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THE IMPORTANCE OF ARTIFICIAL INTELLIGENCE IN MONITORING HUMAN FACTORS AND IMPROVING OCCUPATIONAL SAFETY IN SMART CITIES

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Abstract: This article examines the role of artificial intelligence (AI) in monitoring human factors and improving occupational safety in smart cities. The aim of the paper is to identify directions for AI use in occupational health and safety systems and assess ethical and legal challenges. Smart cities leverage integrated data, IoT, and machine learning to predictively respond to threats, enabling a shift from a reactive to a preventive model. The authors distinguish four main areas of AI application: monitoring employee physiological status, automatic recognition of personal protective equipment (PPE), predictive risk models, and occupational health and safety training in a VR/AR environment. CNN and LSTM algorithms enable high-accuracy fatigue and stress detection, while systems based on YOLOv8 and Mask R-CNN automatically identify safety violations. The article presents examples of implementations in Poland (SmartCity Poznań 2030+, Urban Safety AI, PGE SafetyNet) and the EU, confirming the effectiveness of AI in reducing accidents. The importance of the AI Act and GDPR regulations regarding human oversight, algorithm transparency, and biometric data protection is emphasized. Attention was also drawn to the ethical dilemmas associated with automated supervision and the need to maintain the "human-in-the-loop" principle. The conclusions indicate that AI is a key element of a modern occupational health and safety system, increasing work efficiency and safety. However, its success depends on a balance between technology and human responsibility.
Keywords: artificial intelligence, occupational safety, smart cities

1. INTRODUCTION

Over the past two decades, the concept of a "smart city" has become a central topic in research on sustainable development and digital transformation. As defined by the International Telecommunication Union (ITU-T, 2023), a smart city is "an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, operational efficiency, and competitiveness, while ensuring sustainable economic and social development" (ITU-T, 2023). The European Commission defines a smart city as an integrated ecosystem of data, technologies, and services that aims to

increase the efficiency of urban infrastructure and improve the quality of life of its residents.

Modern smart cities rely on the integration of artificial intelligence (AI), the Internet of Things (IoT), Big Data analysis, and decision-making automation. AI is understood not only as an optimization tool but also as a mechanism for predicting and preventing undesirable phenomena on a city scale - such as infrastructure failures, energy overloads, and threats to public safety (ISO 37122:2019, 2019). These technologies are also increasingly being used in the area of occupational health and safety (OHS), where they can significantly reduce the number of accidents by monitoring human factors and environmental conditions.

According to the International Labour Organization (ILO, 2025), there are over 2.8 million fatal accidents at work worldwide each year, and approximately 374 million workers suffer occupational injuries or illnesses (International Labour Organization, 2025). In the European Union alone, according to the Eurostat Health and Safety Report (2025), over 2.9 million occupational safety incidents were recorded in 2022, of which 3,400 resulted in deaths (Eurostat, 2024). Although these figures are gradually decreasing, they still pose a significant challenge for economies with a high degree of automation and urbanization.

Human factors - such as fatigue, inattention, stress, cognitive overload, and failure to follow procedures - are considered the main causes of operational errors in the workplace. According to a WHO report as many as 80% of incidents in industrial environments are related to human error. In traditional occupational health and safety systems, the role of these factors was analyzed mainly retrospectively, after the event occurred. In the smart city environment, thanks to the development of AI technology, real-time monitoring has become possible and predictive response to threat signals. AI systems now analyze data from industrial cameras, biometric sensors, wearable devices, and urban infrastructure (e.g., transportation networks, energy networks, and smart buildings). This enables the creation of predictive models capable of detecting anomalies in employee behavior - e.g., symptoms of drowsiness, distraction, or physiological stress (El-Helaly, 2024).

The importance of such solutions is growing, especially in the context of the "city 5.0" concept, where the priority is not only efficiency and technological innovation, but above all, human well-being and safety. As Park notes, in cities based on human-machine collaboration (so-called human-centric smart cities), the role of AI in preventing accidents and supporting the psychophysical health of employees becomes crucial (Park, 2024).

From the European Union's perspective, the use of artificial intelligence in the workplace is subject to the rigors of the AI Act (EU 2024/1689), which classifies systems analyzing human factors as "high-risk" technologies. This requires not only technical certification but also ensuring human oversight, algorithm transparency, and documented decision-making processes (European Parliament and Council, 2024).

The development of these solutions in Poland has been gradual but consistent. Examples include the SmartCity Poznań 2030+ project, which implements computer vision systems to monitor personal protective equipment and analyze machine operator behavior, and the Urban Safety AI initiative in Gdańsk, which combines data from city cameras with machine learning models to analyze pedestrian safety (www.poznan.pl).

The conditions outlined above indicate that integrating AI with safety management systems in smart cities is not just a technological trend, but also a civilizational necessity. The following sections present the research methodology, the main directions of AI

applications in human factors analysis, examples of implementations in Poland and the EU, and the legal and ethical challenges related to implementing these technologies.

2. METHODOLOGY AND SCOPE OF RESEARCH

This paper is a review and analysis, developed using an interdisciplinary approach that combines elements of safety science, systems engineering, computer science, ergonomics, and occupational psychology. The aim of the research was to identify and systematize contemporary approaches to the application of artificial intelligence (AI) in monitoring human factors in smart cities, and to identify the main challenges associated with their implementation. The analysis was based on a combination of qualitative and quantitative methods, including a review and evaluation of scientific achievements, institutional reports, and industry documents.

The research utilized content analysis, a systematic literature review, and a comparative analysis of national and international approaches to the use of AI technologies in the context of occupational safety and urban environment management. The research was complemented by a normative and legal analysis, addressing international and European regulations, including legal acts concerning the implementation of AI systems. The selection of sources was based on currency, credibility, and scientific relevance, including peer-reviewed publications, research reports, and strategic documents with a significant impact on safety management practice.

The theoretical framework of the study is rooted in a systems approach to security, consistent with the Human-Technology-Organization (HTO) model, which considers the interconnectedness between humans, technology, and organizations. The analysis focused on three interrelated aspects: technical, organizational, and human, treating security as the result of the interaction of these elements in the smart city environment. The scope of the research covered the European Union, with particular emphasis on the experiences of European countries, including Poland.

It should be emphasized that due to the dynamic development of AI technology and the varying levels of implementation advancement in individual countries, some of the sources analyzed may not fully reflect the current state of research and practice. Despite these limitations, the analysis provided a synthetic picture of development trends, allowing us to identify directions for further research in the integration of AI with occupational safety and urban environment management systems.

3. APPLICATIONS OF ARTIFICIAL INTELLIGENCE IN MONITORING HUMAN FACTORS AND OCCUPATIONAL SAFETY

The implementation of artificial intelligence (AI) technologies in the workplace, particularly in smart city structures, is leading to a fundamental shift in the way human factors are monitored and safety is managed. AI not only collects data but also learns from behavioral patterns and environmental conditions, enabling predictive responses to hazardous situations. Modern AI-based occupational health and safety systems can be divided into four main categories:

- physiological and behavioral monitoring of employees,
- automatic recognition of personal protective equipment (PPE),
- predictive accident risk models,
- training simulations in augmented and virtual reality (AR/VR).

The primary application area for AI in human factors analysis is monitoring employees' physiological and behavioral states. This involves the use of biometric sensors, high-resolution cameras, and wearable systems that collect data on heart rate, heart rhythm, body temperature, stress levels, facial muscle micro -movements, and eye blink rate.
Currently, such systems are being tested in the transportation, energy, and construction industries. In urban practice, biometric monitoring data is often combined with analysis of the environmental context (temperature, noise, light levels, air pollution). This enables the development of predictive models that learn to predict performance degradation and accident risk depending on a combination of factors (ILO, 2025).
The second pillar of AI applications in occupational safety is the automatic recognition of personal protective equipment (PPE) . These systems use computer vision and deep learning algorithms to identify protective equipment - helmets, vests, masks, gloves, goggles - in images from industrial cameras or city surveillance.
Models based on the YOLOv8, Faster R-CNN, and Mask R-CNN architectures are widely described in the literature. According to research by Vukićević et al. (2024), the use of the YOLOv8 model in the construction sector allowed for achieving PPE detection accuracy of 96.8% (Vukićević, et al., 2024). Lee and Lee, in turn, demonstrated that the use of the Mask R-CNN model in an industrial environment enabled the recognition of hard hats and safety vests with an accuracy of 94.2%, with an average system response time of less than 0.2 seconds (Lee, Lee, 2023).
Table 1 presents examples of the use of artificial intelligence technology in occupational safety monitoring.

Table 1
Examples of AI technology applications in occupational safety monitoring

Source	AI technology	Scope of application	Accuracy (%)	Comments
Vukićević et al., 2024 (AI Review)	YOLOv8 + DeepSORT	Construction, heavy industry	95 - 97	High efficiency in daylight
Lee & Lee, 2023 (Sensors)	Mask R-CNN	Energy, urban works	92 - 95	Integration with the 5G network
Scorgie et al., 2024 (Safety Science)	ResNet-50	Occupational health and safety training centers	90 - 93	Use of synthetic data

Source: own elaboration based on Vukićević, M., et al. (2024). *AI-based video analytics for occupational safety: A review. AI Review, 57(2), 112–130.*

The use of these technologies in smart cities allows for ongoing monitoring of occupational health and safety regulations in work zones, construction sites, and infrastructure facilities. These systems are often integrated with city platforms (smart surveillance), which analyze data in real time and automatically report violations to the appropriate authorities (European Commission, 2024).
The third area is risk prediction systems, which use machine learning (ML) algorithms to identify relationships between human, environmental, and technical factors. Input data comes from IoT sensors, incident logs, inspector reports, and camera footage.

Similar solutions are being implemented in the energy sector, where the analysis of data from thermal, acoustic and vibration sensors allows for the prediction of infrastructure failures and the risk of electric shock or overheating of devices (Park, 2024).
Artificial intelligence is also being used in the design and implementation of occupational health and safety training in virtual environments. Virtual reality (VR)
and augmented reality (AR) techniques, supported by AI algorithms, allow for the simulation of emergency situations and employee behavior in controlled conditions.
According to research by Scorgie et al., the use of VR simulations in occupational health and safety training increases knowledge retention by 34% compared to traditional methods (Scorgie, et al., 2024). Additionally, AI systems analyze participants' reactions - reaction time, stress level, number of errors - which allows for personalization of training and identification of those requiring additional training.

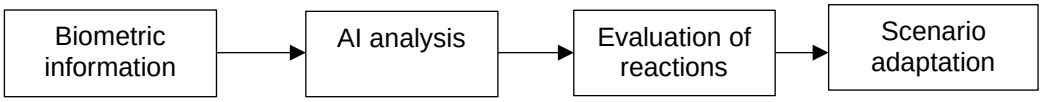

Fig. 1. Diagram of human-AI interaction in VR occupational health and safety systems Source: own study based on Scorgie et al., 2024

Integrating VR with AI analytics is particularly important in high-risk sectors such as energy, transportation, and construction. It can reduce errors made by workers during crisis situations, increasing their operational readiness and risk awareness.
A final, rapidly developing area is multimodal data integration - combining information from multiple sources (e.g., cameras, wearable sensors, IoT, inspector reports, weather data). AI-based systems can process this data in real time, enabling dynamic risk assessment.
One example is the solution developed as part of the SmartSafeCity EU project, which combines data from a network of city sensors (temperature, noise levels, pollution) with information on the psychophysical state of city employees. This allows the system to provide real-time warnings about excessive stress, fatigue, or exceeding environmental standards (SmartSafeCity EU Consortium, 2024).

4. IMPLEMENTATION OF ARTIFICIAL INTELLIGENCE IN POLAND AND THE EUROPEAN UNION

The development of artificial intelligence in the area of occupational safety is an important element of digital and innovation policies implemented in European Union countries. Implementing AI-based solutions in smart cities and municipal enterprises requires striking a balance between process automation and respect for human rights. A key factor in the effectiveness of these efforts is public trust in technology.
Although Poland remains in the early stages of adopting AI technology in occupational health and safety, it is conducting a number of research and implementation initiatives within national and European programs. Key projects focus on data analysis in the workplace, automated monitoring of personal protective equipment, and threat prediction based on data from IoT and urban systems. Examples of AI applications in occupational health and safety in Polish cities (2022–2025) are presented in table 2.
Research conducted as part of these initiatives indicates real benefits in terms of reducing the number of incidents and increasing employee awareness of risks. In the SmartCity Poznań 2030+ project, the implementation of computer vision systems contributed to a

27% reduction in occupational health and safety violations in the first year of operation (Bainbridge, 1983).

Table 2
Examples of urban projects using AI technology in the area of security

City/ Project	Area of application	Solution description	Financing	Year of implementation
SmartCity Poznań 2030+	Infrastructure and health and safety supervision	Computer vision system for real-time video analysis – PPE and risk behavior recognition	Horizon Europe/JST	2023 - 2024
Urban Safety AI – Gdańsk	Pedestrian safety	LSTM model analyzing pedestrian-vehicle collisions based on data from city cameras and sensors	Digital Poland/ NCBR	2024
Warsaw Smart 2030+	Occupational health and safety in construction and logistics	YOLO algorithms for detecting protective measures and dangerous behaviors	EIT Urban Mobility	2023
PGE Distribution – SafetyNet	Energy and field work	Thermal imaging + AI to detect installation overheating and assess operator stress	Just Transition Fund	2024
Krakow CleanAirAI	Municipal services / ecology	Analysis of the psychophysical load of employees in air pollution conditions	LIFE+ / NCBR	2024 - 2025

Source: own study based on data from https://www.poznan.pl/smartcity, https://www.um.warszawa.pl/waw/strategia/strategia-rozwoju-miasta, https://www.krakow.pl/strategia, https://pgedystrybucja.pl.

In Gdańsk, predictive solutions developed by the Gdańsk University of Technology team as part of Urban Safety AI allowed for a 12% reduction in the number of pedestrian collisions in the city centre (Europan Union, 2016).
It is worth emphasizing that Polish implementations are in line with the EU concept of "AI for Human Safety", which assumes ethical use of technology and human supervision over the algorithm (human-in-the-loop).
At the European Union level, research and implementation of AI applications in occupational health and safety are carried out under the Horizon Europe, Digital Europe and European AI Alliance programs. Table 3 presents selected EU projects related to AI in occupational health and safety and smart cities.

Table 3

EU projects on artificial intelligence in occupational safety and smart cities

Project / Consortium	Program / Year	Area of application	Key Results
AI4WorkSafety	Horizon Europe / 2023–2026	Predictive risk models at work	81% Incident Forecasting Success; Tools for Labor Inspectors
HumanE-AI-Net	Horizon Europe / 2024–2027	Ethical and Sustainable AI	Ethical Frameworks and Explainable Algorithms
SmartSafeCity EU	Horizon Europe / 2024–2026	Integrating IoT, AI, and city data	Urban security platform prototype
AI4EU Ethics Observatory	Digital Europe / 2023–2025	Audit and compliance of AI systems with the AI Act	AI Ethical Assessment Metrics Set
SAFE-ENERGY	Horizon Europe / 2022–2025	Energy and inspection works	Autonomous threat assessment systems for field crews

Source: own study based on European Commission, 2023. *Horizon Europe work programme 2023–2024*. Publications Office of the European Union, Brussels, 16-21; European Commission, 2024. *Investing in a sustainable and green urban future*. Smart Cities Marketplace brochure, Brussels,12–14.

In countries such as Germany, the Netherlands, and Finland, AI implementations in occupational safety include integrating data from wearable sensors (EEG, ECG) with ERP systems and predictive platforms. An example is the AI4Industry Safety project (Germany, 2024), in which data from biometric wristbands is processed by AI models to predict stress and fatigue levels in factory workers (www.osha.europa.eu).

From a legal perspective, all these initiatives must comply with the AI Act (EU 2024/1689) and the General Data Protection Regulation (GDPR, 2016/679). The AI Act introduces mandatory registration of high-risk systems, technical documentation, and human oversight of algorithmic decisions (European Parliament and Council of the European Union 2024).

5. CHALLENGES, ETHICS AND LAW IN THE APPLICATION OF ARTIFICIAL INTELLIGENCE IN OCCUPATIONAL SAFETY

The development of artificial intelligence in smart cities, despite its enormous benefits in improving safety and work efficiency, raises numerous ethical, legal, and social challenges . Key among them include:

- privacy and biometric data protection,
- transparency of algorithm operation,
- legal responsibility for AI decisions,
- maintaining human oversight of high-risk systems.

According to the principles developed by the OECD and the European Commission High-Level Expert Group on AI, AI technologies must be "human - centric" and serve to support, not replace, human decisions (OECD, 2023). In the context of occupational safety, this means that algorithms analyzing human factors should play an advisory role – they should warn and support, but not make autonomous decisions about the actions of operators.

In practice, however, there is a risk of the so-called automation-of-trust effect, where employees and supervisors overly rely on the results of AI analysis (Bainbridge, 1983). This phenomenon can lead to distorted risk perception and reduced human vigilance. Therefore, maintaining a balance between automation and human control (human-in-the-loop) is a key ethical requirement.

Another challenge is privacy protection and biometric data processing. Systems monitoring fatigue, emotions, and stress collect sensitive physiological data (EEG, ECG, skin temperature, facial expressions). According to the GDPR (EU 2016/679), such data is considered sensitive and may only be processed for strictly defined purposes, with anonymization and limited access (European Union, 2016).

Regulation (EU) 2024/1689 of the European Parliament and of the Council of 13 June 2024 on laying down harmonised rules on artificial intelligence introduces a risk classification system in which technologies used to analyse human factors in the work environment are classified as "high risk". This requires:

- keeping a record of training data and algorithm decisions,
- ensuring compliance audit and technical documentation,
- the use of human supervision over decision-making processes,
- and implementing a system for reporting adverse effects of AI (European Parliament and Council, 2024).

Under labor law, automated employee behavior assessment systems may conflict with the provisions of the Labor Code and the principle of respect for employee dignity. According to the European Data Protection Board, employers using AI to monitor employees must provide a "real opportunity to object" to algorithmic decisions (European Data Protection Board, 2024).

In Poland, this problem was discussed, among others, by the Personal Data Protection Office in the report "Artificial Intelligence in the Workplace", which emphasized the need to introduce AI ethical codes in occupational health and safety (Personal Data Protection Office, 2024).

The social implications are also significant . Automating safety processes may lead to the marginalization of certain professional groups, such as occupational health and safety inspectors, whose role is shifting from control to analysis. At the same time, new positions related to data analysis, AI auditing, and ethical oversight are emerging (ILO, 2025). Social acceptance of AI systems in the workplace is growing, especially when employees are aware of their purpose and the limitations of the technology. Transparency and the ability to explain decisions made by algorithms (explainable AI) play a key role here.

Predictive ethics also arises. Learning systems can predict future behavior (e.g., the probability of an accident), which raises the risk of discrimination. As indicated by the UNESCO Recommendation on the Ethics of Artificial Intelligence, the use of predictions in relation to individuals must be limited by the principle of proportionality – one cannot punish for something that has not yet happened (UNESCO, 2023).

In European Union countries, increasing emphasis is being placed on the ethical aspects of using artificial intelligence in the workplace. Compliance assessment procedures and mechanisms are being implemented to ensure equal treatment of employees and the transparency of predictive systems.

6. CONCLUSIONS AND SUMMARY

The analysis conducted in this study clearly indicates that artificial intelligence (AI) is playing an increasingly important role in shaping modern occupational safety systems in smart cities. The use of machine learning algorithms, predictive analytics, and IoT technologies allows for a shift from a reactive occupational health and safety model to a preventive and predictive model, in which threats are identified before an accident occurs. Key findings include:

1. Integrating AI with city systems enables continuous monitoring of human and environmental factors in real time. This enables dynamic risk assessment and data-driven decision-making, significantly improving the effectiveness of occupational health and safety systems (ISO 45001:2018, 2018).
2. Human factors remain a central element of any security system. Even the most advanced technology cannot replace the human role in interpreting data, responding to anomalies, and creating a security culture (Reason, 1990).
3. Implementing AI in the workplace requires a balance between automation and human control. Systems based on behavioral analytics must operate transparently and in accordance with work ethics, ensuring employee privacy and autonomy are protected (OECD, 2023).
4. EU law and regulations (especially the AI Act and GDPR) establish clear accountability frameworks to protect employees from abuses related to digital surveillance. Compliance with these regulations is not only a legal obligation but also a prerequisite for the social acceptance of AI (European Parliament, 2024).
5. Poland is seeing a growing number of implementation initiatives, such as SmartCity Poznań 2030+, Urban Safety AI, and PGE SafetyNet . Although many of these are pilot projects, their results (reduced incident numbers, better reporting, improved ergonomics) demonstrate the real potential of AI in improving occupational safety (Poznań City Hall, 2024).
6. A key challenge for the coming years will be the development of common standards for assessing AI algorithms in the context of occupational safety, including ethical certification and algorithmic audits.

Based on the analysis conducted, several recommendations can be made:

- data standardization: it is necessary to develop a uniform model for data exchange between urban, industrial and health systems for better interoperability.
- ethical audits si: every organization implementing predictive systems should conduct periodic ethical audits to assess the risk of discrimination and decision-making errors.
- digital education and competences: implementing SI in the work environment requires a new approach to health and safety training – employees must understand how algorithms work, their limitations and the principles of human-machine interaction.
- trust management: City governments and businesses should transparently communicate the purposes and uses of AI to build public trust in these technologies.
- further research: should focus on modeling the relationship between stress, fatigue and professional performance in highly automated environments.

In short, artificial intelligence is not an end in itself, but a tool supporting humans in their pursuit of a safer and more sustainable work environment. Its application in smart cities

represents a significant step towards a new safety paradigm based on data, knowledge, and human-technology collaboration. However, maintaining human responsibility and ethical oversight remains a key factor in success – humans, not machines, bear the ultimate responsibility for workplace safety.

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