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Deep learning in occupational safety and health and its contribution to workplace risk management: A systematic review

El aprendizaje profundo en seguridad y salud laboral y su contribución a la gestión de riesgos en el lugar de trabajo: una revisión sistemática

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Abstract
Occupational health and safety (OHS) is essential in all industrial sectors due to the significant impact of accidents and occupational illnesses. Traditionally, risk management has relied on periodic assessments and reactive control measures; however, artificial intelligence and deep learning have enabled the development of more proactive and efficient approaches. These technologies facilitate the analysis of large volumes of data to identify hidden patterns, predict risks, and improve workplace safety. In this context, this study analyzes the current use of deep learning in OHS, focusing on its implementation, perceived effectiveness, and the challenges it presents. Furthermore, it examines its application in sectors such as construction, logistics, and mining, where it contributes to risk prevention and the detection of unsafe behaviors. To this end, a systematic review was conducted following the PRISMA protocol, including 14 open-access articles selected from an initial pool of 274 publications retrieved from Scopus, PubMed, Web of Science, and DOAJ. The analysis concludes that deep learning has great potential to reduce unsafe behaviors by identifying and detecting key variables, such as information management, that influence the occurrence of incidents and hazardous conditions. Therefore, this technology emerges as a valuable tool to support OHS professionals in prevention, control, and decision-making in various work environments.

Keywords: deep learning, occupational risks, workplace safety.

Resumen
La salud y seguridad en el trabajo (SST) es fundamental en todos los sectores industriales debido al impacto significativo de los accidentes y las enfermedades laborales. Tradicionalmente, la gestión de riesgos se ha basado en evaluaciones periódicas y medidas de control reactivas; sin embargo, la inteligencia artificial y el aprendizaje profundo han permitido desarrollar enfoques más preventivos y eficientes. Estas tecnologías facilitan el análisis de grandes volúmenes de datos para identificar patrones ocultos, predecir riesgos y mejorar la seguridad laboral. En este marco, el presente estudio analiza el uso actual del aprendizaje profundo en SST, centrándose en su implementación, la percepción de su eficacia y los desafíos que plantea. Además, se examina su aplicación en sectores como la construcción, la logística y la minería, donde contribuye a la prevención de riesgos y a la detección de comportamientos inseguros. Para ello, se llevó a cabo una revisión sistemática siguiendo el protocolo PRISMA, que incluyó 14 artículos de acceso abierto seleccionados de un total inicial de 274 publicaciones recuperadas de Scopus, PubMed, Web of Science y DOAJ. A partir del análisis realizado, se

concluye que el aprendizaje profundo posee un gran potencial para disminuir conductas inseguras mediante la identificación y detección de variables clave, como la gestión de la información, que influyen en la ocurrencia de incidentes y condiciones peligrosas. Por ende, esta tecnología se presenta como una herramienta valiosa para apoyar al personal de SST en la prevención, control y toma de decisiones en diversos contextos laborales.

Palabras clave: aprendizaje profundo, riesgos laborales, seguridad en el trabajo.

Introduction

Occupational safety and health (OSH) is a top priority in all sectors, as workplace accidents and related illnesses can have serious consequences for both workers and organizations. Traditionally, risk management has focused on periodic assessments and reactive controls. However, technological advancements, especially in artificial intelligence (AI), open up new possibilities for more efficient and proactive management (Ajayi et al., 2020).

One of the main challenges in OSH and workplace risk management is the proper handling of the large volume of data generated by organizations, which is often stored in disorganized formats or without rigorous control. This data, despite being complex and heterogeneous, could provide valuable input for decision-making if processed correctly (Antwi-Afari et al., 2022). However, the lack of suitable tools limits the ability to identify and anticipate risks, thus hindering accident prevention and the creation of safe work environments.

In this context, deep learning, an advanced branch of machine learning and a key component of AI, is based on multi-layered artificial neural networks that mimic the hierarchical and complex functioning of the human brain (Casuat et al., 2020). These networks allow for the processing of large amounts of data, the recognition of complex patterns, and the making of automated decisions based on the received information. Unlike traditional machine learning, which requires the manual formulation of complex hypotheses, deep learning generates these hypotheses automatically, enhancing its ability to capture non-linear relationships (Dong et al., 2021; Denning & Denning, 2020).

A crucial aspect of neural networks is the activation function, which transforms the data and facilitates its classification by establishing non-linear relationships between inputs and outputs. Among the most commonly used functions are sigmoid, ReLU, and hyperbolic tangent. In addition, deep learning includes tools such as stacked autoencoders, deep belief networks, Boltzmann machines, and convolutional neural networks (CNNs), which expand its analytical and application capabilities. In the current era of digitalization, the application of deep learning has revolutionized occupational health and safety, promoting a more proactive approach to workplace risk management. This technology allows for the analysis of data from various sources—such as environmental sensors, incident reports, biometric data, and worker profiles—to identify and predict potential risks. The underlying algorithms detect hidden patterns and trends that indicate latent risk situations, facilitating the anticipation of accidents or occupational illnesses and the implementation of preventive measures (Dong et al., 2021).

Furthermore, deep learning facilitates the identification of sectors with higher accident rates and the analysis of the factors that cause them. It also supports the objective evaluation of working conditions by analyzing human resource practices with AI. This technology improves risk monitoring and detection systems by automating tasks that were previously performed manually by occupational health and safety teams (Du et al., 2019). For example, training predictive models with diverse data allows for real-time alerts about unsafe behaviors or conditions.

Another relevant application of deep learning is personalized training for employees, which increases their safety knowledge and reduces the likelihood of accidents. Tools like ChatGPT facilitate the delivery of tailored and accessible content on workplace safety (Fan & Xu, 2021). Similarly, AI-based solutions analyze past events to identify causes and prevent future incidents.

Although the application of AI and deep learning in OHS is in its early stages, studies already demonstrate its usefulness in real-time detection of personal protective equipment (PPE) use (Fang et al., 2018), identification of unauthorized activities in construction (Hunt et al., 2022), and risk assessment of exposure to toxic substances in mining (Jain et al., 2021). Other examples include predicting injury causes through text analysis (Ajayi et al., 2020), automated recognition of awkward postures (Du et al., 2019), detection of hazardous behaviors during structural assembly (Jeong et al., 2023), and analytical management of OHS data (Antwi-Afari et al., 2022). Additionally, models have been developed to predict risks in electrical infrastructure projects (Liu et al., 2022).

Consequently, deep learning is expected to transform workplace risk management by leveraging its ability to analyze large volumes of data and recognize complex patterns, thus improving efficiency, accuracy, and predictive capabilities in identifying and controlling occupational risks. For all the reasons mentioned above, this article, through a systematic review of the literature, explores the applications and benefits of deep learning in occupational health and safety, placing particular emphasis on the identification and prediction of risk situations, real-time monitoring, assessment of worker well-being, and reflection on the ethical challenges and relevant considerations in this field.

Methodology

Research design

This article presents a systematic review, whose purpose is to analyze the current state of knowledge published in academic journals regarding the role of deep learning in occupational health and safety, as well as in occupational risk management.

To this end, a qualitative approach is used to explore how organizations are implementing deep learning, the perceptions of its usefulness and effectiveness among workers and safety managers, and the challenges and barriers that arise during its application. In this context, the research examines key aspects such as technological acceptance, ethical and privacy implications, required training, and the adaptation of work processes.

Furthermore, the study adopts an exploratory and descriptive approach, aiming to provide a systematic and detailed description of the concepts, characteristics, and elements related to the use of deep learning in occupational health and safety. The main objective is to offer a comprehensive overview of how this technology is used to manage occupational risks, delving into the specific methods, techniques, and tools used to collect, analyze, and apply data related to occupational health and safety. In addition, the study identifies and discusses the main challenges that deep learning must overcome to achieve widespread adoption in occupational risk prevention and management.

Search strategy

For data collection, the following keywords were defined: "deep learning," "machine learning," "occupational health and safety," and "occupational risk." The search was conducted in recognized scientific databases such as Scopus, DOAJ, PubMed, and Web of Science. Additionally, search engines such as Google Scholar and SCISPACE, the latter based on artificial intelligence, were used to broaden the search and identify relevant studies within the aforementioned databases. The search strategies combined the keywords using the Boolean operators AND and OR, in order to maximize the number of relevant results. These strategies were adapted according to the syntax and features of each platform to ensure a comprehensive and accurate search for relevant publications on the topic.

Inclusion and exclusion criteria

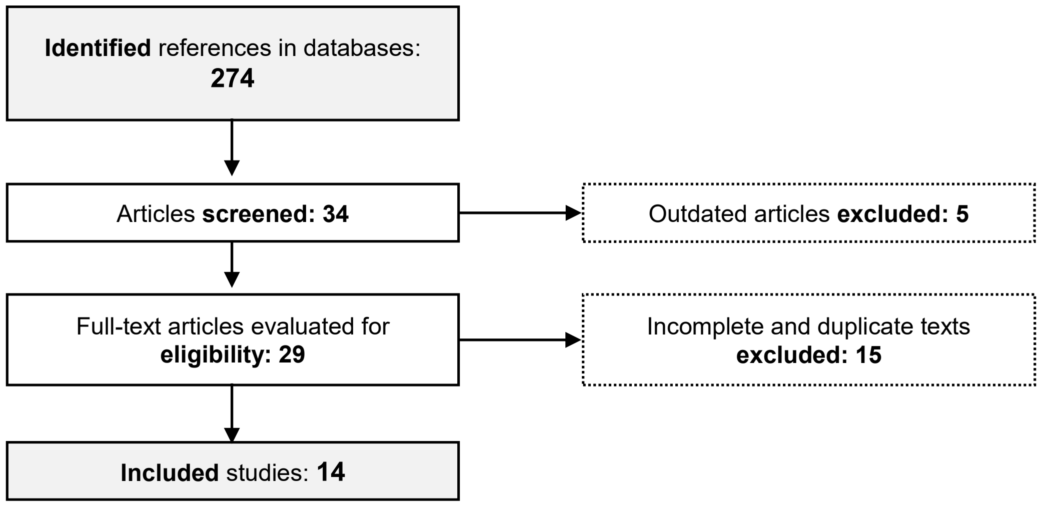
To select the articles, clear inclusion and exclusion criteria were established, applying the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology to ensure transparency and reproducibility in the process, based on a rigorous assessment of the quality of each study.

Studies addressing the application of deep learning in occupational health and safety (OHS) management and/or occupational risk management were included. Publications in any language were considered, although articles written in English were given priority. Given that deep learning is an emerging technology, the selection was limited to articles published between 2018 and 2023. The types of studies considered were experimental, applied research, observational, and narrative systematic reviews.

The initial search yielded 274 references from specialized databases such as Scopus, PubMed, Web of Science, and DOAJ, as well as from academic search engines like Google Scholar and SCISPACE. After a first review of titles and abstracts, 240 references that did not directly relate to OHS were discarded. This left 34 potentially relevant articles, of which 5 were excluded because they did not meet the established time period criterion. During the full-text evaluation, 29 articles were analyzed; of these, 15 were excluded because they were duplicates in different repositories or because their full text was not available. Finally, 14 articles met all the criteria and were included in the final synthesis.

The entire selection and refinement process strictly followed the PRISMA methodology guidelines, thus guaranteeing clarity, replicability, and scientific rigor. Figure 1 presents a flow diagram illustrating step by step the progressive reduction of the initial sample until the final selection of the included studies.

Figure 1
Flowchart of the article selection process



Note. Based on the PRISMA statement

The included articles are those that applied deep learning techniques to specific areas of occupational safety and health and risk management, and whose results are presented in this study.

Results

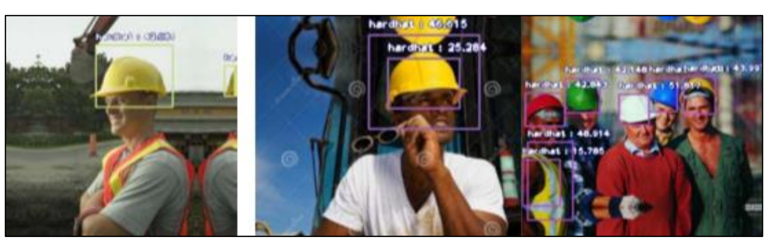
Below are some of the main areas in which deep learning has been applied to improve occupational safety and health, as well as occupational risk management.

Deep learning in occupational risk management in the construction industry

Fang et al. (2018) proposed a system based on deep learning algorithms to verify workers' certifications on construction sites by analyzing video images. In this approach, they defined specific rules to extract key frames from the video, implemented a novel system for automatic professional profile recognition applicable to different specialties, and developed an integrated platform capable of accurately verifying the validity of certifications, using advanced face detection and recognition methods.

On the other hand, Casuat et al. (2020) designed a safety helmet detection system based on image processing, along with a graphical user interface (Figure 2). This system aims to identify whether workers are wearing their helmets correctly. To evaluate its performance, the researchers used public datasets containing images of workers wearing helmets and measured its performance based on the average accuracy achieved. The results showed an average accuracy of 79.24%, indicating a high capacity of the system to detect improper helmet use, and suggesting that it could be used to impose penalties on those who violate safety protocols.

Figure 2
Graphics generated by the helmet detection system based on deep learning image processing



Note. Adapted from "*Deep-Hart: A Deep Learning Approach for Safety Helmet Detection in Workplace Monitoring and Safety*" by Casuat, Merencilla, Reyes, Sevilla & Pascion (2020)

Nath et al. (2020) developed three deep learning models based on the You-Only-Look-Once (YOLO) architecture, with the aim of verifying in real time, through images and videos, the use of personal protective equipment (PPE) – helmet, vest, or both – by workers. In the first model, the algorithm detects workers, helmets, and vests separately, while a machine learning system, combining a neural network and a decision tree, verifies whether each worker is wearing the PPE correctly. In the second model, the algorithm simultaneously identifies workers and verifies the correct use of the equipment using a convolutional neural network (CNN). Finally, in the third model, the algorithm first detects and crops the workers in the image, and then classifies them based on the presence of PPE using CNN-based classifiers, such as VGG-16, ResNet-50, and Xception. Validation tests showed that the second model achieved the best results, with an average accuracy of 72.3% in real-world environments and the ability to process up to eleven images per second on a laptop.

Zhang et al. (2020) proposed a method based on bidirectional convolutional long short-term memory (C-BiLSTM) for the automatic classification of construction accident reports. This method was applied to a dataset extracted from the Occupational Safety and Health Administration (OSHA) website, which contained detailed accounts of incidents. The results showed that the model outperformed several classical machine learning approaches, such as support vector machines (SVM), Naive Bayes (NB), and logistic regression (LR), in classification tasks.

Finally, Antwi-Afari et al. (2022) proposed a system based on pressure sensors embedded in portable insoles, along with recurrent neural network (RNN) models, to automatically recognize and classify different types of awkward postures in the construction industry. From the data collected by the sensors, the system automatically extracts features and performs sequential classification. Furthermore, they evaluated the performance of three deep learning models based on RNNs: unidirectional LSTM networks, bidirectional LSTM networks, and GRU networks.

Deep learning in occupational risk management in the logistics industry

Uchida et al. (2018) developed a deep learning application to capture and process images of facilities and walkways in logistics environments, in order to identify occupational health and safety risks. This technology detects the state of order and cleanliness of objects and pallets, as well as the movements of conveyor belts and workers. The study evaluated the agreement between safety assessments performed by experts and those generated by the deep learning network, using typical images captured during safety inspections. The results indicated that the system is capable of recognizing differences in the arrangement and alignment of elements, the presence of unnecessary objects, and significant dirt as distinctive image features. The accuracy of the model's safety assessment ranged from 60% to 95%, depending on the network used for its development.

Deep learning in occupational risk prevention in electrical infrastructure projects

On the other hand, Ajayi et al. (2020) applied text mining to extract relevant terms from data and create six deep learning models focused on risk management in electrical infrastructure projects. The models included deep neural networks for both classification (risk or no risk) and regression (assessment of time loss, personal injuries, damage to facilities, machinery, equipment, and the environment). For their development, the researchers used a risk database from a leading UK energy construction company, implementing the H2O framework in the R programming language. The classification model achieved 93% accuracy, while the regression models reached 92% accuracy.

Deep learning in occupational risk prevention in the mining industry

Yi (2019) explored the main applications of deep learning in the mining industry, with particular emphasis on the analysis and monitoring of disasters in mining areas. This study highlights research focused on using these techniques to measure and analyze factors associated with disasters such as ground subsidence, slope deformation, landslides, toxic gas leaks, and waste spills during mining activities and during the operational and closure phases of mines. Among the most relevant studies are: 1) Luo et al. (2019), who applied the Information Value Model (IVM), artificial neural networks, and Support Vector Machines (SVM) to analyze the probability of subsidence in mining areas. The comparative analysis included the area under the curve and used historical data from the China Geological Survey, considering variables such as slope, orientation, altitude, curvature, annual precipitation, river density, proximity to rivers and faults, geology, saturation, road density, distance to roads, vegetation indices, water bodies, and urban land use. 2) Du et al. (2019) used Recurrent Neural Networks (RNNs) to predict slope deformation in open-pit silver mines, proposing a weighting method based on the obtained analyses. In this study, they incorporated slope data measured by ground-based synthetic aperture radar (GB-

SAR) and applied techniques such as SVM, Relevance Vector Machines (RVM), Adaptive Neuro-Fuzzy Inference Systems (ANFIS), RNNs, and ensemble methods to improve the prediction.

Deep learning in chemical risk assessment in coal mines

Fan and Xu (2021) analyzed the health risks arising from occupational exposure to toxic chemicals in coal mines, using a deep learning algorithm combined with a mathematical model. Their work involved calculating the lung health status of exposed workers and the composition of harmful gases present, allowing them to establish a risk index for each area. The results demonstrated experimentally that an increase in induced airflow velocity is significantly related to a higher coal extraction rate, while the concentration of toxic substances in the workplace tends to increase.

Deep learning in occupational risk management in the chemical industry

On the other hand, Rybak and Hassall (2021) applied an unsupervised text-based anomaly detection technique using reports from the US Chemical Safety and Hazard Investigation Board. This initiative implemented a data processing method to facilitate the effective assessment of risk factors in industrial accidents by safety experts. Specifically, they introduced a variational autoencoder, a deep learning technique, to classify anomalies present in the CSB reports. Subsequently, they analyzed keywords to identify the underlying causes of the selected accidents.

Deep learning in fire prevention

Similarly, Jain et al. (2021) developed a project that integrates Internet of Things (IoT) technologies with deep learning to detect potential fires and generate preventive alerts. In this system, sensors collect data under the supervision of a control unit that sends it to a cloud database, where a deep learning model processes the information to perform predictive analysis. Among the key variables identified in the tests were flame sensor, temperature, heat index, GPS coordinates, smoke, type of gases, date, and time. This set of features is fed into a deep neural network to generate predictions. Compared to traditional methods, this approach stands out for its innovative combination of IoT and deep learning.

Deep learning for hazard detection in supermarkets

Sarwar Murshed et al. (2020) presented EdgeLite, a lightweight deep learning model designed for fast, local inference on edge devices with limited memory and processing resources. They implemented EdgeLite on three different devices to detect hazards in images of supermarket floors. In their evaluation, EdgeLite outperformed six advanced object detection models when run on all three devices. Furthermore, the experiments demonstrated that its power consumption, memory usage, and inference time were comparable to the benchmark models, highlighting its efficiency and potential for applications in resource-constrained environments.

Challenges of deep learning

According to Liu et al. (2022), the development of deep learning applied to data mining for improving construction safety faces three main challenges: the scarcity of high-quality datasets, the limited capacity of the models, and the low practical applicability in real-world environments. Furthermore, they identify two key challenges for future research in safety management: the development of dynamic multimodal knowledge graphs and decision-making based on these graphs.

Complementarily, Dong et al. (2021) emphasized that the effectiveness of deep learning depends heavily on the quality and diversity of the data used to train the model. While deep neural networks are known for their ability to approximate any polynomial function within a given time, the main challenge lies in optimizing the errors to improve performance.

For their part, Sarwar Murshed et al. (2020) pointed out that modern deep learning models typically have millions of parameters and require complex calculations, which makes their implementation difficult on devices with limited memory. This limitation is particularly relevant when defining the technological resources for deep learning projects, especially those focused on occupational safety and health.

Additionally, it is essential to consider that using artificial intelligence and deep learning to analyze big data and apply iterative methods could lead to unpredictable or unsafe behaviors, especially if productivity is prioritized over safety. Therefore, any application of these technologies must be accompanied by adequate training and the active commitment of workers to adopt preventive measures.

Ethical dilemmas of deep learning

The implementation of deep learning and artificial intelligence in OSH management raises various ethical dilemmas that require careful consideration. These include data privacy and security, the risk of bias and discrimination in decision-making, the accountability and transparency of the systems, the potential replacement of human judgment, and the need to guarantee the consent and autonomy of workers, especially when using health monitoring sensors or tracking devices in the workplace. All these aspects must be thoroughly evaluated before adopting these technologies. Furthermore, the application of AI and deep learning in the field of occupational health and safety and risk management raises the dilemma of the potential displacement of technical professionals due to automation. However, Hunt et al. (2022) suggest that the introduction of new technologies can not only threaten existing jobs but also create opportunities for new job roles, implying a transformation in the labor market that requires attention and adaptation.

Discussion

The current state of the art demonstrates that deep learning, understood as an artificial neural network structure, which has already been applied to occupational safety and health management, makes a significant contribution to workplace risk management. Although its potential applications are practically limitless, currently they are mainly focused on workplace inspections within the construction sector. Among its uses, the evaluation of the use of personal protective equipment (PPE), the identification of unsafe worker behaviors, and the detection of incorrect work postures stand out.

For the effective development of occupational safety and health management projects based on deep learning, and in general on machine learning and artificial intelligence, authors such as Zhong et al. (2020) have proposed modeling frameworks that establish the necessary phases for carrying out these projects. These stages include: identifying the problem and the motivation for its solution, defining objectives, designing and developing the system, and finally, demonstrating and evaluating the project.

The rigorous application of this methodology is essential to guarantee both the feasibility and effectiveness of these initiatives. Regarding the most commonly used algorithms and techniques in deep learning for occupational safety and health management and risk prevention, recurrent neural networks, convolutional neural networks, support vector machines, relevance vector machines, and naive Bayes classifiers stand out.

Conclusions

Deep learning has great potential to contribute to knowledge about reducing unsafe behaviors in various work environments. Furthermore, it plays a crucial role in risk prevention through the early identification and detection of key variables, such as information management, which affect the probability of events or incidents that can lead to unsafe working conditions. For this reason, its application has become an emerging area of research in multiple sectors, such as construction, logistics, electrical infrastructure projects, mining, the chemical industry, and retail, among others.

Likewise, deep learning is emerging as a valuable tool to support supervisors and occupational safety and health personnel, especially in functions related to prevention, control, detection, and real-time decision-making. However, despite the widespread recognition of its advantages, challenges and obstacles persist that must be overcome to achieve its widespread adoption. It is essential to consider the ethical implications of this technology, as its implementation requires careful consideration of the ethical dilemmas involved. Ultimately, solving one problem does not justify creating another, so these aspects must be addressed beforehand.

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Katherin Lizet Huamani: Supervision, conceptualization, visualization.

Milner Segovia Segovia: Research methodology.