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Original Research

HSE Legislation Effects on Reducing Industrial Accidents and Improving Occupational Health: A Systematic Review and Meta-analysis

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Effective Health, Safety, and Environmental (HSE) legislation is critical for reducing occupational accidents and promoting worker health. Although numerous studies have examined individual interventions, a comprehensive synthesis across industries has been lacking. This meta-analysis aimed to evaluate the impact of HSE legal and managerial interventions on reducing industrial accidents and improving occupational health across multiple high-risk sectors. A systematic search of reputable scientific databases was conducted to identify studies up to January 2026. Twelve studies encompassing manufacturing, construction, high-risk sectors such as mining and transportation, and petrochemical and oil industries were included. Risk ratios (RR) and 95% confidence intervals (CI) were extracted. Random-effects meta-analysis and subgroup analyses were performed based on intervention type, industry, and outcome measures. Overall, HSE interventions significantly reduced occupational accident risk (RR=0.788; 95% CI: 0.682–0.894). Subgroup analyses demonstrated that safety management systems (OHSMS, ISO 45001, OHSAS 18001) and regulatory inspections with penalties significantly lowered accident risk. Economic and demographic factors moderated outcomes, with younger, less-experienced, or male workers at higher risk, mitigated by training, resource allocation, and targeted interventions (RR=0.839). Severe occupational injuries and disabling incidents showed the most significant reduction (RR = 0.769). HSE legislation, combined with systematic safety management and targeted inspections, effectively reduces industrial accidents and enhances worker health. Policy implications include enforcing legal standards, implementing safety management systems, and integrating workforce-focused interventions.

Keywords: *Occupational Health, Legislation, Occupational Injuries, Government Regulation.*

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1. Introduction

Industrial accidents and occupational diseases continue to pose significant global public health and socioeconomic challenges, particularly in rapidly industrializing economies(Wang et al., 2025). According to international labor statistics, millions of workers are annually exposed to hazardous working conditions, resulting in preventable injuries, long-term disabilities, and premature mortality(Birhan & Endawoke, 2023). Beyond the human toll, occupational accidents impose substantial economic burdens on organizations and societies through productivity losses, compensation claims, and increased healthcare expenditures. Consequently, enhancing occupational health and safety (OHS) has emerged as a strategic priority for

governments, regulatory agencies, and international organizations(Ashari, 2022). Legislation governing Health, Safety, and Environment (HSE) represents one of the most critical policy instruments for preventing workplace accidents and promoting workers' health. Such legislation typically encompasses regulatory standards, enforcement mechanisms, employer obligations, worker protections, and monitoring systems designed to mitigate occupational hazards(PĂDURE & PĂDURE, 2025). Over recent decades, numerous countries have established comprehensive HSE frameworks, often aligned with international conventions, such as those promulgated by the International Labour Organization (ILO). These legislative initiatives aim not only to reduce accident rates but also to cultivate a preventive safety culture and enhance overall occupational health outcomes(Acheampong & Kemp, 2022).

Despite the widespread adoption of HSE legislation, its effectiveness in achieving intended outcomes remains contested. Empirical evidence is heterogeneous: some studies report significant reductions in industrial accident rates and improvements in occupational health indicators following legislative reforms, whereas others indicate limited or inconsistent effects. Variations in enforcement rigor, organizational compliance, industrial sector characteristics, and socioeconomic contexts likely contribute to these divergent findings. Additionally, methodological differences and inconsistent outcome measures across studies complicate the synthesis of robust conclusions(Acheampong & Kemp, 2022; Adekoya et al., 2023; Adio et al., 2025; Blanc et al., 2022). Previous systematic reviews have examined occupational safety interventions; however, many have focused on specific industries, isolated regulatory components, or non-legislative strategies such as training programs and engineering controls. To date, a comprehensive quantitative synthesis evaluating the overall impact of HSE legislation on both industrial accident reduction and occupational health improvement across diverse settings remains lacking. Therefore, the present study aims to systematically review and quantitatively synthesize existing evidence regarding the effects of HSE legislation on reducing industrial accidents and enhancing occupational health outcomes.

2. Methods

2.1. Study Design and Reporting Framework

This study was conducted as a systematic review and meta-analysis to synthesize empirical evidence on the effects of implementing health, safety, and environmental (HSE) legislation on reducing industrial accidents and improving occupational health outcomes in workplace settings. Given the inherently policy-driven nature of HSE interventions and the substantial methodological heterogeneity across studies in this field, integrating a systematic review with meta-analytic methods was deemed the most appropriate approach for evidence synthesis and pooled estimation of intervention effects. All stages of study design, execution, data analysis, and reporting were performed in strict accordance with the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure methodological rigor, transparency, and reproducibility.

2.2. Information Sources and Systematic Search Strategy

A comprehensive and systematic literature search was conducted across three major international bibliographic databases: PubMed/MEDLINE, Scopus, and Web of Science. These databases were selected for their broad coverage of research on occupational safety and health, industrial regulation, public health policy, and interventional or quasi-experimental study designs. The search strategy was specifically designed to identify both studies that address formal governmental regulatory frameworks, such as those implemented by the Occupational Safety and Health Administration (OSHA), and HSE-based regulatory systems, and empirical investigations evaluating the outcomes of legislative implementation in occupational settings. The search strategy combined controlled vocabulary terms, including Medical Subject Headings (MeSH), with free-text keywords to maximize the retrieval of relevant records. Boolean operators were employed to enhance both the sensitivity and specificity of the search. Search terms encompassed key concepts related to occupational safety legislation, regulatory enforcement, official inspections, and outcomes associated with workplace injuries and industrial accidents. Database-specific modifications of the search strategy were applied to

accommodate variations in indexing structures and search functionalities. In addition to electronic searches, the reference lists of key articles were manually screened to identify potentially eligible studies that may not have been captured through the initial database search.

Mesh term: ((((("Occupational Health"[Mesh] OR "United States Occupational Safety and Health Administration"[Mesh] OR "National Institute for Occupational Safety and Health, U.S."[Mesh]) OR ("Occupational Health/classification"[Mesh] OR "Occupational Health/legislation and jurisprudence"[Mesh] OR "Occupational Health/standards"[Mesh] OR "Occupational Health/statistics and numerical data"[Mesh])) OR ("United States Occupational Safety and Health Administration/classification"[Mesh] OR "United States Occupational Safety and Health Administration/legislation and jurisprudence"[Mesh] OR "United States Occupational Safety and Health Administration/standards"[Mesh] OR "United States Occupational Safety and Health Administration/statistics and numerical data"[Mesh])) AND "Legislation" [Publication Type]) OR ("Social Control, Formal"[Mesh] OR "Government Regulation"[Mesh])) AND "Accidents, Occupational"[Mesh]) OR "Occupational Injuries"[Mesh].

2.3. *Time Frame and Language Restrictions*

Studies published until January 2026 were considered eligible for inclusion. This time frame was intentionally selected to encompass a period marked by substantial regulatory reforms and the strengthening of occupational safety and health legislation across many industrialized countries. Focusing on this interval enabled the assessment of both short-term and long-term effects of HSE and OSHA regulatory implementation. Only studies published in English were included to ensure accurate interpretation of findings and comparability across studies.

2.4. *Eligibility Criteria*

Studies were eligible for inclusion if they provided original empirical evidence and reported quantitative data suitable for effect size estimation. Specifically, included studies directly evaluated the impact of occupational safety and health legislation, regulatory enforcement mechanisms, or official inspection programs and reported at least one quantitative outcome related to occupational accidents or workplace injuries. Priority was given to studies employing interventional, quasi-experimental, or cohort designs, as these methodological approaches allow for more robust estimation or calculation of effect sizes. Studies were excluded if they were review articles, letters to the editor, conference abstracts, lacked access to full-text articles, or did not report sufficient quantitative data to derive effect estimates.

2.5. *Study Screening, Selection, and Data Extraction*

All records retrieved through the initial search were imported into a reference management software, and duplicate records were removed prior to screening. Study selection was conducted in three sequential stages: title screening, abstract review, and full-text assessment. Each stage was performed independently by two reviewers to minimize selection bias. Disagreements regarding study eligibility were resolved through discussion, and when consensus could not be achieved, a third reviewer was consulted to make the final determination. Data extraction was conducted using a standardized, pre-designed extraction form developed specifically for this study in accordance with its objectives. Extracted data included the first author's name, year of publication, methodological characteristics, type and intensity of the legislative intervention, characteristics of the study population, outcome measures, and statistical data required for meta-analysis. To enhance data accuracy and reliability, two reviewers independently extracted data, and the datasets were cross-checked. Any discrepancies were resolved through re-examination of the full-text articles and consensus discussion.

2.6. *Statistical Analysis and Data Synthesis*

A meta-analysis was conducted to synthesize the included studies' findings and estimate the overall effect of HSE legislation on occupational safety outcomes using a random-effects model. This approach was selected to account for anticipated between-study heterogeneity arising from differences in regulatory context, industrial

sectors, enforcement intensity, and follow-up duration. Effect sizes were standardized prior to pooling. Statistical heterogeneity was assessed using the I^2 statistic, and pooled effect estimates were visually presented using forest plots. All statistical analyses were performed using STATA/MP version 17.

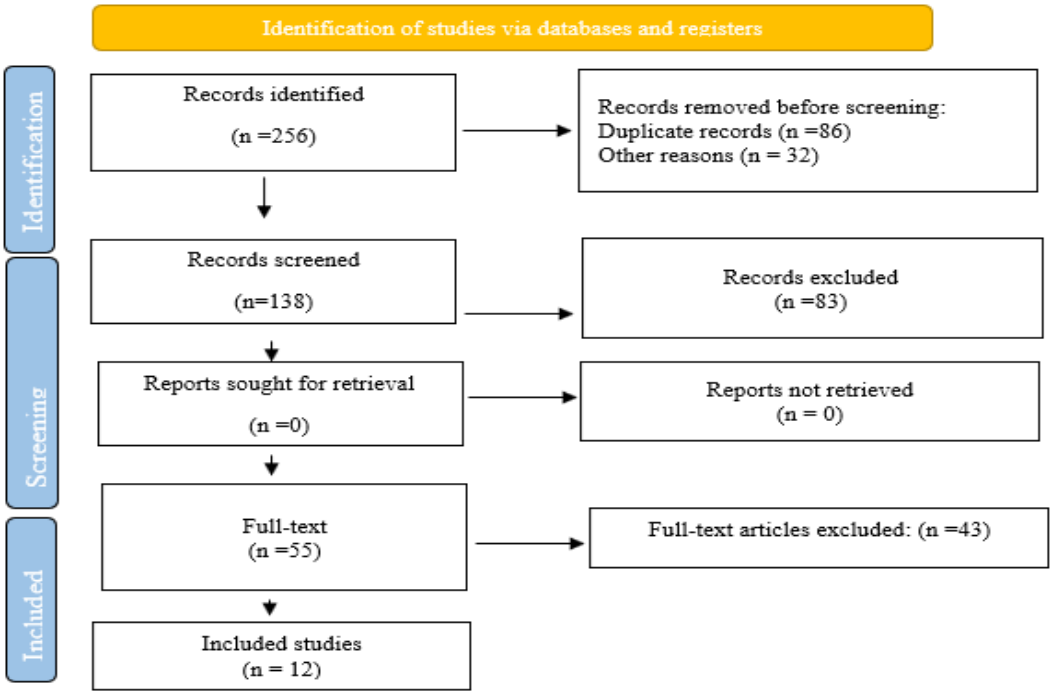
3. Results

3.1. Literature Search

According to the PRISMA 2020 flow diagram, a comprehensive, systematic search using predefined keywords across international databases identified 256 records. Following title screening, studies that did not meet the predefined inclusion and exclusion criteria were removed. Subsequently, the abstracts of 138 articles were assessed, and 83 studies were excluded at this stage for failing to meet the study selection criteria. The full texts of 55 eligible articles were then independently and blindly reviewed by 5 reviewers, with any disagreements resolved through consultation with a third reviewer. Ultimately, after excluding irrelevant studies, 12 articles were included in the final meta-analysis (Figure 1).

Figure 1

PRISMA 2020 Flow Diagram



3.2. Study Characteristics

In the present study, 12 eligible articles were included in the systematic review and meta-analysis. These studies were conducted across several countries, including the United States, Denmark, China, Canada, Turkey, and Egypt. They demonstrated substantial heterogeneity across study design, industrial context, type of safety intervention, and outcome measures. Regarding study design, the majority of the included investigations employed longitudinal, quasi-experimental, or register-based panel data designs. Studies such as those conducted by Dyreborg et al. (2023) and Smith et al. (2015) utilized national registry data and longitudinal designs to examine the effects of implementing occupational health and safety management systems (OHSMS), including OHSAS 18001 and the Certificate of Recognition (COR), on the reduction of severe workplace accidents and disabling injuries. In addition, several studies applied quasi-experimental methods and panel data analyses to assess the effectiveness of regulatory inspections conducted by the United States Occupational

Safety and Health Administration (OSHA), notably those by Gray et al. (1987), Haviland et al. (2008), and Kline et al. (2013). In terms of sample size, the included studies spanned a wide range, from analyses of national-level datasets encompassing more than 13,000 workplaces or multiple decades of historical records to studies based on smaller organizational samples and workforce surveys. The industrial sectors examined were diverse and included manufacturing, high-risk sectors such as mining and transportation, the construction sector, chemical and petrochemical industries, and multi-sectoral national samples. Based on the nature of the intervention or exposure, the studies were categorized into three main groups. The first group comprised studies investigating the impact of implementing occupational health and safety management systems, such as OHSAS 18001, ISO 45001, and COR certification. The second group included studies evaluating the effects of regulatory inspections and enforcement actions, including penalty-imposing inspections conducted by governmental authorities such as OSHA. The third group focused on examining the influence of economic, demographic, or structural factors on the occurrence of occupational accidents and work-related diseases. The outcome measures assessed across the included studies encompassed a broad range of occupational safety indicators, including rates of severe workplace accidents, injuries leading to work absence or disability, occupational fatality rates, work-related diseases, and indices of injury severity (Table 1).

Table 1

Characteristics of included studies.

No.	Source	Country	Study Design	Sample Size	Industry / Sector	Intervention / Regulation	Outcome Measure	Follow-up
1	(Kaplanvural et al., 2026)	Turkey	ARMAX / NLARX modeling	Accident population datasets (y1–y4)	Multiple industries	Predictive safety modeling	Occupational accidents	Not reported
2	(Cao et al., 2025)	China	Longitudinal regression & network analysis	22 years of national data	High-risk industries	OHS measures & economic factors	Fatal accidents, occupational disease	22 years
3	(Hesham et al., 2025)	Egypt	Quasi-experimental survey + factor analysis	90 safety professionals	Petrochemical / Petroleum / Chemical	ISO 45001 + OSHA PSM	OHS performance perception	Cross-sectional
4	(Bilim, 2025)	Turkey	Demographic analysis	National construction data	Construction	Worker demographic factors	Accident probability & severity	2018–2022
5	(McLeod & Macpherson, 2025)	Canada	Matched difference-in-differences	14,377 firms	Multiple industries	COR-certified OHSMS	Lost-time & disabling injuries	2000–2015
6	(Dyreborg et al., 2024)	Denmark	Register-based longitudinal	13,102 workplaces (805 certified, 12,297 controls)	Multiple industries	COHSMS / OHSAS 18001 adoption	Severe workplace accidents	2010–2018
7	(Johnson et al., 2017)	USA	Randomized inspection design	Not specified	Multiple industries	OSHA SST inspections	Days-away-from-work (DAFW) injuries	2001–2010
8	(Li & Singleton, 2019)	USA	Fuzzy regression discontinuity	Not specified	Multiple industries	OSHA SST inspections	DAFW, job restriction & transfer cases	Not reported
9	(Haviland et al., 2012)	USA	Quasi-experimental	Manufacturing firms (>10 employees)	Manufacturing	OSHA inspections with penalties	Lost-time injury rate	1998–2005
10	(Friedman & Forst, 2007)	USA	Time-series (joinpoint regression)	SOII national data	Multiple industries	OSHA recordkeeping regulation	Occupational injury & illness	1992–2003
11	(Gray & Mendeloff, 2005)	USA	Panel data analysis	6,842 large plants	Manufacturing	OSHA inspections with penalties	Workplace injuries	1979–1985
12	(Smitha et al., 2001)	USA	Poisson regression	3,286 establishments	Manufacturing	State-level safety laws	Injury severity rate	1992–1997

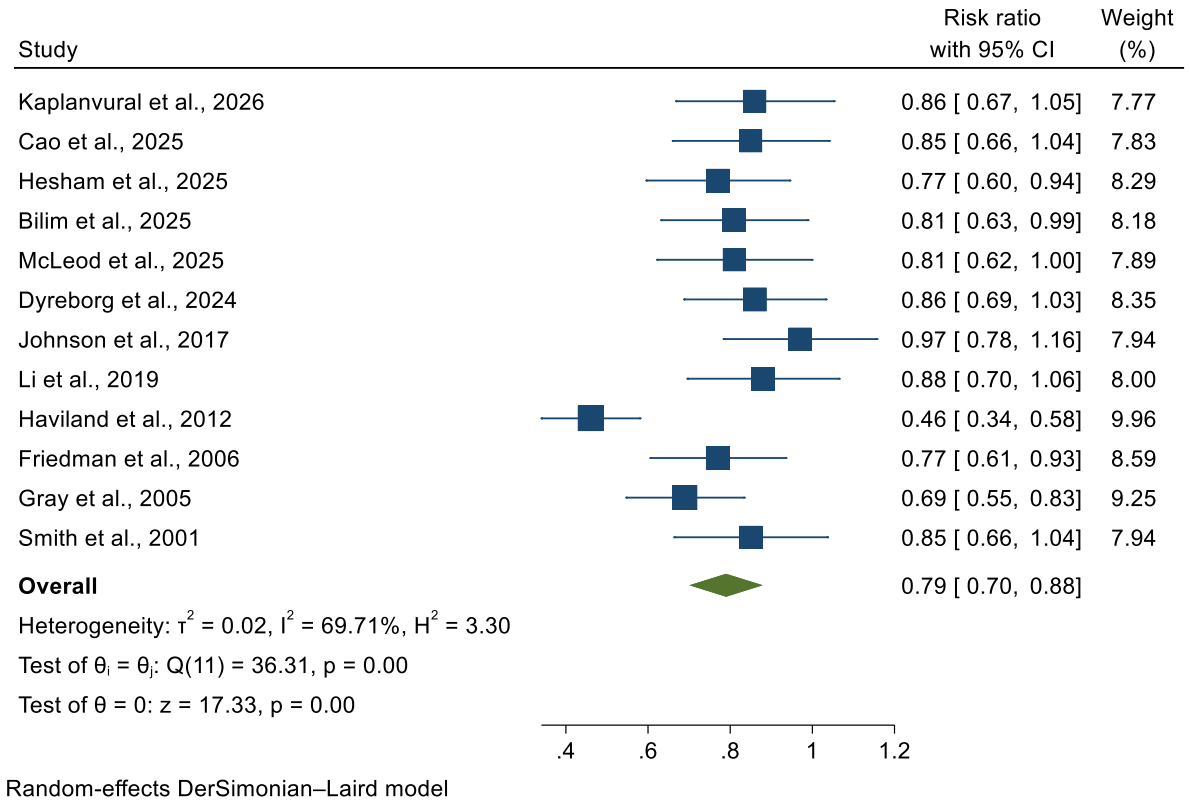
The random-effects model using the DerSimonian–Laird method estimated a pooled risk ratio (RR) of 0.79 (95% CI: 0.70–0.88), indicating a 21% reduction in the risk of industrial accidents following the implementation of occupational health and safety interventions, which was statistically significant ($z = 17.33$, $p < 0.001$) (Figure 2). Substantial heterogeneity was observed among studies ($I^2 = 69.7\%$, $\tau^2 = 0.0171$), reflecting variations in intervention type, industrial sector, regulatory

framework, and follow-up duration. The Cochran's Q test also confirmed significant heterogeneity (Q = 36.31, df = 11, p = 0.0002) (Figure 2).

Effect sizes across studies ranged from RR = 0.46 (Haviland et al., 2012) to RR = 0.97 (Johnson et al., 2017). The most significant reductions in accidents were observed in studies that rigorously implemented occupational safety management systems and legally enforced inspections with penalties or regulatory compliance requirements. Conversely, some studies showed a trend toward reduced risk but did not reach statistical significance due to smaller sample sizes or specific regulatory contexts.

Figure 2

A forest plot shows the reduction in the risk of industrial accidents by implementing occupational safety and health interventions.

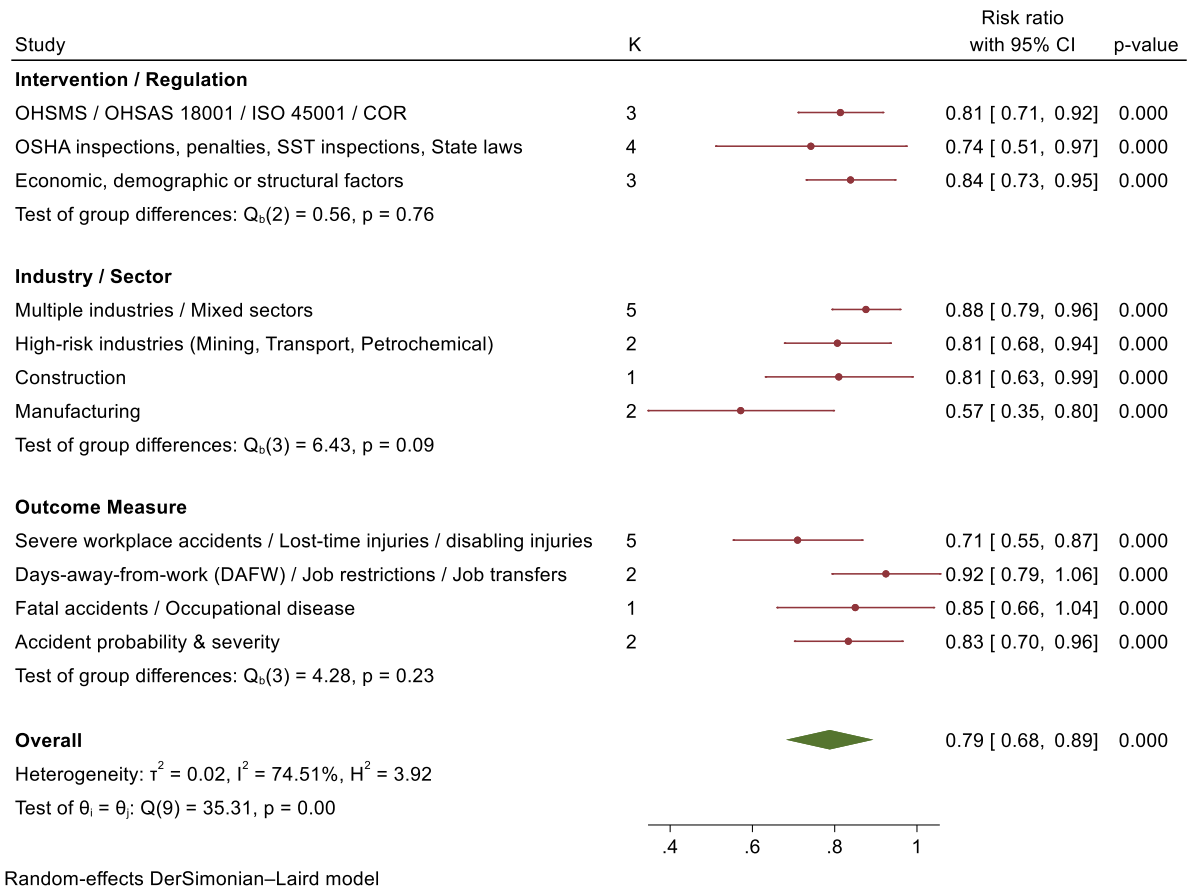


The results indicate that in the first subgroup (economic and demographic factors), the three included studies demonstrated a significant reduction in the risk of occupational accidents (RR=0.839; 95% CI: 0.731–0.946; p<0.001), with high homogeneity observed (I^2=0%), reflecting a consistent effect across studies. In the second subgroup, three studies assessing occupational health and safety management systems (OHSMS, OHSAS 18001, ISO 45001) reported a significant reduction in industrial accidents (RR=0.814; 95% CI: 0.711–0.917; p<0.001) with minimal variability (I^2=0%), confirming the effectiveness of these standards in reducing severe incidents. The third subgroup included four studies evaluating OSHA inspections and penalty enforcement, which also showed a significant risk reduction (RR=0.742; 95% CI: 0.511–0.974; p<0.001). However, lower homogeneity (I^2=88.83%) indicates greater variability in inspection effects, potentially due to differences in industries, sample sizes, enforcement intensity, and legal frameworks across countries (Figure 3). Regarding industry sectors, the findings demonstrate variation in intervention effects. In the construction sector, only one study was available, reporting a significant risk reduction (RR=0.810). In high-risk sectors, including mining and transportation, two studies showed a notable decrease in risk (RR=0.807). In the manufacturing sector, two studies reported an even greater and significant reduction (RR=0.572;

I^2=82.89%), highlighting the stronger impact of interventions in high-risk production environments. Studies examining multiple or national-level industries reported relatively uniform reductions in risk (RR=0.876; I^2=0%) (Figure 3). From an outcome perspective, studies evaluating accident probability and severity demonstrated significant reductions (RR=0.810). The subgroup analyzing fatal accidents and occupational diseases, including two studies, also reported meaningful decreases (RR=0.855). The most pronounced risk reduction was observed in severe workplace accidents and lost-time injuries (RR=0.769; I^2=81.17%), emphasizing the importance of preventive measures and management systems in mitigating serious injuries and fatal incidents (Figure 3). Overall, the pooled effect across all studies indicates a significant reduction in the risk of industrial accidents following various occupational health and safety interventions (RR=0.788; 95% CI: 0.682–0.894; p<0.001) with overall heterogeneity of I^2=74.51%, reflecting variability among studies but a consistent trend of risk reduction (Figure 3). Tests for subgroup differences revealed no statistically significant differences in intervention effects by type of intervention, industry sector, or outcome measure (p>0.05), although effects varied slightly across certain industries or outcomes, particularly in OSHA inspections, which showed lower homogeneity.

Figure 3

The forest plot showed subgroup meta-analysis.



4. Discussion

The present meta-analysis provides strong evidence that HSE legislation reduces industrial accidents and improves worker health. A meta-analysis of 12 studies, including manufacturing, construction, high-risk industries such as mining and transportation, and petrochemical and oil industries, showed a significant reduction in the risk of occupational accidents

(RR=0.788; 95% CI: 0.682–0.894). This finding underscores the importance of compliance with safety regulations and systematic HSE management to protect employees and reduce employers' legal liabilities. Subgroup analysis showed that the effect of interventions varied based on intervention type, industry, and outcome indicator. The findings of the present meta-analysis showed that legal and managerial HSE interventions, including the establishment of occupational health and safety management systems (OHSMS), international standards such as OHSAS 18001 and ISO 45001, as well as the implementation of legal inspections with fines, significantly reduce the risk of industrial accidents and improve employee health. The results of the subgroup analysis also showed that economic and demographic interventions can moderate risk reduction, and that combining multiple interventions provides greater effectiveness in improving occupational safety and health conditions. This is the first comprehensive meta-analysis to examine the legal and managerial effects of HSE on reducing industrial accidents and occupational injuries across industries, and its findings emphasize that both safety management systems and legal inspections, especially in conjunction with fines, play a key role in reducing accidents. The subgroup of economic and demographic factors (RR=0.839) showed that workforce characteristics and macroeconomic conditions moderated the association; young, inexperienced, or male workers were at higher risk of accidents, and interventions related to education, demographic risk reduction, and resource allocation reduced the risk. These results are consistent with previous research across other industries that emphasizes the need for HSE strategies tailored to the workforce and organization's characteristics. Comparing the findings of the present meta-analysis with the existing literature in high-risk and energy industries reveals remarkable consistency in results. A study in the UK offshore oil and gas industry (UKCS) showed that a combination of organizational safety investments and effective regulatory measures led to improved safety indicators and reduced accidents over two decades. The study also emphasized that continuity of HSE programs and ongoing monitoring, even in the face of operational challenges, are essential to maintain the effectiveness of regulations. These results are consistent with the findings of the present meta-analysis, as both show that regulatory enforcement, combined with systematic safety management and stakeholder engagement, significantly reduces occupational hazards (5). A review of the LNG industry also highlights that success in reducing accidents and improving health indicators requires a combination of legal frameworks, organizational culture, and multifaceted HSE management mechanisms. The findings of this study indicate that maintaining a balance between economic growth, environmental responsibility, and safety, as well as compliance with HSE regulations, is a key factor in success (7).

Furthermore, a study examining the UK Health and Safety Executive (HSE) experience with a behavioral and supply chain approach found that leveraging behavioral insights and engaging stakeholders significantly increases the efficiency and effectiveness of monitoring and enforcement, delivering better results than purely deterrent or penalty-based approaches(6). These findings emphasize that a combination of legal, managerial, and behavioral measures can be more effective in reducing accidents and improving employee health. Comparing the results of the present study with those of previous studies shows that the combination of managerial and legal interventions has similar effects on reducing occupational injuries. However, this study is the first meta-analysis to examine high-risk industries and the concurrent role of legal requirements and management standards, demonstrating the importance of these interventions as both a management duty and a legal responsibility. The greatest risk reduction was observed in severe occupational accidents and disabling injuries (RR=0.769), highlighting the importance of preventive measures and safety management systems in reducing serious accidents. The evident heterogeneity (I^2=74.51%) suggests that the effectiveness of interventions may vary depending on national legal frameworks, the intensity of regulatory enforcement, industry characteristics, and the length of the follow-up period. Active employee participation, continuous monitoring, and strict enforcement of rules had the greatest impact on reducing the risk of accidents. Although some differences were observed in the effects of OSHA inspections (I^2=88.83%), the overall trend of risk reduction was observed across all studies, indicating the generalizability of these findings.

5. Limitations and Suggestions

Despite the impressive results, some limitations should be noted. The included studies varied in design, sample size, follow-up duration, and industry, which may have introduced confounding factors. Limited data in some high-risk industries and a paucity of studies from emerging economies limit the global generalizability of the findings. Also, a few studies have examined long-term effects beyond 10–15 years. Future research should conduct subgroup analyses by type of legal intervention, industry, and national legal frameworks, and should adopt a longitudinal design with comprehensive reporting of minor and severe incidents. Incorporating economic and demographic factors into multivariate models can provide a more precise understanding of the effects of interventions in specific contexts. The policy implications of this study are significant: employers are responsible for complying with safety standards, and regulatory bodies must effectively enforce the laws, impose appropriate penalties, and facilitate training and certification programs. The simultaneous use of legal requirements, safety management standards, and demographic interventions can significantly reduce the risk of occupational accidents and diseases. Policymakers should adopt a multi-layered approach that combines the legal framework, management standards, and targeted workforce interventions.

6. Conclusion

The present meta-analysis provides comprehensive evidence that HSE legislation, in combination with safety management systems and targeted inspections, effectively reduces industrial accidents and promotes employee health. Enforcement of laws and systematic HSE management serve as complementary mechanisms, especially in high-risk industries, helping to improve employee safety. The findings emphasize the importance of active regulatory oversight, adherence to safety standards, and consideration of economic and demographic factors in the design of effective HSE policies. Future research should conduct detailed subgroup analyses and assess long-term effects to strengthen the evidence base for evidence-based policymaking in HSE.

Authors' Contributions

Authors contributed equally to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

In this research, ethical standards including obtaining informed consent, ensuring privacy and confidentiality were observed.

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