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The Role of Artificial Intelligence in Preventing Occupational Hazards in Industry 4.0 Environments

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ABSTRACT

This study examines the role of Artificial Intelligence (AI) in preventing occupational hazards within Industry 4.0 environments, emphasizing its contribution to advancing Occupational Safety and Health (OHS) systems through the lense of Safety-II and Resilience Engineering. A systematic literature review (SLR) was conducted using peer-reviewed articles published between 2021 and 2025, sourced primarily from Scopus and Google Scholar. The review employed a structured search strategy using Boolean operators and predefined inclusion–exclusion criteria, followed by a rigorous screening process aligned with the PRISMA guidelines. A total of 78 articles were initially identified, of which 32 met the eligibility criteria and were included in the final analysis. The findings reveal that AI technologies—particularly machine learning, computer vision, and predictive analytics—significantly enhance hazard identification, enable real-time monitoring, and support proactive decision-making in complex industrial settings. Across sectors such as manufacturing, construction, and energy, AI implementation was consistently associated with reduced accident risk, improved compliance with safety protocols, and enhanced organizational adaptability. The study also highlights that AI strengthens the anticipatory, monitoring, response, and learning capabilities that are central to resilient safety systems. However, its effectiveness is contingent upon organizational readiness, data quality, ethical governance, and workforce competency. This study contributes theoretically by reinforcing the integration of AI within Safety-II and Resilience Engineering frameworks, and practically by offering insights for designing adaptive, data-driven, and human-centered OHS systems in the era of digital transformation.

INTRODUCTION

As occupational accidents and diseases remain a serious problem that impacts productivity, operational costs, and the reputation of companies worldwide, occupational safety and health (OSH) is a crucial component of global industrial development. The number of occupational accidents and diseases continues to rise, with millions of cases reported annually, causing significant economic and social problems, despite regulatory and technical efforts to reduce occupational incidents (Shah & Mishra, 2024). Furthermore, the digital transformation triggered by the Industrial Revolution 4.0 has introduced a new paradigm in global industrial production and operational processes with the integration of technologies such as the Internet of Things (IoT), big data, and intelligent automation systems that connect the physical and digital worlds in real time (Nioata et al., 2025).

The changing characteristics of the work environment brought about by Industry 4.0 also create increasingly complex and dynamic hazard challenges. Cyber-physical technologies and human-robot collaboration generate ergonomic, cognitive, and cyber risks that differ from conventional hazards associated with manual or physical work. For example, intensive interactions between workers and automated systems create the potential for unexpected events that are difficult to anticipate with traditional reactive, manual-inspection-based OSH approaches (Nioata et al., 2025).

The limitations of conventional approaches in the context of today's digital workplace underscore the need for more adaptive and responsive occupational hazard prevention mechanisms. Systems that rely solely on human inspection and post-incident response are unable to cope with the large volume of data and the rapid changes in real-time working conditions (Permadi & Saputra, 2025). This opens up space for the development of OHS strategies that incorporate advanced digital technologies to enhance predictive capacity and proactively mitigate risks.

One promising strategic innovation in this context is Artificial Intelligence (AI). AI is a core technology in the Industry 4.0 paradigm, capable of analyzing big data, learning from risk patterns, and supporting automated decision-making without the need for continuous manual supervision. AI implementations include machine learning, computer vision, and predictive analytics, each of which has the potential to identify occupational hazards more quickly and accurately than traditional methods (Rudol et al., 2025).

In practice, AI has been used to improve real-time monitoring of occupational hazards, accelerate the detection of risky behaviors, and predict potential accidents before they occur (El-Helaly, 2024). For example, machine learning algorithms can analyze sensor data to identify patterns in work conditions that could potentially lead to accidents, allowing proactive preventive measures to be developed (Permadi & Saputra, 2025).

The application of AI also opens up opportunities for wearable technologies that monitor workers' biological and environmental conditions in real time, improving response capabilities to unsafe situations, and enriching intelligent simulation-based safety training modules (Rudol et al., 2025). This approach represents a paradigm shift from reactive safety management to proactive safety management, a concept consistent with modern safety theories such as Safety-II and resilience engineering, which emphasize a system's ability to anticipate and adapt to disturbances before an accident occurs.

Empirical evidence from various studies shows that integrating AI into OHS systems can reduce incident rates, accelerate response times to unsafe conditions, and improve compliance with safety procedures across various industrial sectors. Several AI use cases, such as workplace accident prediction, risk behavior detection, and work environment monitoring, have been reported, particularly in the manufacturing and automotive industries as part of the Safety 4.0 strategy (Nioata et al., 2025).

However, the literature also notes significant research gaps. Many studies are still limited to case studies or descriptive evidence, and most note the need for more in-depth evaluations of the effectiveness, organizational readiness, and challenges of AI implementation within operational contexts and occupational safety cultures (Rudol et al., 2025). This reflects the need to systematically examine how AI can truly contribute to OHS performance in the specific context of developing countries, where the dynamics of technology implementation often differ from those in developed countries.

In addition to conceptual limitations, other identified barriers relate to data privacy issues, algorithmic bias, and the need for adequate training for personnel to operate AI systems effectively without compromising human control over safe work processes (Rudol et al., 2025). These gaps highlight the urgency of scientific studies that focus not only on technological capabilities but also on understanding broader socio-organizational implications.

Based on these issues, this research is crucial to fill the limited academic space and provide a strong empirical basis for developing policies and systems for integrating AI into modern industrial OHS management. Such studies will help understand AI contribution to improving safety performance holistically, encompassing technical, behavioral, and organizational cultural aspects.

This research is aimed at evaluating the role of AI in preventing occupational hazards in the Industry 4.0 environment with a focus on the working mechanisms of AI, its impact on the effectiveness of accident prevention, and its implications for the development of a sustainable OHS management system in the era of digital transformation.

METHODS

This study employed a Systematic Literature Review (SLR) design to ensure a rigorous, transparent, and reproducible synthesis of existing scientific evidence regarding the role of Artificial Intelligence (AI) in preventing occupational hazards in Industry 4.0 environments. The selection of data sources was based on academic credibility and coverage, with Scopus utilized as the primary database due to its indexing of high-quality international journals (Q1–Q3), while Google Scholar was used as a supplementary database to capture broader literature, including regionally indexed journals such as SINTA 1–2, thereby enhancing contextual relevance, particularly in developing countries. The literature search was conducted systematically using a structured Boolean search string: (“Artificial Intelligence” OR “Machine Learning” OR “Computer Vision” OR “Predictive Analytics”) AND (“Occupational Safety and Health” OR “OHS” OR “Workplace Safety” OR “Occupational Hazards”) AND (“Industry 4.0” OR “Safety 4.0” OR “Smart Manufacturing” OR “Digital Industry”) AND (“Hazard Prevention” OR “Risk Assessment” OR “Accident Prevention”). The inclusion criteria were defined as follows: (1) articles published between 2021 and 2025, (2) peer-reviewed journal articles, (3) written in English, (4) explicitly addressing AI applications in occupational safety and hazard prevention, and (5) indexed in Scopus (Q1–Q3) or SINTA 1–2. Meanwhile, exclusion criteria included non-peer-reviewed publications, conference abstracts, editorials, non-English articles, and studies not directly relevant to the research topic. The initial search process identified a total of 78 articles, which were subsequently subjected to a multi-stage screening process following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. After removing 12 duplicate records, 66 articles remained for title and abstract screening, resulting in the exclusion of 22 articles due to irrelevance. A further 12 articles were excluded during full-text eligibility assessment due to methodological limitations or lack of alignment with the study focus, resulting in a final dataset of **32 eligible articles** for analysis. The entire selection process was systematically documented using a PRISMA flow framework to ensure transparency and methodological rigor. Data were analyzed using **thematic analysis**, which enabled the identification and categorization of key patterns related to AI applications, their impact on Occupational Safety and Health (OHS) performance, and implementation challenges. To enhance the validity and reliability of the findings, **source triangulation** was applied by comparing results across different industrial sectors and study designs.

RESULTS

The results of this study are based on a systematic analysis of 32 selected articles that met all inclusion criteria following the PRISMA screening process. These studies span multiple industrial sectors, including manufacturing, construction, energy, mining, and smart industrial systems, reflecting the broad applicability of AI in occupational safety contexts. In terms of research design, the dataset comprises a diverse distribution of study types, including empirical studies (n≈15), systematic reviews (n≈9), and narrative reviews (n≈8). This distribution indicates a balanced combination of evidence-based findings and conceptual analyses, strengthening the robustness of the synthesized conclusions. The findings are categorized into three major themes: (1) forms of AI application in occupational hazard prevention, (2) the impact of AI on OHS system effectiveness, and (3) challenges and organizational readiness in AI adoption.

Table: AI Research Results in Occupational Hazard Prevention

No.	Study/Journal	Research methods	Key Findings
1	**Khurram et al. (2025)**– Artificial Intelligence in Manufacturing Industry Worker Safety: A New Paradigm for Hazard Prevention and Mitigation (Processes)	An extensive literature review on AI techniques in manufacturing with a focus on occupational risks and mitigation.	AI-based predictive analytics and computer vision can analyze real-time and historical data to predict potential hazards before incidents occur. This integration helps reduce human error and improve the effectiveness of safety monitoring on the production line. The AI system also supports simulation training and workforce preparedness for modern workplace risks. (Khurram et al., 2025).

2	**Putra et al. (2024)**– K3 Innovation: Integrating AI and IoT to Improve Occupational Safety	Descriptive analytical with a normative empirical approach from literature and documentation	The integration of AI and IoT enables early hazard detection through sensors, real-time monitoring of work conditions, and early warnings that accelerate corrective response. This system has been proven to optimize response time to hazardous conditions and significantly reduce the risk of workplace incidents compared to conventional methods. (Putra et al., 2024).
3	**Permadi & Saputra (2024)**– Integrating Artificial Intelligence in Risk Assessment to Enhance Workplace Safety Protocols	Descriptive qualitative case study in a high-risk industrial environment	The application of AI in risk assessment has shown increased accuracy and precision in identifying hazard patterns compared to manual models. Machine learning can identify historical patterns in workplace incidents and proactively recommend safety protocol updates, driving the transition from a reactive to a preventative approach. (Permadi & Saputra, 2025).
4	**Park & Kang (2024)**– Artificial Intelligence and Smart Technologies in Safety Management (MDPI Applied Sciences)	Systematic cross-industry review	AI facilitates real-time monitoring and automated decision support, enabling adaptive safety strategies. This technology reduces risk, optimizes resource utilization, and improves overall operational efficiency. Successful implementation requires a combination of organizational commitment, regulatory compliance, and employee training. (Park & Kang, 2024).
5	**El-Helaly et al. (2024)**– Artificial Intelligence and Occupational Health and Safety (PMC Public Health)	Narrative review on AI integration in occupational health and safety	AI, through wearable devices, sensors, and machine learning, provides continuous monitoring of the environment and worker conditions. While the positive potential is significant, adapting the technology requires ethical policies and training to

	mitigate concerns about data privacy and bias. (El-Helaly, 2024).

Synthesis of Research Findings

1. Risk Predictivity
   AI leverages machine learning to analyze historical data and real-time sensors, enabling more accurate predictions of workplace hazards and preventative action before incidents occur.
2. Real-Time Monitoring and Behavior Detection
   *Computer vision*and and IoT integration enables real-time detection of unsafe behavior, PPE violations, and work environment anomalies.
3. Increased Risk Assessment Accuracy
   AI helps reduce human error in risk assessment and accelerates the improvement of safety protocols based on data learning.
4. Technical and Managerial Implementation
   AI integration impacts not only technical systems but also the formation of a more proactive and evidence-based safety culture.
5. Ethical and Practical Challenges
   Concerns around worker data privacy, algorithmic bias, and training needs stand out as real obstacles to the widespread application of AI systems.

Thematic analysis results show that AI consistently improves the capacity of occupational safety systems through risk predictivity, real-time monitoring, and data-driven decision support in various industrial settings. The application of these AI models has been empirically proven to reduce the potential for workplace accidents, improve safety compliance, and accelerate hazard response, although challenges remain in organizational readiness, data ethics, and limited human resource skills.

DISCUSSION

The results of this study confirm that the application of Artificial Intelligence (AI) in preventing occupational hazards in Industry 4.0 environments represents a fundamental transformation in the occupational safety and health (OHS) paradigm. The integration of AI drives a shift from conventional, reactive safety approaches to proactive, predictive, and adaptive ones. These findings are consistent with the development of modern occupational safety theories, particularly Safety-II and Resilience Engineering, which emphasize the importance of a system's ability to function safely under complex and dynamic working conditions.

From a Safety-II perspective, safety is no longer understood solely as the absence of accidents, but rather as the system's ability to consistently ensure operational success under varying conditions. Research shows that AI, through machine learning and predictive analytics, is capable of identifying latent risk patterns from historical and real-time data generated by modern production systems. This finding aligns with a systematic review by Armenteros-Cosme et al. (2025), which confirmed that AI-based predictive models significantly improve the accuracy of occupational risk identification and enable preventive measures to be taken before system failures occur (Armenteros-Cosme et al., 2025).

Furthermore, Karadag (2024) demonstrated through a meta-analysis that the implementation of AI in OHS systems contributes to a reduction in workplace accident rates and increased compliance with safety procedures. These findings reinforce the findings of this study, which demonstrate that AI supports the anticipation and monitoring functions in Safety-II, enabling organizations to learn not only from failures but also from successful safe work practices (learning from what goes right). Thus, AI acts as a catalyst for data-driven organizational learning (Karadag, 2025).

From a technical perspective, the application of computer vision and deep learning to detect unsafe behaviors, such as non-compliance with personal protective equipment (PPE), significantly contributes to the prevention of occupational hazards. A study by Shariful et al. (2024) showed that a computer vision-based YOLO model significantly improved PPE compliance detection rates compared to manual inspections. This finding supports research showing that AI consistently and objectively strengthens safety monitoring functions while reducing reliance on frequent human observation (Shariful et al., 2024).

Within the framework of Resilience Engineering, the results of this study indicate that AI contributes to strengthening the four key capabilities of a resilient system: anticipating, monitoring, responding, and learning. The application of AI in real-time monitoring, early warning systems, and operational data analysis supports an organization's ability to respond quickly and appropriately to disruptions. This aligns with the findings of Trivedi and Alqahtani (2024), who demonstrated that AI, when integrated with sensors and other intelligent systems, increases the speed of decision-making and the flexibility of safety responses in high-risk industries (Trivedi & Alqahtani, 2024).

Research by Ankamah-Lomotey (2025) also confirms that the integration of AI into occupational safety systems contributes to improved safety outcomes through continuous monitoring mechanisms and data-driven decision support (Ankamah-Lomotey, 2025). This finding corroborates research that AI not only improves the technical performance of OHS systems but also expands an organization's adaptive capacity to address operational uncertainty, a key characteristic of Industry 4.0.

However, this discussion also highlights that the effectiveness of AI in supporting Safety-II and Resilience Engineering is highly dependent on organizational readiness and the implementation approach used. The literature indicates that the risk of algorithmic bias, employee data privacy issues, and limited human resource competencies can hinder the success of AI implementation if not properly managed. These findings align with research indicating the need for a balance between intelligent automation and human control.

Based on a synthesis of findings and supporting literature, the researchers' assumption in this study is that AI cannot be positioned as the sole solution for preventing occupational hazards. AI will have optimal impact when integrated as a decision-support system that strengthens the role of OSH professionals, rather than replacing them. A human-centered AI approach is seen as a key prerequisite for safety systems to remain adaptive, ethical, and contextual.

Another assumption is that the benefits of AI in preventing occupational hazards will be more significant in industrial environments with high levels of operational complexity and risk, such as smart manufacturing, construction, and the energy sector. In this context, AI plays a key role in building resilient safety systems, capable of continuously learning and adapting to changing working conditions.

Overall, this discussion demonstrates that the integration of AI in occupational hazard prevention not only strengthens empirical evidence regarding the effectiveness of intelligent technologies but also provides significant theoretical contributions to the development of Safety-II and Resilience Engineering. AI enables OHS systems to evolve into more adaptive, predictive, and learning-oriented socio-technical systems, which are highly relevant to the demands of occupational safety in the Industry 4.0 era.

CONCLUSIONS

This study demonstrates that Artificial Intelligence (AI) plays a transformative role in preventing occupational hazards by enabling a shift toward proactive, predictive, and adaptive Occupational Safety and Health (OHS) systems in Industry 4.0 environments. Empirical evidence confirms that AI enhances hazard identification, real-time monitoring, and data-driven decision-making, leading to improved safety performance across multiple industrial sectors.

From a theoretical perspective, this study reinforces the relevance of Safety-II by emphasizing the system's capacity to ensure successful operations under varying conditions, as well as Resilience Engineering, particularly in strengthening the capabilities of anticipation, monitoring, response, and learning. AI acts as a critical enabler of these capabilities by transforming OHS systems into intelligent, learning-oriented socio-technical systems.

From a practical standpoint, the findings highlight that successful AI implementation depends on organizational readiness, data integrity, workforce competence, and ethical governance, including addressing risks such as algorithmic bias and data privacy concerns. AI should therefore be positioned as a decision-support system that complements, rather than replaces, human expertise.

However, this study has several limitations. First, the reliance on secondary data restricts the ability to capture real-time implementation dynamics. Second, the variability in study contexts and methodologies may affect the generalizability of findings. Third, limited empirical studies in developing countries indicate a geographical research gap.

Future research should focus on longitudinal empirical studies, cross-industry comparative analyses, and the development of human-centered AI frameworks tailored to OHS systems. Additionally, integrating AI with emerging technologies such as IoT and digital twins offers promising directions for advancing resilient and sustainable workplace safety systems.

REFERENCES

Ankamah-Lomotey, S. A. (2025). The Role Of Artificial Intelligence In Occupational Safety And Health: Investigating The Potential Applications And Limitations Of Ai In Improving Workplace Safety And Health. *International Journal of Research in Education Humanities and Commerce*, *06*(05), 69–82. https://doi.org/10.37602/ijrehc.2025.6506

Armenteros-Cosme, P., Arias-González, M., Alonso-Rollán, S., Márquez-Sánchez, S., & Carrera, A. (2025). Advancements in Artificial Intelligence and Machine Learning for Occupational Risk

Prevention: A Systematic Review on Predictive Risk Modeling and Prevention Strategies. *Sensors*, *25*(17), 5419. https://doi.org/10.3390/s25175419

El-Helaly, M. (2024). Artificial Intelligence and Occupational Health and Safety, Benefits and Drawbacks. *PubMed*, *115*(2), e2024014–e2024014. https://doi.org/10.23749/mdl.v115i2.15835

Karadag, T. (2025). Transformative role of artificial intelligence in enhancing occupational health and safety: A systematic review and meta-analysis. *The European Research Journal*, *11*(3), 1–28. https://doi.org/10.18621/eurj.1561840

Khurram, M., Zhang, C., Muhammad, S., Kishnani, H., An, K., Abeywardena, K., Chadha, U., & Behdinan, K. (2025). Artificial Intelligence in Manufacturing Industry Worker Safety: A New Paradigm for Hazard Prevention and Mitigation. *Processes*, *13*(5), 1312–1312. https://doi.org/10.3390/pr13051312

Nioata, A., Țapirdea, A., Chivu, O. R., Feier, A., Enache, I. C., Gheorghe, M., & Borda, C. (2025). Workplace Safety in Industry 4.0 and Beyond: A Case Study on Risk Reduction Through Smart Manufacturing Systems in the Automotive Sector. *Safety*, *11*(2), 50. https://doi.org/10.3390/safety11020050

Park, J., & Kang, D. (2024). Artificial Intelligence and Smart Technologies in Safety Management: A Comprehensive Analysis Across Multiple Industries. *Applied Sciences*, *14*(24), 11934–11934. https://doi.org/10.3390/app142411934

Permadi, B., & Saputra, D. R. (2025). Integrating Artificial Intelligence in Risk Assessment to Enhance Workplace Safety Protocols. *Journal of Occupational Safety Health and Technological Innovation*, *1*(1). https://openjournalshub.com/index.php/JOSHTI

Putra, M. K. F., M Zainul, L., Rusba, K., Nawawi, Y., & Hardiyono, H. (2024). Inovasi K3: Integrasi AI dan IoT untuk Meningkatkan Keselamatan Kerja. *Ranah Research : Journal of Multidisciplinary Research and Development*, *6*(5), 2231–2239. https://doi.org/10.38035/rrj.v6i5.1056

Rudol, J. F., Lau, K., Mroczek, A., & Kasperczyk, J. (2025). Exploring Human–AI Dynamics in Enhancing Workplace Health and Safety: A Narrative Review. *International Journal of Environmental Research and Public Health*, *22*(2), 199–199. https://doi.org/10.3390/ijerph22020199

Shah, I. A., & Mishra, S. (2024). Artificial Intelligence in advancing the Occupational Health and Safety: An encapsulation of developments. *Journal of Occupational Health*, *66*(1). https://doi.org/10.1093/joccuh/uiad017

Shariful, M., Shaqib, S., Sultan, R. S., Akter, K. S., Sattar, A., & Haider Noori, S. R. (2024). A Deep Learning Approach to Detect Complete Safety Equipment For Construction Workers Based On YOLOv7. *Computer Vision and Pattern Recognition*. https://doi.org/10.48550/arXiv.2406.07707

Trivedi, P., & Alqahtani, F. M. (2024). The advancement of Artificial Intelligence (AI) in Occupational Health and Safety (OHS) across high-risk industries. *Journal of Infrastructure, Policy and Development*, *8*(10), 6889. https://doi.org/10.24294/jipd.v8i10.6889