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SMART DIGITAL MONITORING SYSTEMS FOR OCCUPATIONAL SAFETY IN SMART MANUFACTURING. ARE THEY SAFE?

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Abstract In recent decades, research has focused intensively on the development of methods, tools and technologies specific to smart manufacturing, but aspects related to the working conditions of the human factor remain insufficiently addressed. This paper aims to contribute to reducing this knowledge gap by identifying the main issues associated with the use of intelligent digital monitoring systems in the field of occupational safety and health, based on a systematic review of the specialized literature. The findings were placed in four categories: physical risks, psychosocial risks, privacy and ethical concerns, and barriers to adoption. Recognizing both the need and opportunity to enhance the adoption of these systems, this study also provides a series of recommendations based also on the systematic review analysis.

Key words: occupational safety, smart digital monitoring systems, risk assessment, systematic review.

1. INTRODUCTION

In the field of smart manufacturing, as in all 4.0 industries, modern technologies and intelligent software are used not only to increase productivity but also to protect the safety of workforce and to improve working condition. To protect, you must first know the dangers you face. This is done through monitoring.

A monitoring system for occupational safety and health (OSH), according to the definition provided by the European Agency for Safety and Health at Work EU-OSHA is one that uses “digital technology to collect and analyse data to identify and assess risks, prevent and/or minimise harm, and promote occupational safety” [1]. Using sensors, software, and internet connectivity to monitor, in real-time, activities and working conditions of employees, smart digital monitoring systems (SMDS) are advanced technologies collecting data that will be analyzed and used to identify potential risks and hazards, as well as to improve occupational safety [1].

The data collected cover a wide range, from physical movements, posture, workload, to environmental conditions such as temperature

and humidity. Occupational safety and health monitoring system are capable to identify and assess hazards and risks, in all sectors and all type of job tasks. They can perform checks and maintenance work, they can send warning signals to workers, activate emergency buttons, trace exposure. They also could help with hazardous working situations, including but not limited to rescue operations thanks to features such as „panic buttons”, „man-down”, and „localization”. Smart digital monitoring systems can improve training, risk assessments, inspections, accident reporting, and investigation [2].

But these new OSH monitoring systems can also have limitations in terms of what they can achieve and even can have adverse effects. There are important issues around these new technologies, starting with the lack of an accepted definition among academics, legislators, practitioners, and continuing with limited research on practical application. The impact of SDMS on the workers and the workplace is also insufficiently studied [3].

Considering all the above, the aim of our paper is to approach the safety concerns related

to smart digital OSH monitoring systems through an in-depth literature review.

The specific objective is to find the major challenges related to the SMDS and categorize them.

2. METHODOLOGY

The methodology used in this paper for the literature review is the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), a method that ensures, through its checklist items and the flowchart, a high-quality research process [4]. PRISMA helped us to collate and synthesize findings of studies that address our research question: what are the main safety concerns regarding smart digital monitoring systems for occupational safety?

The search in the literature was conducted in three databases: Scopus, Web of Science - Core Collection, and Taylor & Francis. These databases were chosen because they include scientific documents from different publishers, allowing full-length searches or searches only in specific fields of the works, filtering options such as publication year and using logical expressions or a similar mechanism. Secondary sources, such as the grey literature, including academic reports, doctoral theses and websites, were identified using the Google search engine.

The review process began with a preparatory phase, which involved defining the search parameters, including search terms, thesaurus terms, language restrictions, and other relevant criteria. We then followed the PRISMA flowchart steps. The first step consisted in conducting database searches using Boolean operators (AND, OR) and applying predefined limits such as publication years, full-text availability, and English language restrictions. In Table I are presented search engine criteria and results (Table I).

	digital AND monitoring AND systems AND occupational safety) [OR] [TITLE-ABS-KEY] (smart AND digital AND monitoring AND systems AND health and safety)		journals, title, and by reading the abstracts, where it was the case
Web of Science	[TOPIC] (smart digital monitoring systems for occupational safety) [OR] [TOPIC] (Health and safety smart digital monitoring systems)	22 documents	10 Papers Selected by type of journals, title, and by reading the abstracts, where it was the case
Taylor Francis	[smart digital monitoring systems for occupational safety] [OR] [health and safety smart digital monitoring systems]	9 documents	4 Papers Selected by type of journals, title, and by reading the abstracts where it was the case

After combining all search terms, applying the necessary filters, and removing duplicate records, we identified 42 articles. This number was recorded in the second-left box of the PRISMA flowchart.

During the eligibility phase, articles were screened, and those not relevant to our research were excluded. The exclusion criteria were related to text availability (articles without full text available were excluded), year of publication (articles published outside the ten years limit 2015-2025 were excluded). The

Table 1

Search engine criteria and results.

Database	Search engine syntagma	Results	Final papers
Scopus Elsevier	[TITLE-ABS-KEY] (smart AND	11 documents	5 Papers Selected by type of

number of excluded articles was subtracted from the total records screened, and the remaining count was introduced in the "Full-text articles assessed for eligibility" box.

All full-text articles were then carefully reviewed based on predefined inclusion criteria. At this stage, we referred to our guidelines to determine the expected number of articles to be retained. The articles excluded in this phase were documented in the "Full-text articles excluded" box, along with a brief justification for exclusion (which, in some cases, mirrored the reasons used during the screening phase).

Finally, we subtracted the number of excluded articles from the total assessed full-texts, arriving at the final selection of 19 articles. This number was recorded in the last box of the PRISMA flow diagram (Fig. 1).

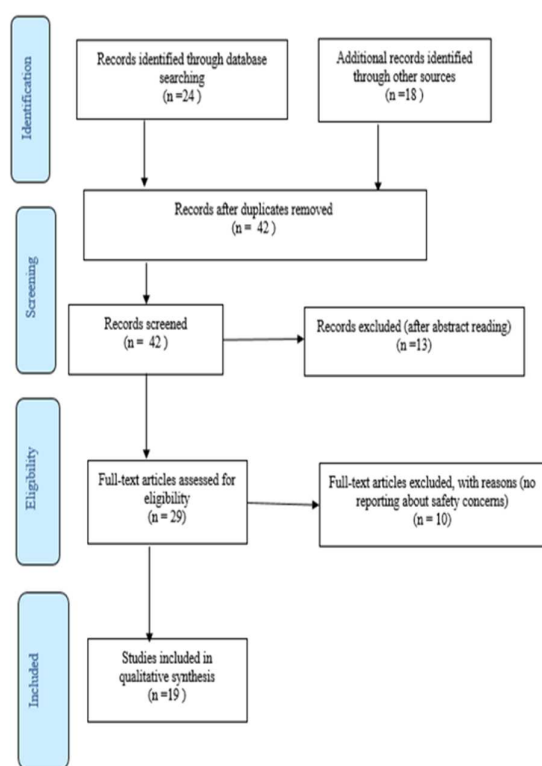


Fig. 1. The PRISMA flow diagram

The 19 scientific papers included in our study were distributed in research areas as follows: 10,52% automation control systems, 36,84% computer science, 5,26% construction building technology, 47,36 % engineering, 10,52 % general medicine (fig.2).



Fig. 2. Distribution of scientific papers on research areas

Regarding the publications years, 2020 was the most prolific one (with 4 papers), followed by 2019 and 2022 (both with 3 papers each). 2024 and 2025 reported 2 papers each (fig.3).

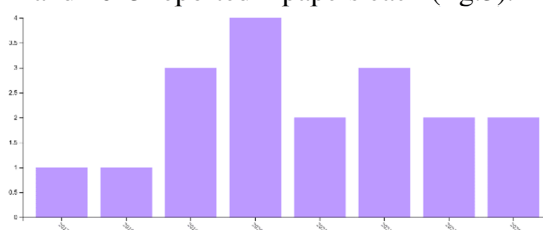


Fig. 3. Distribution of scientific papers on publications years

3. RESULTS AND DISCUSSION

We grouped our findings about the major challenges related to the SMDS in four categories: A. physical risks, B. psychosocial risks, C. privacy and ethical concerns and D. barriers to adoption (table 2).

Table 2

Major challenges related to the SMDS.	
Challenges	Form of manifestation
A. Physical risks	Technology malfunctioning Hardware hindering movement Impact of the redistribution of weight Water infiltration into sensor-based wearable devices System malfunctions or data transmission errors Electromagnetic fields Prolonged exposure to radiation
B. Psychosocial risks	Work intensification Increased stress Blurring OSH responsibilities
C. Privacy and ethical concerns	Invasion of privacy Data issues (data privacy, data security, data accuracy, data interpretation, and misuse)

Challenges	Form of manifestation
D. Barriers to adoption	Legislation that is old and complicated, There are no suitable standards. Developing new technologies can be costly

A. Physical risks

Despite their potential to enhance occupational safety and health, smart technologies systems also introduce new risks and limitations that must be carefully considered. Malfunctions in these technologies, such as failing sensors, battery defects, or software errors, can lead to serious incidents. For example, malfunctioning equipment may cause explosions, musculoskeletal disorders (MSDs), accidental collisions, lacerations, burns, and even long-term effects like cyber sickness or visual strain due to prolonged use of screens or augmented reality interfaces [5].

Wearable devices, particularly those not ergonomically designed, can hinder natural movement and cause discomfort over time. Poorly distributed weight, especially in the case of exoskeletons, can alleviate strain in targeted areas while inadvertently transferring load to other muscle groups or joints, potentially creating new injury risks [6].

Environmental factors also play a critical role. Exposure to water or moisture can compromise sensor-based systems, leading to short circuits or electric shocks, especially when devices lack proper insulation or waterproofing [7].

Furthermore, system malfunctions or delays in data transmission may interrupt timely alerts. This is particularly dangerous if workers become overly reliant on automated warnings and allow their situational awareness to diminish. In such scenarios, delayed or missing alerts could significantly increase the risk of accidents, especially in dynamic or hazardous environments [8].

These technological challenges underline the importance of robust system design, thorough testing under real-world conditions, and ongoing worker training. Workers must be equipped not

only with reliable tools but also with the knowledge and skills to recognize technological failures and maintain active awareness of their surroundings.

A study of several portable sensors for measuring worker heat exposure showed that direct solar radiation significantly influences the recorded ambient temperature values. Devices exposed directly to the sun showed a tendency to overheat. This phenomenon led to an overestimation of the actual temperature and to the appearance of a possible delay effect in the sensor response. Also, the positioning of the sensor on the body influences the reliability of the measurements, especially in different microclimate conditions. [9].

Another concern is the potential interference of electromagnetic fields (EMFs) emitted by wearable devices with sensitive medical implants, such as pacemakers or defibrillators. Although such occurrences are relatively rare, they represent a serious safety risk for affected individuals and necessitate precautionary measures [10].

Emerging research also points that long exposure to low levels of radiation emitted by wearable electronics may have a potential health risk associated. Although current evidence suggests these risks are superficial and limited, they warrant further investigation, especially as device usage becomes more widespread and continuous [11].

The success of wearable systems in occupational settings is strongly tied to worker comfort and acceptance. Devices that are bulky, rigid, or poorly adapted to the diversity of body types and genders often result in discomfort or even pain, leading to reduced compliance or outright rejection by workers. Issues such as improper sizing or lack of adjustability can significantly hinder the usability of these devices across varied worker populations [12].

Moreover, the long-term use of wearable devices may contribute to physical fatigue, skin irritation, or psychological stress. In particular, feelings of frustration or helplessness may arise during technology malfunctions, software glitches, or power outages, situations in which workers may feel they are lacking control or clear alternatives [13].

To maximize the benefits of wearable technologies in OSH contexts, it is essential to adopt a user-centered design approach. This includes ensuring inclusive sizing, minimizing discomfort, addressing the psychosocial impact of constant monitoring, and providing clear protocols for handling technical failures. These considerations are vital to promoting both safety and sustained adoption in diverse work environments.

B. Psychosocial risks

Introduction of SMDS into occupational safety and health (OSH) systems, while offering numerous benefits, also presents significant psychosocial challenges. These risks can impact both the mental well-being of workers and the effectiveness of safety interventions if not carefully addressed.

The widespread deployment of monitoring technologies can contribute to work intensification, with some workplaces likened to “electronic sweatshops.” The constant collection and analysis of performance and behavioral data may lead workers to feel excessively monitored, fostering an environment of pressure, surveillance, and diminished autonomy [14].

In jobs involving lone working, repetitive tasks, or monotonous routines, stress levels may be exacerbated by frequent warnings issued by automated systems. For example, a recent study implementing an advanced hazard warning system combining deep learning with IoT modules found that although real-time alerts were effective, limitations in system design led to information overload. Due to a 5-second interval in the Line API, users received multiple notifications for a single hazard event. To mitigate this, the authors proposed a “cooldown mechanism” that consolidates multiple alerts into a single message over a 30-second window (e.g., “*Worker in the hazardous zone for 30 seconds*”) to reduce cognitive burden for site managers [15].

Malfunctions in wearable systems, such as inaccurate data, false alerts, or connectivity issues, can result in user frustration and erode trust in the technology. Moreover, devices that frequently distract workers or require constant interpretation of safety data may impair

concentration and decision-making, potentially increasing accident risks [16].

The continuous monitoring of physiological and biometric data may induce stress as workers feel compelled to maintain optimal health and performance levels. This pressure is intensified when complex alerts demand rapid understanding and response, adding cognitive strain to routine tasks [17].

Overreliance on automated systems may erode workers’ sense of ownership over their roles and diminish their confidence in personal judgment. In some cases, this can lead to a psychological disconnect or feelings of alienation from one’s work. The “augmented workforce” may become overconfident in technological safeguards, which can foster complacency and increased risk-taking behavior.

The integration of complex monitoring systems may also blur lines of OSH responsibility. When safety is perceived to be “automated,” both workers and managers might neglect traditional safety protocols. At the same time, OSH professionals may find themselves overwhelmed by the volume of real-time data and unrealistic expectations regarding their capacity to act on every alert, leading to role strain and burnout [18].

C. Privacy and ethical concerns

One of the most pressing concerns relates to how personal data, particularly physiological and biometric information, is collected, stored, and managed. Workers often have limited control over the data collected by wearable devices, and there is growing unease about how this data might be used beyond its intended purpose. Questions surrounding consent, data ownership, and the transparency of data processing remain largely unresolved in many organizational settings [19].

Even when data is anonymized, risks of re-identification or misuse persist, particularly if data is shared with third parties or used for performance evaluation rather than purely for safety. Employers must therefore ensure that robust data governance frameworks are in place, compliant with relevant regulations (such as GDPR), and developed with clear input from employee representatives [20].

Although wearable devices are often promoted as tools for enhancing safety, they can quickly evolve into instruments of continuous surveillance. Many of these systems collect location data, monitor vital signs, and track behaviors, which can be reported directly to management. This raises ethical concerns when such information is used for disciplinary purposes, such as issuing warnings or penalties based on algorithmic performance benchmarks, rather than for health promotion or accident prevention [21].

Workers often report feeling uninformed or uncertain about how wearable data is used, interpreted, and shared. Such practices risk shifting the organizational culture from one of support and prevention to one of control and monitoring. Without clear communication and transparent policies, the implementation of wearable technologies can breed suspicion and resistance. Workers may perceive this as a violation of personal boundaries, leading to resistance, reduced morale, and increased workplace stress. Effective adoption requires that employees not only consent to the use of such devices but also understand the scope and implications of the data being collected [22].

D. Barriers to adoption

In the reviewed literature, we identified a series of barriers: legislation that is old and complicated, there are no suitable standards, developing new technologies can be costly, especially the specific ones.

SMDS, especially those tailored to specific occupational risks or worker populations, require substantial financial investment. These include not only initial procurement and deployment costs but also ongoing maintenance, software updates, device calibration. Small and medium-sized enterprises (SMEs), in particular, may find these expenses prohibitive [23]. In addition, the costs associated with research and development, pilot testing, and customization to suit different industries or job roles can discourage innovation and scalability.

Adapting wearable technologies to fit into existing safety protocols and operational workflows is a complex process. Compatibility with legacy systems, data infrastructure, and established communication protocols can be challenging. Furthermore, training workers and

supervisors to use new technologies effectively requires time and dedicated resources [24]. The shift from small-scale pilot testing to full-scale deployment often reveals gaps in usability and real-world performance, particularly in dynamic environments like construction or manufacturing.

Technical functionality alone is not sufficient. Devices that are not user-friendly, intuitive, or ergonomically designed are likely to be rejected by workers. Poor fit, discomfort during prolonged use, or lack of perceived relevance to daily tasks can significantly reduce compliance and effectiveness. Tailoring solutions to diverse user profiles, including gender, body type, and task-specific needs, is critical but not always prioritized during the design phase.

In these circumstances, the development of solutions must be approached responsibly, taking into account the interests of both workers and employers. In the context of the accelerated pace of technological progress, the regulatory framework may not always be able to adapt promptly to all emerging innovations and opportunities. For this reason, taking responsibility and applying common sense principles becomes essential.

Recommendations for policy, research and practice (industry)

In the literature studied, we found a series of useful recommendations for all stakeholders:

- the development of regulations for the use of SMDS technologies in the field of OSH is extremely necessary and urgent. There are several reasons why companies resist the introduction of new technologies. In addition to the financial reason (the still high cost of implementing such technologies), the lack of regulations is the main reason why small and medium-sized companies tend to postpone the adoption of modernizations for monitoring work environments
- the design of solutions must be carried out responsibly and must take into account the concerns of workers and employers. It is important to note that, given the rapid technological evolution, it is expected that regulations cannot always keep up with all the new developments and possibilities that arise.

Therefore, responsibility and common sense are more indispensable than ever.

- there is the possibility of labor lawsuits for the use of sensitive data that can have a devastating impact especially in the case of smaller companies.

- it is important to ensure the dignity, rights and privacy of workers, and a positive socioeconomic and occupational impact of new OSH monitoring systems – overall and for specific workers’ needs. As digital technologies increasingly tend to become something usual in our world – within and beyond the workplace – and offer immense opportunities, it is possible that portions of privacy may be sacrificed for the goal of improving OSH.

Future research. Since the trend is towards increased adoption of these digital OSH monitoring systems in the near future, despite the barriers that have so far limited their market penetration, one direction for future research is represented by the generation and evaluation of specific scenarios that are emerging in the future.

In terms of applicability in industry, we believe that the findings of our study contribute by raising awareness and offering useful suggestions in guiding long-term OHS decisions.

4. CONCLUSIONS

Using sensors, software, and internet connectivity to monitor, in real-time, activities and working conditions of employees, smart digital monitoring systems are advanced technologies collecting data that will be analyzed and used to identify potential risks and hazards, as well as to improve occupational safety. Intelligent digital monitoring systems contribute to the optimization of training processes, risk assessment activities, inspections, as well as accident reporting and investigation procedures.

But these new OSH monitoring systems can also have limitations in terms of what they can achieve and even can introduce new risks or hide the existing ones. There are important issues around these new technologies. We grouped our findings about the major challenges

related to the SMDS in four categories: physical risks, psychosocial risks, privacy and ethical concerns and barriers to adoption.

Introductions of SMDS into occupational safety and health (OSH) systems, while offering numerous benefits, also presents significant psychosocial challenges. These risks can impact both the mental well-being of workers and the effectiveness of safety interventions if not carefully addressed. The widespread deployment of monitoring technologies can contribute to work intensification. The constant collection and analysis of performance and behavioral data may lead workers to feel excessively monitored, fostering an environment of pressure, surveillance, and diminished autonomy.

Overreliance on automated systems may erode workers’ sense of ownership over their roles and diminish their confidence in personal judgment. In some cases, this can lead to a psychological disconnect or feelings of alienation from one’s work. The "augmented workforce" may become overconfident in technological safeguards, which can foster complacency and increased risk-taking behavior.

The integration of complex monitoring systems may also blur lines of OSH responsibility. When safety is perceived to be “automated,” both workers and managers might neglect traditional safety protocols. At the same time, OSH professionals may find themselves overwhelmed by the volume of real-time data and unrealistic expectations regarding their capacity to act on every alert, leading to role strain and burnout.

There are also privacy and ethical concerns, such as how personal data, particularly physiological and biometric information, is collected, stored, and managed.

In these circumstances, the development of solutions must be approached responsibly, taking into account the interests of both workers and employers. In the context of the accelerated pace of technological progress, the regulatory framework may not always be able to adapt promptly to all emerging innovations and opportunities. For this reason, taking

responsibility and applying common sense principles becomes essential.

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Sisteme de monitorizare digitală inteligentă pentru securitatea muncii în manufactura inteligentă. Sunt ele sigure?

Abstract. În ultimele decenii, cercetarea s-a concentrat intens pe dezvoltarea de metode, instrumente și tehnologii specifice producției inteligente, însă aspectele legate de condițiile de muncă ale factorului uman rămân insuficient abordate. Această lucrare își propune să contribuie la reducerea acestui decalaj de cunoștințe prin identificarea principalelor probleme asociate cu utilizarea sistemelor inteligente de monitorizare digitală în domeniul securității și sănătății în muncă, pe baza unei analize sistematice a literaturii de specialitate. Rezultatele au fost clasificate în patru categorii: riscuri fizice, riscuri psihosociale, preocupări legate de confidențialitate și etică, precum și bariere în calea adoptării. Recunoscând atât necesitatea, cât și oportunitatea de a spori adoptarea acestor sisteme, acest studiu oferă și o serie de recomandări bazate, de asemenea, pe analiza analizei sistematice.

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