IIoT trends in Occupational Safety and Health: a perspective from text-mining data analysis

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Abstract. Limited research explores the specific challenges and opportunities of IIoT-based safety technologies in developing countries like Ecuador. This study addresses this gap by analysing IIoT trends in Occupational Safety and Health (OSH) from a local context perspective. The analysis of the workers' attitude toward use of technologies in large companies in Ecuador using a non-probabilistic sample, revealed a predominant focus on Supervisory Control and Data Acquisition (SCADA) systems applications. This analysis led the query for a systematic review using text-mining data analysis of open-source publications from Scopus, WoS, and Scielo to determine potential gaps between existing local practices and the full potential of Industry 4.0 (I4.0) technologies enhancing worker safety on a global scale. This research proposes two priority pathways for future research: wearable technology for smart health monitoring and advanced safety monitoring for industrial workers. These findings can guide the development and adoption of IIoT solutions tailored to address the specific needs and challenges of local companies, ultimately improving worker safety and well-being in the I4.0 era.

1 Introduction

To adapt emerging challenges, undergraduate programs undergo continuous revision. Knowledge production and the subsequently derivation to academic teaching is a matter of concern of higher education institutions (ISE) responsible for monitoring the research areas leading the faculties and colleges to design specific contributions according to the expertise field.

Occupational Health and Safety (OSH) is an important aspect of Industrial Engineering in the Industry 4.0 (I4.0) context. I4.0 integrates technologies and tools that support productivity, facilitating real-time monitoring, analysis, and decision-making in productive and safety processes.

Industry 4.0 manufacturing jobs will inevitably turn to more efficient digital work and physical tasks reduction. In this sense, new professional skills must be developed for complex management, abstraction, and problem-solving demands to accomplish the local industrial ecosystem.

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Existing research works have explored the potential of IIoT for worker safety but remains a need to understand how these advancements translate to the specific contexts of developing countries. In Latin America, the adoption technology status in industry is behind the schedule compared with other countries globally. Brazil, Mexico, Colombia, Argentina, and Chile showcase promising initiatives in the adoption of some type of advanced technology in production applications (up to 55%) [1]. SELA [2] also pointed out that Latin American companies perceived safety issues as an expense and not as an investment. This short-sighted approach can lead to focus on compliance rather than proactive safety measures, being the lack of budget the main challenging aspect in Ecuadorian large companies [3]. The work done by León [4] indicated that Ecuadorian companies make efforts to adopt technologies for goods or services, reducing costs, improving customer satisfaction, and automation, but there is not strong evidence in adoption of technologies for occupational safety applications.

This exploratory work aims to establish research pathways for IIoT-based safety technologies from the perspective of local workers using a non-probabilistic sample, derived from a systematic mapping of open-source publications in recent years (2019-2023).

1.1 Understanding IIoT-based safety technologies

1.1.1 Safety management

Monitoring plays a crucial role in ensuring workplace safety. From screening air quality and noise levels to identifying equipment functioning out of range, numerous IIoT devices actively mitigate safety hazards, like wearable sensors detecting harmful gaseous pollutants, workers position, and notifying workers upon reaching prescribed exposure limits (Smart PPE). During pandemic, home office policies and OSH framework for remote work to ensure a psychologically-safe work environment became critical [5]. Voordt and Jensen [6], found that healthy workplace influences the well-being behaviour and the productivity via safety management. Adopting OSH standards, organizations improve the dynamic structure to manage safety issues and promote the corporate social responsibility [7].

1.1.2 IIoT and Industry 4.0

A network of interconnected things implies interactions of distributed physical and digital components and the clouds, embedded with sensors, actuators, and software for controlling and exchanging data in real-time. IIoT technologies in-volve Operational Technologies (OT); like Supervisory Control and Data Acquisition (SCADA), Industrial Control Systems (ICS), and Distributed Control Systems (DCS), gathering a large network of devices, systems, and applications communicating and sharing intelligence with each other, the external environment, and with users (workers) [8]. In industry production internet- connected sensors enables capabilities related with 'smart manufacturing' for monitoring and predictive maintenance and customized products [9, 10].

Other verticals where IIoT systems are used include logistics, health-care; for safety oversight and a real-time prediction [11] , environmental monitoring; with sensor deployment to improve workplace safety [12] , transportation; monitoring current location and even predict the movement of vehicles [13, 14] , machining processes; obtaining real-time data to identify the cutting tool wear phenomena [15],or building IIoT framework summarizing components, functionalities and selected technologies for specific applications and safety monitoring [16, 17] .

Bavaresco, R. et al. [18] determined the sectors of industry where occupational 'well-being' research has been focused on: automotive industry, chemical and energy industry,

manufacturing, and metallurgical industry, with applications towards accident prevention, fire o gas, and physical injuries mainly. They also categorized sensors and communication technologies supporting occupational well- being into environmental and physiological applications connected by 3G, 4G or 5G Bluetooth, IEEE protocols, GSM, WiFi, or radio-frequency identification. Other findings approached data fusion techniques to support wireless sensor network.

1.2 Workers' attitude toward use of technologies

The Acceptance Model (TAM), the Unified Theory of Acceptance and Use of Technology (UTAUT), and the Technology Organization Environment framework (TOE) demonstrated that perceived usefulness (perception of performance improvement), the 'ease of use' (minimization of pressure when adopting technology), and the perceived risk [19] are the most critical factors affecting people´s decisions to accept or reject technology.

The association with IoT determinants (accident prevention, cognitive state, ergonomics, fire o gas, and work well-being) [18] and aspects of perceived workers' attitude (willingness to use monitoring and portable devices, personal measurement, willingness to share data, and concern about personal data sharing) via Häikiö, J. and colleagues [20] is believed to support the queries for a systematic search criterion.

1.3 Text mining

Text-mining applications to identify and gathering topics are available in the literature: comparing five clustering algorithms for interpretation of safety cli-mate factors [21]. A human-centered approach outlining industrial environments and aspects of health concerning workers' well-being via full-text reading of articles and data extraction. Machine-learning hierarchical clustering of hazard incident data services based on ward's minimum variance method to calculate a group of centroids [22]. Other contributions supported the application of ward's method and K-mean algorithm for clustering documents. [23]

In this regard, we are motivated to give further evidence going into the re-search questions shown in Table 1.

Table 1. Research questions of the study.

Questions	Method
¿Which are the IIoT-based safety technologies currently used in Ecuador?	Workers' attitude toward use of technologies
¿How to categorize topics related to occupational safety and health (OSH) based on IIoT data?	Clustering approach
¿How the literature progressed between 2019-2023?	Bibliometric analysis
¿What research directions should guide the development of new professional skills for IIoT-based safety technologies within local context?	Clustering approach / Bibliometric analysis

2 Methodology

The authors conducted a systematic literature supported by orange package and guided by an iterative- SEMMA approach to identify, evaluate, and interpret relevant content regarding specific research question (Figure 1). SEMMA is an acronym that stands for Sample, Explore, Modify, Model, and Assess conducting text mining. In-depth and visually engaging analyses were performed using the R package Bibliometrix [24], complementing the data processing.

The initial step to extract hidden knowledge about patterns and the relationship between OSH and IIoT, is led by the association of worker perceptions toward data exchange technology with aspects addressed in the literature on IIoT over the last 10 years, according to Bavaresco and colleagues [18].

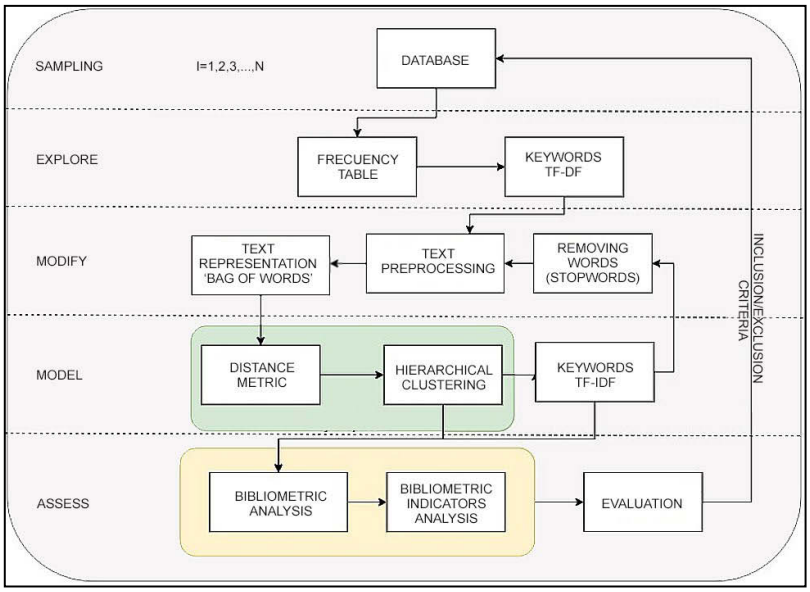

Fig. 1. Iterative-SEMMA model.

2.1 Sample

2.1.1 Keywords for queries

Search keywords were based on the status of new technology usage concerning welfare and occupational safety based on IoT, in the context of large companies in Ecuador which are widely perceived to possess the resources leading the adoption of IoT technologies.

The study followed the instrument proposed by Häikiö et al. [20] linking the perception of workers within the context of occupational safety: Ease to Use (3 questions), Perceived Usefulness (3 questions), and Perceived Risks (4 questions). The instrument considered additional data of the context: sociodemographic information (3 questions), work expertise (4 questions), internet connectivity access (2 questions), and familiar IIoT-safety application (7 statements). Additionally, each question uses 5-point Likert scale: very high (5), high (4), medium (3), low (2), and very low (1)

A convenience sample of interested workers from 277 large companies by economic sectors, occupying operational, professional, and technical positions was employed to determine the current situation in occupational safety and health based on IIoT. The survey was applied between November 2022, and January 2023.

A Spearman's rank correlation analysis was conducted to investigate local IIoT-safety based technologies applications [25]. The discussion led us to draw the answer to the question: ¿Which are the IIoT-based safety technologies currently used in Ecuador? The general statements shown in Table 2, let the authors provided a checklist of queries to initiate

the sampling phase, encompassing most scientific studies to build the concept 'IIoT-based safety technologies' in the context of local large companies (micro-level connection): Occupational Safety AND Innovation Technology, Big Data AND Industrial Safety AND IIoT, Data Collection AND Wearable Technology, Monitoring AND Er-gonomics AND Portable Devices, Big Data AND Occupational Safety, Big Data AND Wearable Device, Monitoring AND Industrial Safety, Innovation AND Industry AND Occupational AND Safety, Innovation AND Monitoring AND IIoT, IIoT AND Industrial Hygiene.

2.1.2 Search strategy

Data mining was conducted using large and widely accepted databases for publications of high-impact scientific content: Scopus, WoS, Scielo. The spatial and temporal context compiles a systematic analysis of scientific papers published in recent years (2019-2023) regarding the research queries.

Initial eligibility screening involved 7751 peer-reviewed scientific articles published in open access journals in recent years (2019-2023) in English language Table 3. After removing duplicates, a total of 3600 articles remained. Further filtering also excluded 3052 papers: articles pursuing medical studies, no abstract in English language and top-10 open access journals only.

Table 2. Welfare and occupational safety based on IoT in the context of large companies in Ecuador.

Statements	Adoption technologies factors	IIoT determinant
Workers in supervisory and operational position share data and use tech devices for supervision and monitoring of work activities.	Perceived ease to use / Perceived usefulness	Innovation
Professional workers share data and are currently using portable tech devices in workplaces.	Perceived usefulness	Innovation
Supervisors, professionals, and technicians use wearable sensors to share data and collaborate on ensuring workplace safety.	Perceived usefulness	Innovation / Monitoring /
Workers in supervisory, professional, and technical positions use tech devices for data loss prevention.	Perceived risk / Perceived usefulness	Monitoring / Data Collection
Experienced workers are more likely to report OSH data.	Perceived ease to use / Perceived usefulness	Monitoring / Data Collection
Low-moderate risk perception sharing data.	Perceived risk	Monitoring
Moderate risk perception about others accessing to personal data to threat privacy.	Perceived risk	Monitoring
Large companies include control and safety devices in the workplace.	Perceived ease to use / Perceived risk	Innovation / Monitoring / Data Collection
Large companies include tech for training.	Perceived ease to use / Perceived usefulness	Innovation / Data Collection

Source: Silva, J. & Pizarro, P. [25]

2.2 Exploring and modeling

Exploring corpus data coming from the Bib Text file, revealed the relevant words according to the highest TF-IDF score by term frequency. Next, the preprocessing text was intended to

remove stop words and special characters and add new words regarding IIoT-based safety technologies within each iteration.

Before applying hierarchical clustering at the i-iteration, K-means was performed to pre-cluster observation points. Subsequently, normalized Euclidean distances between every pair of observation points was calculated to create clusters that capture relevant information of abstracts via Ward-linkage method (Figure 2a).

Table 3. **Initial information of the dataset.**

Database	Total number (*)	Eligibility (+)
WoS(◦)	41888	5352
Scopus (')	19660	2389
Scielo	105	10

(*) Total number of manuscripts after applying the checklist of queries, (+) Reduced number of manuscript after the initial eligibility screening, (°) Clarivate editorial company, (') Elsevier editorial company

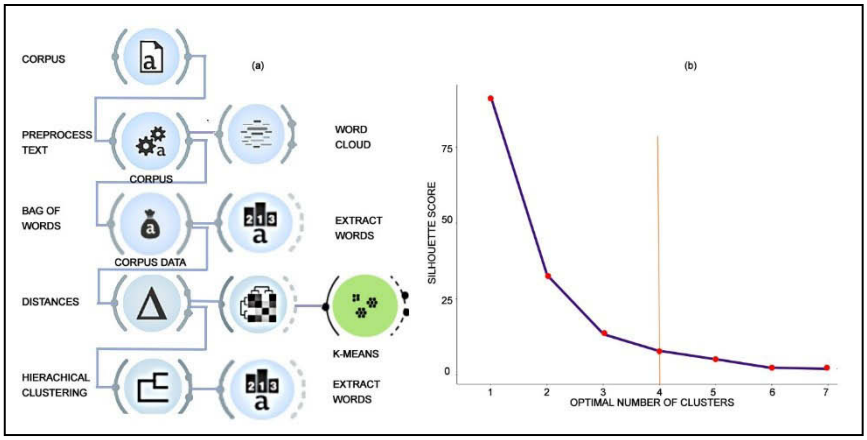

Fig. 2. (a) Data mining: exploring, modifying, and modeling using Orange Package. (b) Silhouette Score [26]

To categorize topics related to occupational safety and health (OSH) based on IIoT data, the optimal number of clusters is subject to subjectivity depending on the purpose of the research. Keywords were extracted from each i-th iteration clustering to optimize the original checklist of queries for the next iteration and the subsequent cluster diagrams. The displayed dendrogram was trimmed by selecting the height ratio.

The elbow method was applied to determine the optimal number of clusters 'k' based on the sum of squared error along the curve, via Silhouette Score representation (Figure 2b).

The contribution level of each cluster to the overall dissimilarity or distance between all data points, is depicted in Figure 3. The findings showed priority pathways for future research: D1 (Wereables tech for smart health monitoring), and D2 (Safety monitoring for industrial workers). The categories and subcategories were represented by C1 (IoT solutions for occupational safety and health) and C2 (Health monitoring and control systems), and C3 (Wireless tech and network monitoring solutions), C4 (User behaviour and human-machine interaction) respectively.

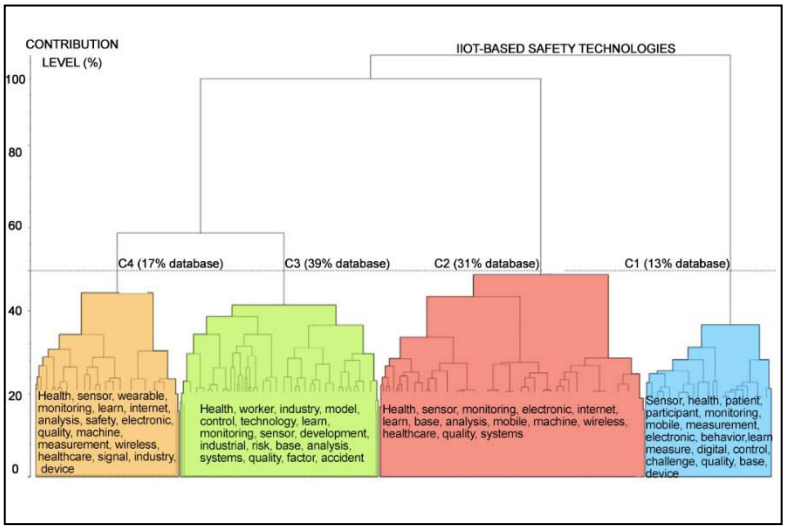

Fig. 3. Primary shaping areas about IIoT-based safety technologies in local context

2.3 Assess

The database was also utilized to performance a bibliometric analysis in the R-package Bibliometrix, mapping the relationship among sources (SO), outstanding authorships (AU), and relevant keywords (DE) to understand how the literature progressed between 2019-2023. Sources such as Sensor and IEEE Journals compile work published by prolific authors like Chen M, Zhang Y. and Li Y., regarding big data, IoT, wearable devices, sensors, healthcare and safety.

In the United State and China, the most cited authors include Chen M. (h-index=9) and Liu Y. (h-index=10). Sensor, Automation in Construction, and IEEE-access journals maintain the highest citation rates, with 3102, 1351 and 1223 between 2019 and 2023 respectively. Sensor also has the maximum number of papers N with at least N citations in the last two years (h-index=28).

Figure 4 shows the most relevant topics over time, published by the aforementioned sources globally. Anomaly detection, remote monitoring, internet of things, wearable devices, and safety have been the relevant long term topics describing OSH-concerned issues lately. In addition, deep learning and digital twin could be capturing the attention of the scientific community for further applications.

A set of topic-based clusters from an abstract analysis is shown in Figure 5. Results supported the areas compiled previously (Figure 3). The cluster analysis yielded three groupings. The ’red’ cluster showed similarities with keywords describing current Industrial IoT (IIoT) solutions for workplace safety in Ecuador, suggesting that existing safety practices likely involve established IIoT technologies in supervisory and operational applications meant to accomplish the statements in Table 2. Meanwhile, the purple cluster presents topics to be fully explored within the Ecuadorian workplace context, regarding wearable sensors and health remote monitoring of physical activity in the workplace, promoting digital applications for occupational health and safety. The orange cluster was meant to encompass the I4.0 determinants where efforts should be focused on.

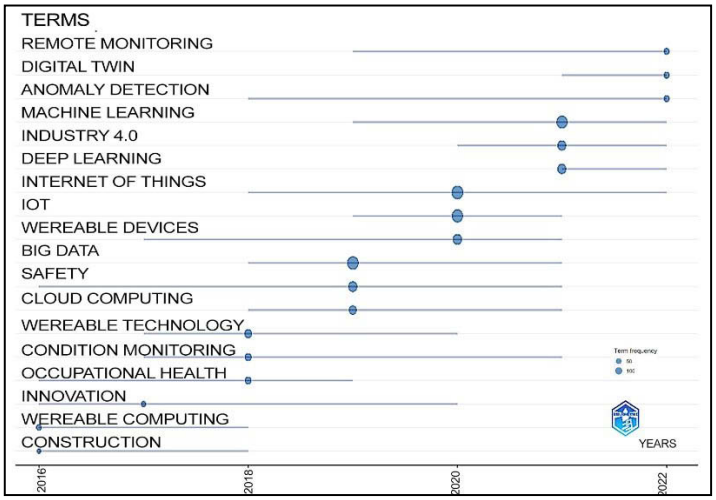

Fig. 4. Trend topics

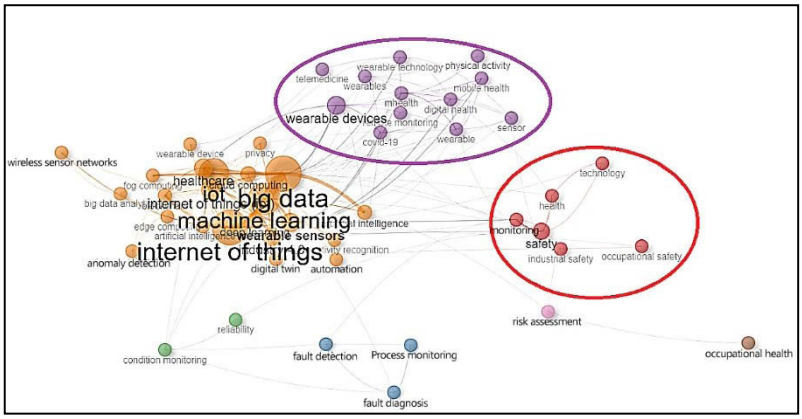

Fig. 5. Topic-based clusters from abstract analysis

Regarding the local context, IIoT applications in Ecuadorian companies are fully oriented to the worker data collection. To move forward, key aspects should be considered for a more complex I4.0 technologies implementation: a reliable communication and connectivity network is essential for the integration and connection of systems promoting IIoT-OSH solutions. Important barriers challenge the safety technologies implementation in Ecuador: stakeholders' commitment, the absence of human-centered legal frameworks promoting technology adoption, incentives, and obligations to adopt new technologies, and cybersecurity concerns. From a human perspective, the use of technologies could exacerbate the ongoing self-perceived OSH situation of workers in industry addressing another psychosocial risk factor in workplaces characterized by work-related stress caused by long working hours and low social support already [27].

Healthcare information technologies are moving forward the extraction and management of quality data, regarding IoT and Big Data applications. Cloud services are supporting IoT-health systems for predicting and supervising cardiovascular diseases, neurological disorders, environment assisted living and activity tracking in general context [28, 29]. Bavaresco, R. et al. [18] highlighted the importance of some research fields: process monitoring sensors, and those for environmental and physiological data collection.

3 Conclusions

This research pointed out IoT, deep learning, big data, and cloud computing as promising technologies for fostering workplace safety and worker well-being through a feasible technology adoption strategy, promoted by a human-centered legal framework in local context.

Specific research lines might help to promote IIoT applications in Ecuadorian companies. The descriptions were extracted from the bibliometric and cluster analysis regarding occupational safety and health in the local context:

IoT in occupational health and safety through networked sensor systems and wearable devices

Works should be oriented to improve the quality control of occupational safety by proactively addressing potential risks supervision using sensors and devices connected to the network, enhancing real-time data collection and transmission.

Development of air quality monitoring technologies for the prevention of workers respiratory diseases

This research line is devoted to develop technologies based on monitoring systems to minimize the concentration of harmful biological agents in workplaces. Air quality is a main aspect to be considered.

Application of wireless network-connected sensors for early detection of chemical hazards

This topic seeks to conduct a feasibility analysis of the application of sensors that help in the early detection of chemical hazards through a wireless network. Controlling and supervising are the goal to minimize abrupt changes.

Evaluation of worker behaviour towards the use of monitoring systems and wearable technology in industries

The outline research seeks to analyse the impact of the implementation of monitoring systems and wearable technologies on the workers' attitude concerning the use of technologies in industries. The work should be focused on reducing psychosocial risk factors.

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Author contribution statement:

Data acquisition or analysis: Yomar González-Cañizalez, conceptualization and design: Lady Sangacha-Tapia, writing and revising the Manuscript: Rubén Manrique-Suarez and Jonathan Silva-Barreto.

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