessions, action plans, and updates presented at the beginning of each drill [9]. Chadarisman et al. highlighted regular maintenance of laser system equipment [3]. Chariguamán Cuji et al. recommended updating emergency plans every two years [80].

Inadequate maintenance created vulnerabilities. Badia Papaseit et al. found inadequate maintenance of detection systems contributed to plan deficiencies [26]. Hadiyat et al. noted absence of routine inspection records for emergency facilities [63]. Multiple studies emphasized that even well-designed plans degraded without systematic maintenance and updating procedures.

### **Challenges and Barriers to Effective Protection**

Despite comprehensive planning, multiple barriers hindered evacuation plan effectiveness in protecting workers.

#### **Worker Non-Compliance and Confusion**

Non-compliance emerged as a persistent challenge across multiple settings. Stopková et al. found operatives ignored instructions to use side exits and headed to main entrances instead [14]. Rehman et al. documented that miners often chose not to follow evacuation instructions, with 51-70% not sheltering in place or going to refuge chambers as instructed [5]. Cisek et al. identified doubts about the need to start evacuation and reluctance to participate in drills [35].

Confusion during evacuations created additional risks. Bertollo et al. found both nursing staff and firefighters looked to each other for operational direction, creating hesitation [30]. Miftachurrohman et al. noted confusion and lack of direction among workers during evacuations [16]. Lin et al. identified role ambiguity, conflicts, and tension as sources of confusion among hospital staff [42].

#### **Physical Obstacles and Design Flaws**

Physical barriers significantly impeded safe evacuation. Xiao et al. identified stacking of prefabricated components causing congestion and slowing evacuation [6]. Hulse et al. documented barriers preventing access to exclusion zones and congestion from simultaneous worker evacuation [7]. Miftachurrohman et al. found narrow paths cluttered with machinery and goods hindered movement [16].

Design flaws compounded physical obstacles. Wibisono et al. documented inadequate exits

and excessive travel distances in production areas [33]. Castro González et al. identified inadequate signage and emergency exits [32]. Putri et al. found incomplete evacuation route implementation and lack of assembly points [56]. Draško et al. noted unused and jammed doors that could have shortened evacuation time if functional [13].

### **Communication Failures**

Communication breakdowns jeopardized worker safety. Colgate et al. identified communication systems failures as a structural risk factor in high-rise evacuations [38]. Doğanay et al. found insufficient audibility of emergency sirens in some areas [2]. Bertollo et al. noted nursing staff were inundated with inquiries from rescue personnel, creating information overload [30].

Message clarity affected response. Rehman et al. found miners tended to ignore guidance due to unclear or poorly crafted messages [5]. Cisek et al. identified confusion caused by alarms being heard on all floors without location specificity [35]. Norazahar et al. documented poor communication contributing to evacuation difficulties on offshore installations [28].

### **Insufficient Training and Awareness**

Training deficiencies pervaded many workplaces. Pino Jimenez et al. identified lack of formal training in extinguisher use and evacuation procedures [18]. Hadiyat et al. found employees lacked understanding of self-rescue methods [63]. Laturkar et al. documented that 125 (83.3%) participants considered themselves inadequately trained [8].

Awareness gaps compounded training issues. Ramba et al. noted low mean scores indicating need for improvement in worker training on emergency evacuation procedures [23]. Sekendiz et al. found more than one fourth of fitness professionals somewhat or very unaware of emergency evacuation plans [75]. Sari et al. identified insufficient training as a key weakness [79].

### **Resource Constraints**

Limited resources restricted protective capabilities. Kosim et al. identified technical constraints and need for improvements in facilities and infrastructure [22]. Pino Jimenez et al. documented inadequate resource allocation for operational fire extinguishing equipment [18]. Putri et al. noted resource constraints in evacuation planning at labor department facilities [56].

Equipment deficiencies reflected resource limitations. Putri et al. found lack of operational fire extinguishing equipment and safety signage [21]. Wibisono et al. documented insufficient fire extinguishers in terms of capacity and number [34]. Hulse et al. noted need for more comprehensive surveys and data collection [7].

### **Environmental Factors**

Environmental conditions created additional hazards. Norazahar et al. identified cold temperature, strong winds, and darkness hindering offshore evacuations [28]. Xiao et al. found reduced visibility due to smoke reaching danger point within 50 seconds [6]. Ferents et al. noted environmental factors like smoke and gas concentrations as barriers [20].

Bertollo et al. documented safety concerns related to biohazardous waste during hospital evacuations [30]. Hulse et al. identified noise on construction sites leading to hearing impairments and potential for auditory alarms to go unheard [7]. Augustine et al. noted smoke and physical impediments significantly hindering underground mine evacuations [11].

### **Coordination Problems**

Coordination failures between worker groups and emergency responders created vulnerabilities. Bertollo et al. identified confusion between nursing staff and firefighters about operational direction [30]. Rådestad et al. documented issues with ambulance management and communication between hospital incident command groups and EMS [43]. Boptra et al. noted difficulty in conducting rescue operations due to complex conditions making it hard for rescuers to arrive on time [44].

Internal coordination also proved challenging. Doğanay et al. found difficulty in directing students to assembly points and accounting for all participants [2]. Stopková et al. identified lack of effective communication and tracking systems [14]. Todorova et al. noted contradictions among staff in specialized and university hospitals regarding preparedness [73].

### **Critical Success Factors and Best Practices**

Analysis across studies revealed key factors and practices that enhanced worker protection during evacuations.

### **Regular Drills and Simulations**

Routine practice emerged as fundamental to preparedness. Cronin et al. achieved significant improvements through quarterly in situ evacuation drills, with 90% of participants rating the experience positively and 100% reporting increased confidence [9]. Comstock et al. attributed the prevention of injuries to 1,200 employees during a tornado to routine practice through drills, tests, and education [4]. Terumoto et al. found that practical drills and discussions with colleagues proved more effective than seminars or non-practical training [48].

Simulation-based approaches enabled optimization without risk. Augustine et al. used agent-based simulations to improve evacuation efficiency by 35-37% through smart device integration [11]. Marzouk et al. employed BIM and agent-based simulation to optimize construction site evacuations [39]. Tarshizi et al. developed discrete-event system simulation as a powerful tool for improving emergency response protocols [52].

### **Clear Communication and Messaging**

Effective communication proved critical for worker compliance. Cisek et al. developed an alarm model with clear, unambiguous messages tailored to specific threats and locations [35]. Doğanay et al. found multi-component interventions including QR code-based information significantly improved evacuation performance [2]. Григорьев et al. emphasized that trust built through effective communication shaped victim compliance with instructions [49].

Message content and delivery method mattered. Rehman et al. found that more detailed emergency messages led to more evacuations, though channel of communication (text vs. voice) did not significantly affect decisions [5]. Nissen et al. documented that employers should educate employees on evacuation procedures through meetings, electronic communication, and visual aids [53].

### **Comprehensive Training Programs**

Training must be regular, practical, and role-specific. BambangSulistyo et al. emphasized formation of emergency teams, fire drill training, and general drill simulations [74]. Ariyanti et al. achieved 57% to 76% improvement in knowledge through disaster awareness training using Participatory Learning and Action methods [10]. Rachmad Caesario et al. reported 100% increase in understanding through training sessions on evacuation, CPR, and oxygen administration [64].

Training effectiveness depended on methodology. Terumoto et al. found experience in practical drills affected perceptions better than other training methods [48]. Sekendiz et al. emphasized need for better education and policy development to ensure adequate emergency preparedness [75]. Todorova et al. recommended training programs specifically target different types of staff and facilities [73].

### **Physical Infrastructure Optimization**

Proper design and maintenance of evacuation infrastructure proved essential. Xiao et al. demonstrated that re-planning component stacking and reducing personnel optimized evacuation times [6]. Stopková et al. recommended use of side emergency exits, staircase renovation, and advanced ventilation systems [14]. Miftachurrohman et al. showed 3D evacuation route design significantly reduced evacuation time [16].

Infrastructure must meet regulatory standards. Wibisono et al. emphasized compliance with NFPA standards for exit numbers and capacity [33]. Setiawan et al. highlighted ensuring travel distances meet safety standards and having adequate exit points [68]. Putri et al. stressed comprehensive evacuation plan design with adequate exit widths and strategically located assembly points [56].

### **Management Commitment and Resource Allocation**

Leadership support enabled effective implementation. Nissen et al. found that employers showing commitment to security measures enhanced perceived safety [12]. Gold et al. emphasized increased management support and regular training as crucial for effective worker protection [60]. Comstock et al. attributed successful response to the plant's commitment to emergency response planning [4].

Resource allocation must be adequate. Stopková et al. recommended substantial investments in smoke detectors, wider doors, and AI cameras [14]. Kosim et al. identified need for improvements in fire extinguishers, sprinkler systems, alarms, and hydrants [22]. Carrera Oña et al. documented 27% reduction in labor risk index through infrastructure adaptation and equipment implementation [1].

### **Technology Integration**

Advanced technologies enhanced evacuation capabilities. Chadarisman et al. achieved 100% reactivity and 96% warning effectiveness through the LASER IoT-based early warning system [3]. Augustine et al. demonstrated smart evacuation devices improved efficiency by 35% compared to passive signage [11]. Du et al. developed cloud-based services integrating data from monitoring systems for mine water inrush [47].

Technology must be accessible and reliable. Maskari et al. implemented cloud-connected personal gas monitoring with real-time location tracking [19]. Doğanay et al. used QR codes for digital information access [2]. However, technology effectiveness depended on proper implementation, maintenance, and user training.

### **Role Clarity and Organizational Structure**

Clear roles prevented confusion during emergencies. Lin et al. identified five distinct evacuation roles among hospital staff, with behavior shaped by personal, organizational, and environmental factors [42]. Pazmiño Linzán et al. formed brigades with defined functions and responsibilities [29]. Rådestad et al. emphasized adaptive thinking, leadership, communication, and clarification of critical functions [43].

Organizational structure must support rapid response. BambangSulistyo et al. emphasized establishment of emergency teams with clear protocols [74]. Sampedro et al. documented effectiveness of trained brigades for first aid, fire response, evacuation, and communication [76]. However, role systems required maintenance, with Cisek et al. noting that functionary systems often failed due to turnover and organizational changes [35].

### **Gaps and Areas for Improvement**

Despite progress, significant weaknesses remained in current approaches to worker evacuation protection.

#### **Incomplete Plan Coverage**

Many evacuation plans lacked comprehensive hazard coverage. Santiasih et al. found old procedures only addressed fires and leaks, not other potential emergencies [66]. Putri et al. identified incomplete evacuation route implementation and lack of assembly points [56]. Castro González et al. documented absence of manuals, policies, and comprehensive safety plans at

HOTESA [32].

Plan updating procedures often proved inadequate. Badia Papaseit et al. identified need for revision of plan structure and evaluation of risks [26]. Chariguamán Cuji et al. recommended updating emergency plans every two years [80]. Multiple studies emphasized gaps between plan documentation and actual implementation capabilities.

### **Technology and Infrastructure Deficiencies**

Physical infrastructure commonly fell short of needs. Wibisono et al. documented insufficient exits, excessive travel distances, and unclear meeting points [33]. Sekendiz et al. found most fitness facilities did not clearly display emergency plans, evacuation procedures, or emergency numbers [75]. Stopková et al. identified lack of smoke detectors, fire alarms, and efficient occupancy tracking systems [14].

Technology gaps limited protection. Hadiyat et al. noted emergency response facilities were not well-managed and lacked routine inspection [63]. Du et al. identified conventional emergency evacuation responses lacking integration of data from monitoring systems [47]. Aramiko et al. found inadequate water supply and insufficient training in equipment use [58].

### **Training and Awareness Shortfalls**

Training quality and coverage remained inconsistent. Laturkar et al. found 125 (83.3%) participants demonstrated poor or very poor knowledge scores [8]. Shikhalev et al. identified necessity to improve personnel training of shopping mall staff [51]. Sari et al. noted insufficient training as a key weakness [79].

Awareness gaps persisted despite training efforts. Sekendiz et al. documented more than one fourth of fitness professionals somewhat or very unaware of emergency evacuation plans [75]. Todorova et al. identified psychological impact of disasters on medical staff affecting preparedness [73]. Multiple studies emphasized need for more effective, sustained training approaches.

### **Coordination and Communication Weaknesses**

Inter-organizational coordination proved challenging. Rådestad et al. identified shortcomings in communication and coordination during hospital evacuations [43]. Bertollo et al.

found both hospital staff and firefighters looked to each other for operational direction [30]. Bopra et al. noted difficulty in rescue operations due to complex conditions [44].

Communication systems often failed to meet needs. Doğanay et al. found insufficient audibility of emergency sirens in some areas [2]. Cisek et al. identified confusion from voice alarm system management [35]. Colgate et al. documented communication systems failures as structural risk factors [38].

### **Special Population Considerations**

Protection of vulnerable workers received insufficient attention. Chanthakhhot et al. noted need for special consideration of evacuees with physical disabilities [15]. Hulse et al. documented challenges for non-native English speakers requiring pictorial aids [7]. Gershon et al. identified individual factors like physical condition and health status affecting evacuation [41].

Role-specific needs varied. Lin et al. identified role ambiguity, conflicts, and tension as areas for improvement among hospital staff [42]. Norazahar et al. emphasized workers must have good physical conditions and mental fitness to accomplish escape activities [69]. Few studies systematically addressed how evacuation plans accommodated diverse worker capabilities and needs.

### **Maintenance and Sustainability**

Plan maintenance proved inadequate in many settings. Hadiyat et al. found absence of routine inspection records for emergency facilities [63]. Badia Papaseit et al. documented inadequate maintenance of detection systems [26]. Multiple studies emphasized need for systematic maintenance procedures.

Sustainability required ongoing commitment. Cronin et al. highlighted importance of debriefing sessions and updates [9]. BambangSulistyo et al. recommended monitoring validity of procedures and training certifications [74]. Without sustained management attention, even well-designed plans degraded over time.

### **Synthesis**

The evidence reveals that evacuation plans play a crucial but complex role in protecting workers, with effectiveness dependent on multiple interacting factors rather than plan existence alone.

### **Integration of Plan Components**

Single-component approaches proved insufficient compared to integrated strategies. Doğanay et al. demonstrated this most clearly, showing that combining alarm system improvements, updated evacuation plans, basic safety training, and QR code-based information reduced evacuation time by 64% (from 581 to 212 seconds) [2]. This holistic approach outperformed studies focusing on single elements. Similarly, Carrera Oña et al. achieved 64.7% evacuation time reduction and 27% risk index reduction through combined infrastructure adaptation, signage, equipment provision, and brigade formation [1].

The integration principle extended across settings. Cronin et al.'s success in preventing safety events over four years stemmed from combining quarterly drills, equipment identification, metal safety protocols, and staff education [9]. Chadarisman et al.'s LASER system achieved 100% reactivity by integrating IoT sensors, immediate notification via sirens and radio, employee training, and emergency drills [3]. Augustine et al. documented that smart devices alone improved efficiency by 35-37%, but emphasized this required supporting infrastructure, training, and communication systems [11].

### **Context-Specific Application**

Evacuation plan effectiveness varied substantially by workplace context, requiring tailored approaches rather than one-size-fits-all solutions. In healthcare settings, Cronin et al. addressed unique challenges of the cardiac MRI suite's technical environment with specialized metal safety protocols and equipment-specific training [9]. Rådestad et al. emphasized hospital-specific needs including patient mobility limitations and medical equipment constraints [43]. Lin et al. identified five distinct evacuation roles in hospitals that differed from those in other industries [42].

Construction sites presented distinct challenges. Xiao et al. found that material stacking patterns and equipment placement critically affected evacuation in prefabricated building construction, requiring site layout optimization [6]. Hulse et al. documented construction workers'

reliance on pictorial aids for wayfinding due to language diversity, contrasting with verbal instruction effectiveness in other settings [7]. Marzouk et al. emphasized that construction evacuation planning must account for continuously changing physical layouts [39].

Underground mining environments demanded specialized approaches. Augustine et al. demonstrated that smart evacuation systems accounting for stamina variations improved efficiency by 35% compared to passive signage [11]. Du et al. developed mine-specific cloud-based services integrating water inrush monitoring data [47]. Chadarisman et al. created landslide-specific early warning systems with 96% effectiveness in warning employees [3].

### **Population and Experience Effects**

Worker characteristics substantially modulated evacuation plan effectiveness. Kriswijayanti et al. found age, work period, education level, and training participation all significantly affected evacuation route knowledge [71]. Laturkar et al. confirmed prior training, longer work experience, and previous fire incident exposure positively associated with better preparedness [8]. This suggests evacuation plans must account for workforce composition, with newer or less educated workers requiring additional support.

Experience shaped behavioral responses. Terumoto et al. found workers with practical drill experience and colleague discussions demonstrated better preparedness than those with only seminar training [48]. Cronin et al.'s quarterly drill approach leveraged repeated exposure to build confidence, with 100% of participants reporting increased confidence after multiple drills [9]. Conversely, Cisek et al. noted that excessive drill frequency could lead to reluctance and complacency [35].

Cultural and linguistic factors influenced effectiveness. Hulse et al. documented that non-native English speakers relied on pictorial aids for wayfinding, with "vulnerable" workers not appearing disadvantaged when appropriate accommodations existed [7]. Григорьев et al. emphasized that trust—shaped by cultural perceptions of legitimacy and competence—determined whether victims complied with evacuation instructions [49].

### **Technology's Modulating Role**

Technology enhanced but did not replace fundamental evacuation principles. Chadarisman

et al.'s LASER system achieved superior performance (100% reactivity, 50% higher evacuation speed) through IoT-enabled immediate notification [3]. However, this required supporting elements including employee training, regular drills, and maintenance of sensors and devices [3]. Augustine et al. demonstrated smart devices reduced median evacuation time from 10.8 to 7 minutes, but noted success depended on miners' behavior and social interactions [11].

Simple technologies proved effective when properly implemented. Hidayat et al. achieved significant evacuation time reduction (3.95 to 2.26 minutes) through basic evacuation signage [25]. Doğanay et al. found QR code-based information, while technologically modest, contributed to holistic improvements when combined with other interventions [2]. This suggests technology value lies in appropriate application rather than sophistication alone.

Technology failures created vulnerabilities disproportionate to benefits. Stopková et al. identified lack of smoke detectors and alarms as critical gaps despite other planning efforts [14]. Colgate et al. documented communication systems failures as structural risk factors [38]. Hadiyat et al. noted poorly managed emergency response facilities undermined overall preparedness [63]. These findings indicate technology introduction without adequate maintenance and integration can worsen rather than improve worker protection.

### **Training Quality Over Quantity**

Training effectiveness depended more on methodology than frequency. Terumoto et al. found practical drills and colleague discussions more effective than seminars or non-practical training [48]. Ariyanti et al. achieved 57% to 76% knowledge improvement through Participatory Learning and Action methods versus traditional approaches [10]. Rachmad Caesario et al. documented that hands-on training with equipment led to 66.7% of participants correctly performing CPR [64].

Drill realism enhanced preparedness. Cronin et al.'s use of live volunteers in quarterly drills created authentic scenarios that built genuine confidence [9]. Bertollo et al. reduced evacuation time from 14 to under 9 minutes between first and second simulations, demonstrating rapid learning from realistic practice [30]. Rådestad et al. emphasized that real-time simulation mirroring actual hospital resources enabled effective training [43].

However, excessive or poorly designed training proved counterproductive. Cisek et al. noted frequent drills led to reluctance and complacency [35]. Sekendiz et al. found many fitness professionals unaware of emergency plans despite existing training programs [75]. This suggests training quality—including relevance, engagement, and realism—matters more than simple repetition.

### **Management and Organizational Culture**

Management commitment shaped all other factors. Nissen et al. found that employees' perceived safety increased when employers showed commitment to security measures [12]. Gold et al. emphasized management support and leadership involvement as crucial for effective worker protection [60]. Comstock et al. attributed zero injuries during a tornado to the plant's commitment to emergency response planning [4].

Resource allocation reflected priorities. Stopková et al. documented that renovation recommendations and AI camera installation represented substantial investments requiring management support [14]. Carrera Oña et al. achieved 27% risk reduction through infrastructure investments in signage, equipment, and personnel training [1]. Conversely, Pino Jimenez et al. identified inadequate resource allocation as preventing effective worker protection [18].

Organizational culture influenced behavioral responses. Stopková et al. found workers ignored instructions to use side exits and headed to familiar main entrances despite training [14]. Григорьев et al. documented that organizational legitimacy and competence shaped trust and compliance [49]. BambangSulistyo et al. emphasized organizational commitment to worker safety through systematic implementation and review [74].

### **Compliance and Human Behavior**

Worker compliance emerged as both a determinant and outcome of plan effectiveness. Cronin et al. achieved high compliance through clear protocols, regular practice, and strong safety culture [9]. Chadarisman et al. reported 100% response rate among employees in affected areas through effective warning systems and training [3]. Conversely, Rehman et al. found 51-70% of miners did not follow instructions, with unclear messages driving non-compliance [5].

Behavioral responses reflected rational decision-making under uncertainty. Rehman et al.

suggested miners acted loss-aversely given uncertainty, requiring messages accounting for risk perception [5]. Григорьев et al. emphasized recognizing victims' ability to remain rational and use information received [49]. This indicates evacuation plans must account for human decision-making processes rather than assuming automatic compliance.

Social dynamics shaped evacuation behavior. Gershon et al. identified group behavior and leadership as influential factors [41]. Lin et al. documented five distinct evacuation roles influenced by organizational and environmental factors [42]. Cisek et al. noted social interaction as a phenomenon affecting alerting processes [35]. Effective plans must therefore address collective as well as individual behavior.

### **Summary**

Emergency evacuation plans significantly improve worker protection when properly designed, implemented, and maintained, but effectiveness depends critically on integration of multiple components rather than plan existence alone. The evidence demonstrates that comprehensive approaches combining physical infrastructure, technology, training, communication systems, and organizational commitment consistently outperform single-intervention strategies.

Worker protection varies substantially by industry context, workforce characteristics, and organizational culture, requiring tailored rather than generic evacuation approaches. Healthcare, construction, mining, manufacturing, and other sectors face distinct challenges demanding sector-specific solutions. Similarly, worker experience, education, language proficiency, and physical capabilities modulate plan effectiveness, necessitating accommodation of diverse populations.

Training quality proves more important than frequency, with practical drills, realistic simulations, and participatory methods demonstrating superior outcomes compared to traditional classroom approaches. However, training alone cannot compensate for inadequate infrastructure, unclear communication systems, or lack of management commitment. Effective worker protection requires sustained organizational investment in both initial implementation and ongoing maintenance.

Technology enhances but does not replace fundamental evacuation principles. Advanced systems like IoT-enabled warning devices and smart evacuation guidance improve outcomes when

properly integrated with training and organizational processes, but simple interventions like clear signage also prove effective when implemented systematically. Technology failures create disproportionate vulnerabilities, emphasizing the need for redundancy and maintenance.

Significant gaps persist in current approaches, including incomplete plan coverage, inadequate training quality, insufficient accommodation of vulnerable workers, and poor maintenance procedures. Addressing these weaknesses requires sustained management commitment, adequate resource allocation, and systematic integration of evidence-based practices. Future research should examine long-term plan sustainability, special population protection strategies, optimal technology integration approaches, and cross-cultural effectiveness variations to strengthen worker protection during evacuations.

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## DISCUSSION

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### **Integration of Plan Components: The Foundation of Effectiveness**

The evidence unequivocally demonstrates that emergency evacuation plans protect workers most effectively when implemented as integrated systems rather than collections of standalone elements. Doğanay et al.'s (2) landmark study provides the most compelling evidence, demonstrating that combining alarm system improvements, updated evacuation plans, basic safety training, and QR code-based information reduced total evacuation time by 64% (from 581 to 212 seconds). This multi-component approach outperformed any single intervention studied, supporting our first hypothesis regarding the superiority of integrated strategies.

The integration principle operated across diverse settings. Carrera Oña et al. (1) achieved 64.7% evacuation time reduction and 27% reduction in labor risk index through combined infrastructure adaptation, vertical safety signage, fire-fighting equipment provision, and emergency brigade formation. Cronin et al. (9) prevented any patient or staff safety events over four years by integrating quarterly in situ drills, equipment identification protocols, metal safety procedures, and comprehensive staff education in a high-risk cardiac MRI suite. These findings align with systems thinking approaches to safety management, where component interactions

produce emergent properties exceeding individual element contributions (26,27).

The mechanistic basis for integration effectiveness likely involves multiple pathways. Detection systems provide early warning (3,15), clear routes enable efficient movement (6,16), communication guides behavior (35,53), training builds competence (10,64), and role assignments prevent confusion (29,42). When these elements function synergistically, they create redundant safety layers compensating for individual component failures (28). Conversely, studies examining isolated interventions showed limited effects. Hidayat et al. (25) achieved significant but modest evacuation time reduction (3.95 to 2.26 minutes) with signage alone, while Rehman et al. (5) found text message alerts improved but did not eliminate non-compliance. These findings carry important implications: organizations should prioritize comprehensive plan development over piecemeal improvements, and regulators should emphasize integrated system requirements rather than checklist compliance.

### **Context-Specific Effectiveness: One Size Does Not Fit All**

Evacuation plan effectiveness varied substantially by workplace context, supporting our hypothesis regarding context-specific tailoring requirements. Healthcare settings presented unique challenges requiring specialized approaches. Cronin et al. (9) addressed the cardiac MRI suite's technical complexity with equipment-specific protocols and metal safety procedures. Rådestad et al. (43) emphasized hospital-specific needs including patient mobility limitations, medical equipment constraints, and coordination with multiple professional groups. Lin et al. (42) identified five distinct evacuation roles among hospital staff—organizers, followers, hesitators, self-centered individuals, and emergency responders—that differed markedly from role structures in other industries. Kekreli et al. (50) found 83.3% of healthcare participants demonstrated poor disaster preparedness knowledge, highlighting context-specific training needs.

Construction environments demanded different approaches. Xiao et al. (6) demonstrated that material stacking patterns and equipment placement critically affected evacuation in prefabricated building construction, requiring site layout optimization. Hulse et al. (7) documented construction workers' reliance on pictorial aids for wayfinding due to language diversity, contrasting with verbal instruction effectiveness in other settings. Marzouk et al. (39,45)

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emphasized that construction evacuation planning must account for continuously changing physical layouts and varying labor densities. These findings reflect the inherent characteristics of construction work: temporary worksites, multiple contractors, and dynamic hazards (29).

Underground mining presented perhaps the most challenging context. Augustine et al. (11) demonstrated that smart evacuation systems accounting for worker stamina variations improved efficiency by 35% compared to passive signage and by 37% compared to chaotic decision-making. Chadarisman et al. (3) achieved 100% reactivity and 96% warning effectiveness through IoT-based landslide early warning systems specifically designed for mining areas. Du et al. (47) developed mine-specific cloud-based services integrating water inrush monitoring data. Salami et al. (40) identified unique mining hazards including smoke propagation patterns, refuge chamber requirements, and self-rescuer device dependencies. The extreme environment—darkness, confined spaces, toxic gases—necessitates specialized solutions not transferable from surface industries (30,31).

Manufacturing settings demonstrated intermediate complexity. Stopková et al. (14) optimized automotive manufacturing evacuation through smoke detectors, side emergency exits, staircase renovation, and AI camera installation. Chanthakhot et al. (15) integrated fire dynamics simulation with agent-based modeling for home appliance manufacturing. Miftachurrohman et al. (16) showed 3D evacuation route design significantly reduced evacuation time in textile manufacturing by providing superior visual representation. Ferents et al. (20) modeled paper factory evacuation considering machinery layouts and production processes. These studies illustrate how manufacturing evacuation planning must address industry-specific factors including production equipment, material storage, shift patterns, and worker density.

The context-specificity finding carries profound implications for policy and practice. Generic evacuation templates, while providing useful starting points, cannot substitute for site-specific risk assessment and tailored planning. Organizations must invest in understanding their unique hazards, worker characteristics, and physical constraints. Regulators should require context-appropriate plans rather than one-size-fits-all compliance. Future research should develop context-specific best practice guidelines for major industry sectors.

## **Training Quality Over Quantity: The Critical Role of Methodology**

Training effectiveness depended more on methodology than frequency, supporting our hypothesis regarding practical training superiority. Terumoto et al. (48) provided the most direct evidence, finding that practical drills and discussions with colleagues proved more effective than seminars or non-practical training for tourism workers facing tsunami emergencies. This finding aligns with experiential learning theory, which posits that concrete experience and reflective observation produce deeper learning than abstract conceptualization alone (32).

Participatory approaches demonstrated particular promise. Ariyanti et al. (10) achieved 57% to 76% knowledge improvement through Participatory Learning and Action methods versus traditional approaches, with workers actively engaged in disaster awareness and evacuation training. Rachmad Caesario et al. (64) documented that hands-on training with equipment led to 66.7% of participants correctly performing CPR, representing 100% increase in understanding. These methods leverage adult learning principles: relevance, engagement, and practical application enhance retention and transfer (33).

Drill realism emerged as a critical success factor. Cronin et al. (9) used live volunteers in quarterly in situ drills, creating authentic scenarios that built genuine confidence, with 100% of participants reporting increased confidence after multiple drills. Bertollo et al. (30) reduced hospital evacuation simulation time from 14 minutes to under 9 minutes between first and second simulations, demonstrating rapid learning from realistic practice. Rådestad et al. (43) emphasized that real-time simulation mirroring actual hospital resources enabled effective training for infrastructure failure scenarios. Realistic drills activate the same cognitive and behavioral processes required in actual emergencies, building both procedural knowledge and stress tolerance (34).

However, training alone cannot compensate for other deficiencies. Kriswijayanti et al. (71) found that while training significantly affected worker knowledge of evacuation routes, age, work period, and education level also exerted independent effects. Laturkar et al. (8) confirmed prior training, longer work experience, and previous fire incident exposure positively associated with better awareness, but 83.3% of participants still demonstrated poor or very poor knowledge scores.

These findings suggest that training must be part of comprehensive systems rather than standalone solutions.

The training methodology findings challenge common organizational practices. Many workplaces rely on annual classroom training or online modules that satisfy regulatory requirements but fail to build genuine capability (35,75). The evidence supports shifting resources toward practical, scenario-based, participatory training approaches, even if this means reducing training frequency. Organizations should conduct training needs assessments to identify specific knowledge gaps, design drills reflecting actual workplace hazards, and incorporate debriefing sessions to maximize learning from each exercise (9,74).

### **Technology as Enhancer, Not Replacement**

Technology enhanced but did not replace fundamental evacuation principles, supporting our hypothesis regarding technology's modulating role. Chadarisman et al. (3) achieved superior performance through the LASER IoT-based early warning system, with 100% reactivity, 96% warning effectiveness, and 50% higher evacuation speed compared to conventional systems. However, success depended on supporting elements including employee training, regular drills, and systematic sensor maintenance. Augustine et al. (11) demonstrated smart evacuation devices reduced median evacuation time from 10.8 to 7 minutes (35% improvement) compared to passive signage, but noted success depended on miners' behavior, social interactions, and organizational factors.

Simple technologies proved remarkably effective when properly implemented. Hidayat et al. (25) achieved significant evacuation time reduction (3.95 to 2.26 minutes) through basic evacuation signage alone. Doğanay et al. (2) found QR code-based information, while technologically modest, contributed to holistic improvements when combined with other interventions. Cisek et al. (35) developed a voice alarm system model with high message intelligibility that improved sequential evacuation from high-rise buildings. These findings suggest that technology value lies in appropriate application meeting specific needs rather than sophistication alone.

Technology failures created vulnerabilities disproportionate to benefits. Stopková et al.

(14) identified lack of smoke detectors and fire alarms as critical gaps despite other planning efforts. Colgate et al. (38) documented communication systems failures as structural risk factors in World Trade Center evacuations. Hadiyat et al. (63) found emergency response facilities were not well-managed and lacked routine inspection records, undermining overall preparedness. Maskari et al. (19) successfully implemented cloud-connected personal gas monitoring devices but emphasized the need for redundancy and fail-safe mechanisms.

The technology findings carry important implications for investment decisions. Organizations should prioritize reliable, maintainable technologies addressing identified gaps rather than pursuing cutting-edge solutions creating new vulnerabilities. Technology introduction requires parallel investments in training, maintenance procedures, and integration with existing systems. Regulators should establish standards for technology performance, testing, and maintenance rather than simply mandating technology presence.

### **Human Behavior: The Critical Variable**

Worker compliance emerged as both a determinant and outcome of plan effectiveness, revealing the centrality of human factors in evacuation success. Cronin et al. (9) achieved high compliance through clear protocols, regular practice, and strong safety culture. Chadarisman et al. (3) reported 100% response rate among employees in affected areas through effective warning systems and comprehensive training. Conversely, Rehman et al. (5) found 51-70% of miners did not follow evacuation instructions, choosing not to shelter in place or go to refuge chambers as directed. Stopková et al. (14) documented that operatives ignored instructions to use side exits and headed to familiar main entrances despite training.

Behavioral responses reflected rational decision-making under uncertainty rather than simple non-compliance. Rehman et al. (5) suggested miners acted loss-aversely given uncertainty about threat severity and shelter reliability, requiring messages accounting for risk perception. Григорьев et al. (49) emphasized recognizing victims' ability to remain rational and use information received, with trust shaped by organizational legitimacy, competence, and communication effectiveness determining compliance. Cisek et al. (35) identified doubts about evacuation necessity and reluctance to participate in drills as barriers to effective response.

Social dynamics profoundly influenced evacuation behavior. Gershon et al. (41) identified group behavior and leadership as influential factors in World Trade Center evacuations. Lin et al. (42) documented how personal characteristics, organizational factors, and environmental considerations shaped five distinct evacuation roles among hospital staff. Cisek et al. (35) noted social interaction as a phenomenon affecting alerting processes, with workers consulting colleagues before deciding to evacuate. These findings align with social identity theory, which posits that group membership and norms shape behavior in emergencies (36).

The human behavior findings necessitate fundamental shifts in evacuation planning approaches. Traditional command-and-control models assuming automatic compliance must yield to approaches recognizing worker agency and decision-making. Plans should provide clear, credible information supporting informed decisions rather than simply issuing directives. Training should address psychological factors including risk perception, decision-making under stress, and social dynamics. Communication systems should deliver threat-relevant information enabling appropriate responses rather than generic alarms causing confusion (35,53).

### **Management Commitment as Enabling Factor**

Management commitment emerged as the foundation enabling all other factors, supporting our hypothesis regarding leadership's critical role. Nissen et al. (12,53) found that employees' perceived safety increased when employers showed commitment to security measures through visible investments and communication. Gold et al. (60) emphasized management support and leadership involvement as crucial for combating workplace complacency in fire evacuations. Comstock et al. (4) attributed zero injuries to 1,200 employees during an F4 tornado to the plant's sustained commitment to emergency response planning, routine drills, and continuous improvement.

Resource allocation reflected organizational priorities. Stopková et al. (14) documented that renovation recommendations, smoke detector installation, wider doors, and AI camera implementation represented substantial investments requiring management support. Carrera Oña et al. (1) achieved 27% risk reduction through infrastructure investments in signage, equipment, and personnel training. Kosim et al. (22) identified need for improvements in fire extinguishers,

sprinkler systems, alarms, and hydrants, requiring ongoing resource commitment. Conversely, Pino Jimenez et al. (18) identified inadequate resource allocation for operational fire extinguishing equipment and safety signage as preventing effective worker protection.

Organizational culture shaped behavioral responses through management actions. Stopková et al. (14) found that despite training, workers ignored instructions to use side exits and headed to familiar main entrances, reflecting organizational norms and habits. Григорьев et al. (49) documented that organizational legitimacy and perceived competence shaped trust and compliance during emergencies. BambangSulistyo et al. (74) emphasized organizational commitment to worker safety through systematic implementation, monitoring, and review of emergency response plans.

The management commitment findings highlight the need for leadership engagement at all organizational levels. Evacuation planning cannot be delegated solely to safety professionals but requires active executive involvement, resource allocation, and visible support. Organizations should integrate evacuation performance into management accountability systems, conduct regular management reviews of plan effectiveness, and ensure safety culture assessments include evacuation preparedness dimensions (60,74).

### **Barriers and Challenges: Persistent Vulnerabilities**

Despite progress, significant barriers continued to reduce evacuation plan effectiveness across multiple studies. Worker non-compliance and confusion emerged as persistent challenges, with Rehman et al. (5) documenting 51-70% of miners ignoring instructions, Stopková et al. (14) finding workers ignoring designated exits, and Cisek et al. (35) identifying doubts about evacuation necessity. These findings suggest that even well-designed plans fail when human behavior diverges from assumptions.

Physical obstacles and design flaws created preventable hazards. Xiao et al. (6) identified stacking of prefabricated components causing congestion and slowing evacuation. Hulse et al. (7) documented barriers preventing access to exclusion zones and congestion from simultaneous worker evacuation. Miftachurrohman et al. (16) found narrow paths cluttered with machinery and goods hindered movement. Wibisono et al. (33) documented inadequate exits and excessive travel

distances exceeding safety standards. These physical constraints often resulted from design decisions prioritizing production over safety, requiring proactive integration of evacuation considerations into facility design and operations.

Communication failures jeopardized worker safety across multiple studies. Colgate et al. (38) identified communication systems failures as structural risk factors in high-rise evacuations. Doğanay et al. (2) found insufficient audibility of emergency sirens in some areas. Bertollo et al. (30) noted nursing staff were inundated with inquiries from rescue personnel, creating information overload. Rehman et al. (5) found miners ignored guidance due to unclear or poorly crafted messages. These failures reflect inadequate attention to communication system design, testing, and redundancy.

Insufficient training and awareness pervaded many workplaces. Pino Jimenez et al. (18) identified lack of formal training in extinguisher use and evacuation procedures. Hadiyat et al. (63) found employees lacked understanding of self-rescue methods. Laturkar et al. (8) documented that 125 (83.3%) participants considered themselves inadequately trained. Ramba et al. (23) noted low mean scores indicating need for improvement in worker training. These findings suggest systematic underinvestment in training quality and quantity across industries.

The barrier findings underscore the need for comprehensive approaches addressing multiple vulnerability sources simultaneously. Organizations should conduct regular barrier analysis, identifying specific factors limiting plan effectiveness in their contexts. Improvement strategies should target the most significant barriers, recognizing that eliminating single barriers may not improve overall effectiveness if other barriers persist (14,16).

### **Vulnerable Worker Populations: An Understudied Priority**

Protection of vulnerable workers received insufficient attention across included studies, representing a critical gap requiring urgent research and practice attention. Chanthakhot et al. (15) noted need for special consideration of evacuees with physical disabilities in industrial settings. Hulse et al. (7) documented challenges for non-native English speakers requiring pictorial aids for wayfinding. Gershon et al. (41) identified individual factors like physical condition and health status affecting evacuation capability in high-rise buildings.

Worker characteristics substantially modulated plan effectiveness. Kriswijayanti et al. (71) found age, work period, education level, and training participation all significantly affected evacuation route knowledge. Laturkar et al. (8) confirmed prior training, longer work experience, and previous fire incident exposure positively associated with better preparedness. These findings suggest that newer, younger, less educated, or untrained workers require additional support and differentiated approaches.

Role-specific needs varied across worker categories. Lin et al. (42) identified role ambiguity, conflicts, and tension as areas for improvement among hospital staff with different professional backgrounds. Norazahar et al. (69) emphasized workers must have good physical conditions and mental fitness to accomplish escape activities on offshore installations. Terumoto et al. (48) found tourism workers' perceptions of supporting tourist evacuation varied by experience and training.

The vulnerable population findings highlight the need for inclusive evacuation planning. Organizations should conduct workforce demographic analysis to identify vulnerable groups, assess specific barriers they face, and develop targeted interventions. Universal design principles should guide evacuation route design, communication systems, and equipment provision. Training should address diverse learning needs and language requirements. Future research should systematically examine evacuation experiences of workers with disabilities, language barriers, limited experience, and other vulnerability factors.

### **Research Gaps and Future Directions**

This review identified several critical gaps requiring future research attention. First, long-term plan sustainability remains understudied, with most research examining initial implementation rather than ongoing maintenance and adaptation (3,9). Longitudinal studies tracking plan effectiveness over years would identify factors supporting or undermining sustained performance. Second, optimal technology integration approaches lack evidence, particularly regarding human-technology interaction and technology failure modes (11,19). Research should examine how different worker populations interact with various technologies and develop design principles maximizing usability and effectiveness.

Third, cross-cultural effectiveness variations remain unexplored despite evidence that cultural factors shape evacuation behavior (13,49). Comparative studies across national and organizational cultures would identify universally effective practices versus culturally-specific approaches. Fourth, economic evaluation of evacuation interventions is virtually absent, limiting ability to make resource allocation decisions (14,60). Cost-effectiveness studies examining different intervention combinations would support evidence-based investment decisions.

Fifth, vulnerable population protection strategies require systematic investigation (7,15). Research should identify specific barriers facing different vulnerable groups and develop and test targeted interventions. Sixth, integration of behavioral science insights into evacuation planning remains underdeveloped (5,41). Studies applying behavioral economics, social psychology, and decision science to evacuation behavior could generate novel intervention approaches.

Seventh, real-world evacuation data remain limited, with most studies relying on drills, simulations, or hypothetical scenarios (1,9). Research capturing actual emergency evacuations, while challenging, would provide invaluable insights into plan performance under authentic conditions. Eighth, interoperability between organizational and community evacuation systems needs examination (30,43). Studies should explore coordination mechanisms between workplace plans and community emergency response systems.

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## CONCLUSION

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### Summary of Key Findings

This systematic review of 80 studies across diverse industries demonstrates that emergency evacuation plans significantly improve worker protection when properly designed, implemented, and maintained. The evidence reveals eight essential plan components: emergency detection and alarm systems, evacuation route design and signage, assembly points and safe areas, communication protocols and technologies, role assignments and responsibilities, training and drill requirements, equipment provision, and coordination with emergency services.

Integrated multi-component approaches consistently outperform single-intervention

strategies, with documented evacuation time reductions up to 64% and complete prevention of worker injuries in severe events. Training quality proves more important than frequency, with practical drills, realistic simulations, and participatory methods demonstrating superior outcomes compared to traditional classroom approaches. Technology enhances but does not replace fundamental evacuation principles, with both advanced IoT systems and simple signage proving effective when properly implemented.

Effectiveness varies substantially by industry context, workforce characteristics, and organizational culture, requiring tailored rather than generic approaches. Critical success factors include regular drills, clear communication protocols, management commitment, adequate resource allocation, and systematic plan maintenance. Major barriers comprise worker non-compliance (affecting up to 70% of workers in some contexts), physical obstacles, communication failures, insufficient training (with 83.3% demonstrating poor knowledge in some studies), and coordination problems between worker groups and emergency responders.

### **Theoretical Implications**

The findings advance theoretical understanding of evacuation behavior and safety system effectiveness. The integration principle supports systems safety theory, demonstrating that component interactions produce emergent protective capabilities exceeding individual element contributions. The context-specificity findings align with contingency theory, suggesting optimal evacuation approaches depend on environmental, organizational, and workforce characteristics. The human behavior findings support naturalistic decision-making models, recognizing worker agency and rational adaptation under uncertainty rather than assuming automatic compliance.

### **Practical Implications**

For organizations, the findings provide evidence-based guidance for improving worker protection. Priority actions include: (1) conducting comprehensive risk assessments identifying site-specific hazards and worker vulnerabilities, (2) developing integrated plans addressing all eight essential components, (3) implementing regular practical drills with realistic scenarios and debriefing sessions, (4) ensuring clear communication systems with redundant backup, (5) providing role-specific training accounting for worker characteristics, (6) securing management

commitment through visible leadership and resource allocation, (7) establishing systematic maintenance and updating procedures, and (8) conducting regular barrier analysis to identify and address effectiveness limitations.

For regulators, the findings support moving beyond compliance-based approaches toward performance-based standards requiring demonstrated evacuation capability. Regulatory frameworks should emphasize integrated system requirements, context-specific tailoring, regular testing and validation, and continuous improvement processes. Training standards should specify practical, participatory methodologies rather than classroom hours alone.

For researchers, the findings identify priority areas for future investigation including long-term sustainability, technology optimization, vulnerable population protection, cross-cultural effectiveness, economic evaluation, behavioral science integration, real-world evacuation data collection, and system interoperability.

### **Concluding Statement**

Emergency evacuation plans represent critical investments in worker protection, capable of preventing injuries and saving lives when properly designed and implemented. However, plan existence alone proves insufficient; effectiveness requires sustained organizational commitment, systematic integration of multiple components, context-specific tailoring, and continuous attention to human factors. As workplaces evolve with new technologies, work arrangements, and hazard profiles, evacuation planning must similarly advance, incorporating emerging evidence and adapting to changing circumstances. The ultimate measure of success remains simple but profound: every worker returning safely after every emergency.

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