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Safety Hazards Detections in Electrical Industry: A Systematic Literature Review

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Abstract. The electrical sector drives economic growth and poses significant occupational health and safety challenges. The dynamic nature of electrical infrastructure and the expansion of power plants and distribution networks, particularly in Indonesia, heightens the risk of electricity-related workplace accidents. However, Indonesia's limited research focuses on hazard detection within the electrical industry. This study aims to map the factors contributing to hazards and methods to detect hazards in the electrical industry with several contributing factors, particularly human factors, in identifying potential hazards and mitigating accident risks. The search engines utilized in this study included Science Direct, Google Scholar, Taylor & Francis Online, MDPI, and the Institute of Electrical and Electronics Engineers (IEEE). A total of 2,446 articles were initially reviewed, and after thorough screening, 15 articles were selected for further analysis. The results show some factors contributing to safety hazard detection, including human, environmental, organizational, technological, and physical factors. The factors with the most substantial evidence demonstrated a significant level of $P< 0.001$. Subsequently, some methods were used for the detection of hazards, such as surveys, interviews, machine learning, deep learning, eye tracking, and virtual reality, which are applied in power plants, transmission, and distribution electrical sectors. Future research could focus on IoT for hazard detection, work culture, and enhancing the human-machine interface.

Introduction

In a global context, the electrical sector is vital for economic growth and presents significant occupational health and safety challenges [1]. This sector includes power generation, distribution and sales, involving public and private entities for Indonesian conditions. In 2022, Indonesia's electricity supply substantially increased up to 80% especially in electricity used in households, industry, and services[2]. Despite its critical role in energy provision, the industry requires rigorous attention to its workforce's health and safety. The dynamic conditions of electrical infrastructure and the expansion of power plants and distribution networks in the electrical industry, especially in Indonesia, increase the risk of electrical workplace accidents. Electrical hazards in the sector include electric shock, current surges, and fire risks from electrical faults. The key factors are operational procedures, as identified by the Occupational Safety and Health Administration (OSHA) scenario analysis [3]. Addressing these complex hazards requires consideration of factors such as worker skills and experience [4].

Electrical workplace accidents significantly impact productivity in the electrical industry and affect workers. According to OSHA data, electrical issues account for 86% of production, transmission, and distribution losses, leading to 12,976 lost workdays annually [5], [6]. The National Institute for Occupational Safety and Health (NIOSH) reports 244 accidents involving scenarios such as electrical network equipment (21%) and contact with power lines (16%) [7]. Several quantitative and qualitative methods exist for identifying workplace hazards. Typically, risk identification uses two parameters: severity and probability. Methods include a safety checklist, Job Safety Analysis (JSA), Hazard and Operability Study (HAZOP), Failure Mode and Effects Analysis (FMEA), and Fault Tree Analysis (FTA) [8]. These methods can be adapted to specific job types or regional

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conditions. Additionally, effective risk measurement requires regulatory approaches to occupational health and safety in the electrical industry [7].

Other previous research studies have been to understand the unique features of the transmission and distribution sector of the electrical industry with detection hazards. The methods were used for quantifying the safety risk, safety risk mitigation, and safety hazard detection [9], [10]. One of the most effective ways to reduce casualties and property damage in electrical sites was to provide safety hazard detection models. The model that existed used a visual attention mechanism for detecting situations as hazardous or not based on a dataset for processing the results[10]. Research about occupational health and safety in the electrical industry has recently been limited, especially regarding safety hazard detection in Indonesia. This systematic literature review focuses on safety hazard detection factors that contributed to accidents in distribution and transmission activity in the electrical industry over the past four years (2021-2024). The review explores recent advancements aimed at safety hazard detection factors that can reduce the frequency of near-miss and accidents for electrical industry workers. By examining conditions and personal and environmental factors contributing to accidents, this review highlights potential areas for improvement and innovations that could enhance occupational health and safety in the electrical industry.

Methodology

The methodology of this study was a systematic literature review (SLR). This study started by searching for relevant articles about safety hazard detection in the electrical industry and observing the condition of the electrical Indonesian sector. After identifying the real issue, we conducted SLR using a systematic rule of review in the University of Edinburgh and several other articles through the review literature research. This literature review consists of three stages: literature search and data management, included and excluded criteria, screening process, and evaluation process[11], [12], [13], [14].

Literature Search and Data Management

The systematic literature review uses five types of search databases from 2020 to 2024, using the same keyword and advanced search features. Article databases that were used were Science Direct, Google Scholar, Taylor & Francis Online, MDPI, and the Institute of Electrical and Electronics Engineers (IEEE). The keywords in this review are safety hazard detection in the electrical industry, and the process review uses Mendeley Reference Management and Microsoft Excel software.

Included and Excluded Criteria

In this systematic literature review, safety hazard detection in the electrical industry focuses on power plants, distribution and transmission. These are the criteria for the chosen article:

1. It is connected to safety hazard detection in the electrical industry.
2. Year of article publication: 2021-2024.
3. Report on several factors contributing to safety hazard detection in the electrical industry.
4. One of the investigation tools or methods for examining the safety hazard detection process is interviewing, modelling, direct observation, and analyzing institutions' hazard databases.

Screening Process

An initial paper search was conducted using the advanced search feature with specified keywords. Once relevant papers were identified, a verification process ensured no duplicates were present. The screening process involved reviewing the abstracts as they summarize the research problem and conclusions. This examination of abstracts helped determine if a paper met the criteria for inclusion in the systematic literature review on safety hazard detection in the electrical industry.

Evaluation Process

In this stage, the evaluation process of factors contributing to safety hazard detection in the electrical industry focuses on the study's significance. P-value identifies a string relationship. The classification of factors in safety hazard detection is as follows:

1. Factors with solid evidence (P-value < 0.001)
2. Factors with moderate evidence (P-value < 0.05)
3. Factors with insufficient evidence (P-value > 0.05)

Results and Discussion

The findings of this process were the importance of a structured data management approach, which was adopted to ensure the accuracy and reliability of reference sources. In the first stage of the literature search, there was a broad screening process of 2,475 articles from various source databases. Upon closer examination, 2,472 articles remained after identifying and removing three duplicate entries. This preliminary filtering process allowed for the elimination of redundancies and ensured that unique sources were retained for further analysis. Through subsequent stages of refinement, additional exclusion criteria were added. Furthermore, 15 studies were relevant and selected for inclusion in this research. A detailed overview of the systematic literature review process is depicted in Fig. 1, illustrating the filtering stages and decision points that guided the final selection of sources.

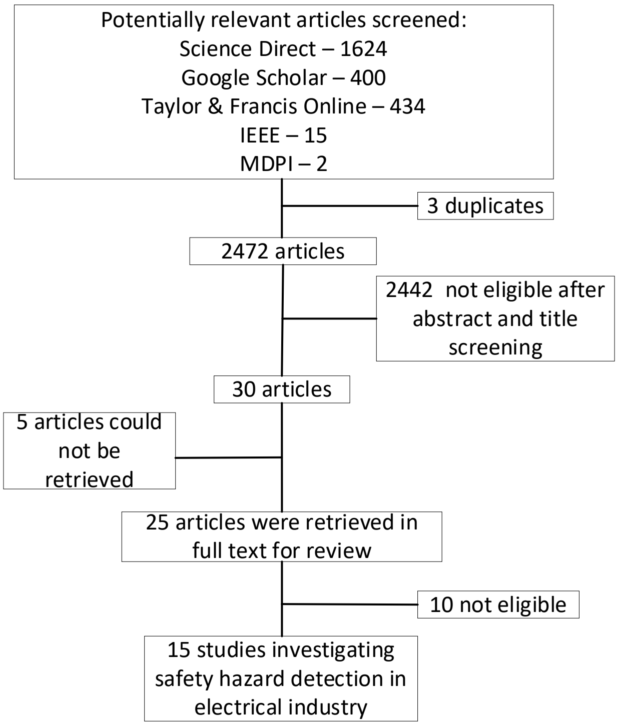

Fig. 1. Stage Of Systematic Literature Review of Studies Safety Hazard Detection in Electrical Industry.

Investigation of Tools and Methods for Safety Hazard Detection in Electrical Industry

There are a few ways to investigate safety hazard detection in the electrical industry, such as using subjective perspectives, data analysis, model development, and applied technology [4], [15], [16], [17]. Each of these methods has its strengths and weaknesses regarding research. Previous research has extensively explored the application of various techniques that spread over several scopes of electrical industries and countries. The results of classification tools and methods used are shown in Fig. 2.

Electrical Scope	Power Plant	Electrical transmission	Electrical Distribution
Reference	[20], [26]	[4], [10], [22]	[7], [15], [16], [17], [18], [19], [21], [23],[24], [25]
Methods	Survey, Virtual Reality	Survey, Deep Learning	Survey, Machine Learning, Eye Tracking, Interview
Country	China, Malaysia	United States, India	China, Turkey, Iran, Ghana, Spanyol, Indonesia, United States, Saudi Arabia

Fig. 2. Classification Tools and Methods Based on Systematic Literature Review.

The valuable insights into personal experiences and how people perceive safety hazards are found by collecting several subjective perspectives from stakeholders at different levels. The collected data used questionnaires, interviews, and focus group discussions. For data processing, fuzzy AHP, performance map analysis and necessary condition analysis (NCA) were used for measuring the probability of hazards, exposure and consequence [4], [7], [10], [18], [19], [20], [21], [22], [23], [24].

On the other hand, data analysis provides a more objective and quantifiable way to spot patterns and potential risks. However, it might miss out on details that aren't easily captured in numbers. Developing models can help us simulate and predict potential safety issues, which is a proactive way to address hazards. Still, these models depend on accurate data and assumptions, which can take time. The dataset used for detecting safety hazards comes from the accident analysis and the safety database department [4], [15], [16], [25].

Eye-tracking technology is another helpful tool because it shows how people interact with their surroundings and can highlight hazards that might be overlooked, giving us a detailed and real-time view of safety awareness. However, eye-tracking can be expensive and complicated to set up. Each method has its role in improving safety in the electrical industry, and using a combination of these approaches could provide the most thorough understanding of safety hazards [17].

Virtual Reality (VR) is being explored as a powerful tool to help construction workers stay alert to electrical hazards, often overlooked despite regular safety training. By immersing workers in a VR environment where they repeatedly encounter these hazards, they can safely experience what happens when accidents occur, like getting electrocuted. Using eye-tracking technology, researchers found that this immersive, simulated experience could sharpen workers' attention and make them more vigilant. This approach shows promise as a more engaging and effective way to reduce the risk of electrocution on construction sites [26].

Safety Hazards Detection Factors in Electrical Industry

Detecting safety hazards in the electrical industry involves a wide range of factors influencing workplace safety and accident rates. Studies have demonstrated that hazard control and prevention are crucial in mitigating unsafe actions, particularly in high-risk environments such as coal-fired power plants and electrical construction projects[10], [19], [22]. Research conducted in Malaysia and Saudi Arabia revealed that safety planning, management, verification, strong leadership, and employee motivation are vital in improving safety compliance and participation[22], [23]. Structured safety protocols have proven effective in reducing occupational accidents and fatalities, with a clear link between these measures and improved safety outcomes.

In addition to organizational and leadership factors, personal attributes of workers, such as age, job role, and work experience, significantly influence safety behaviour in the electrical industry[23]. A study conducted in Kerala, India, found that personal stress, job-related fatigue, and safety climate factors were strongly correlated with occupational accident rates[20]. This underscores the importance of providing comprehensive safety training, enhancing safety knowledge, and addressing personal issues such as stress to create a safer working environment. Effective leadership in motivating workers and fostering a strong safety culture can bridge the gap between safety knowledge and field compliance[4], [23].

Technological approaches are also becoming increasingly important in detecting and mitigating safety hazards. Virtual reality (VR) simulations, wearable eye-tracking systems, and machine learning algorithms such as the Gaussian Process Classifier (GPC) have shown great potential in improving workers' vigilance toward electrical hazards and increasing the accuracy of hazard detection[15], [17], [26]. These innovations enable more effective safety training and early detection of electrical panel fires, providing practical solutions to the persistent issue of electrical accidents. The integration of these technologies, along with continued education and regulatory enhancements, holds significant potential for improving safety in the electrical industry.

Factors Considered in This Study

In this study, the factors considered for detecting safety hazards in the electrical industry focus on human, environmental, and operational dimensions, as highlighted in the reviewed literature[7], [20]. This study focuses on developing a hazard detection model that incorporates working culture and is centred on a Human-Machine Interface (HMI) to minimize workplace accidents in the electrical industry. The reviewed literature emphasizes the critical role of human, environmental, and operational factors in workplace safety; however, many existing models need to integrate these dimensions comprehensively[4], [10], [20]. Current research often addresses these factors in isolation, requiring a holistic view of how they interact in real-world scenarios. By emphasizing working culture, this research seeks to fill that gap, recognizing that safety behaviours and perceptions are heavily influenced by cultural norms and organizational practices, which are crucial to addressing hazards effectively.

One of the critical gaps in existing models is the need for more understanding of how human factors interact with environmental conditions, especially in high-risk industries like electrical utilities[4]. For instance, extreme weather or poor lighting conditions can significantly affect human performance, yet these factors are not consistently accounted for in hazard detection models. This research will explore how such environmental conditions, combined with human factors like fatigue or stress, increase the likelihood of accidents. Furthermore, by integrating emerging technologies such as the Internet of Things (IoT) and machine learning, the proposed model will enhance the precision and speed of hazard detection, offering real-time monitoring and adaptive responses to safety threats.

The core innovation of this research lies in integrating Human-Machine Interface (HMI) technology as a crucial output of the hazard detection model. HMI will serve as the communication bridge between workers and machines, providing intuitive, real-time alerts that can be customized to reflect the organization's working culture and safety priorities [27]. This user-centric approach will improve hazard recognition by making it easier for workers to interact with complex systems, ensuring that safety interventions are timely, easy to understand, and implemented. By aligning HMI with both the operational environment and the workers' cultural context, the model aims to reduce human error and improve safety compliance.

The findings of this research have the potential to contribute significantly to the academic field by offering a comprehensive, culture-sensitive approach to workplace safety. This integrated model addresses the technological aspects of hazard detection and emphasizes the importance of human and cultural factors in shaping safety outcomes. By bridging the gap between existing safety frameworks and the realities of human-machine interaction in culturally diverse work environments, this study offers a novel contribution to reducing workplace accidents in the electrical industry, providing practical solutions that can be adapted across various high-risk sectors.

Future Research Stages

The future stages of research based on the abstract would involve a comprehensive, multi-phase process to enhance the understanding and implementation of hazard detection models and safety behaviour frameworks in the electrical utility industry. In the first phase, a detailed assessment of existing safety measures and hazard detection models will be conducted. This phase will collect real-time data from multiple power plants using advanced data collection tools such as IoT devices and machine learning algorithms. The goal is to identify gaps in the current system, especially in integrating personal and organizational factors that influence safety behaviours. This phase will also assess the relevance and effectiveness of safety compliance frameworks and their direct impact on reducing workplace accidents.

The second phase of the research will focus on developing an enhanced hazard detection model that emphasizes the Human-Machine Interface (HMI) and considers the working culture within the industry. A crucial part of this phase will involve conducting pilot tests using virtual reality (VR) simulations to expose workers to various safety scenarios and measure their reactions to hazards in a controlled environment. The inclusion of eye-tracking technology, as well as AI-driven analysis, will help evaluate worker responses, providing insights into improving hazard perception and vigilance. Additionally, this phase will explore how working culture impacts safety compliance, participation, and overall hazard recognition, allowing for developing a more comprehensive and adaptive safety model.

The final stage will aim to validate the proposed hazard detection model through extensive field testing across different industrial sites. The research will measure the model's efficacy in minimising workplace accidents by comparing accident rates, safety compliance, and employee safety behaviour before and after implementing the new model. This phase will also involve using predictive analytics to forecast future trends in safety performance and offer recommendations for continuous improvement. Ultimately, this research aims to contribute significantly to advancing safety practices in high-risk industries by providing an integrated approach that bridges technological innovation and cultural considerations.

Conclusion

In conclusion, this systematic literature review highlights the critical factors influencing safety hazard detection in the electrical industry, particularly emphasizing human, environmental, and organizational components. As the electrical infrastructure in countries like Indonesia expands, the risk of workplace accidents grows, necessitating more robust hazard detection mechanisms. Despite the limited focus on this issue within Indonesian research, this review demonstrates that combining technological advancements, such as IoT integration and enhanced human-machine interfaces, alongside a deeper understanding of human factors can significantly mitigate risks. By analyzing critical findings from a broad selection of scholarly sources, this study provides a comprehensive overview of the current state of safety hazard detection in the electrical industry. It underscores the need for future research to refine and implement these solutions effectively across diverse cultural and operational contexts.

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