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REVIEW ARTICLE

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# Artificial Intelligence Based Surveillance for Real-Time Occupational Hazard Detection in High-Risk Industries: Implications for Waste Management

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**ABSTRACT**

Occupational injuries and illnesses remain a preventable public health burden, disproportionately affecting workers in safety-sensitive industries such as waste management. Conventional occupational health surveillance relies largely on retrospective data sources, limiting opportunities for timely intervention. Advances in Artificial Intelligence (AI) now enable real-time, predictive occupational hazard surveillance through the integration of wearable sensors, computer vision, telematics, and machine learning analytics. This viewpoint examines emerging AI-based surveillance applications relevant to occupational health, with particular attention to fatigue detection, Personal Protective Equipment (PPE) compliance monitoring, and predictive injury analytics. This review positions these technologies within the waste management industry, where mobile work environments, heavy vehicle interaction, and biological and chemical exposures create complex and dynamic risk profiles. Ethical, legal, and equity considerations are critically examined, including worker privacy, algorithmic bias, and governance of continuous monitoring systems. This review argues that AI-based occupational surveillance should be conceptualized as a digital public health intervention rather than a disciplinary or productivity tool. When implemented with appropriate epidemiologic validation, transparency, and worker participation, AI-based surveillance systems have the potential to meaningfully reduce preventable occupational injury while advancing health equity in high-risk sectors.

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## Introduction

Occupational injury and illness remain leading contributors to preventable morbidity and mortality, with disproportionate risk concentrated in safety sensitive and labor intensive industries. In the United States, waste and recyclable materials collection is consistently ranked among the most hazardous occupations, with fatality rates markedly exceeding national workforce averages [1,2]. Transportation related incidents, including struck by events and vehicle collisions, account for the majority of deaths in this sector, underscoring the persistent danger of mobile and roadside work environments [1].

Despite incremental reductions in fatality rates in recent years, waste collection work remains associated with injury and death rates approximately an order of magnitude higher than the average U.S. occupation [2]. These disparities reflect sustained exposure to interacting hazards such as heavy manual handling, large vehicle operation, uncontrolled public environments, and contact with biological and chemical agents [3,4].

Conventional occupational health surveillance systems, including injury logs, workers' compensation claims, and periodic inspections, remain essential for regulatory compliance but function largely as retrospective or lagging indicators. Such systems are poorly suited to capturing dynamic risk in real time, particularly in industries characterized by variable routes, changing environments, and short cycle tasks. Consequently, opportunities for primary prevention are frequently missed.

Artificial Intelligence (AI) enabled surveillance systems offer a shift toward continuous and predictive risk detection. Through the integration of sensor derived data and machine learning analytics, AI supports near real time identification of hazardous conditions and unsafe behaviours [5,6]. From a public health perspective, this transition aligns with epidemiologic principles emphasizing early intervention and population level prevention. This viewpoint examines core AI based occupational surveillance applications and considers their relevance, benefits, and ethical implications for the waste management industry.

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## Literature Review

Relevant literature was identified through a targeted narrative review of publications indexed in OVID, PubMed, and Google Scholar. Searches focused on studies examining the application of artificial intelligence within the waste and industrial sectors, including technologies related to occupational health. A lower temporal boundary of 1975 was applied to capture the chronological development of occupational disease detection methods and technological solutions used in industrial settings. Articles were selected based on relevance to the topic rather than adherence to formal systematic review criteria.

### AI-Based occupational surveillance as digital public health infrastructure

AI based occupational surveillance integrates continuous data collection with algorithmic analysis to identify risk patterns preceding injury or illness. Common data streams include wearable biosensors, vehicle telematics, environmental sensors, and computer vision systems deployed in workplaces and vehicles [7]. Machine learning models analyze these data to detect deviations from baseline exposure or behavioral patterns associated with increased injury risk.

Unlike traditional surveillance methods, AI enabled systems offer high temporal resolution and contextual sensitivity, enabling detection of transient and cumulative risks that static assessments often overlook. Importantly, these systems should be conceptualized as decision support tools that enhance occupational health expertise rather than replace professional judgment [5]. When framed as prevention-oriented infrastructure, AI based surveillance aligns with digital public health approaches increasingly emphasized in population health research. Figure 1 illustrates AI-based occupational surveillance as a digital public health system that integrates multimodal data inputs and analytics to support prevention-oriented decision making.

Multimodal data inputs, including wearable biosensors, vehicle telematics, computer vision, and environmental sensors are integrated through machine learning analytics to detect fatigue, unsafe behaviors, PPE noncompliance, and elevated injury risk in real time. Outputs function as decision-support signals for occupational health professionals, enabling preventive public health actions such as alerts, engineering controls, training, and surveillance reporting. Ethical governance, equity, transparency, and worker participation are embedded across all system layers.

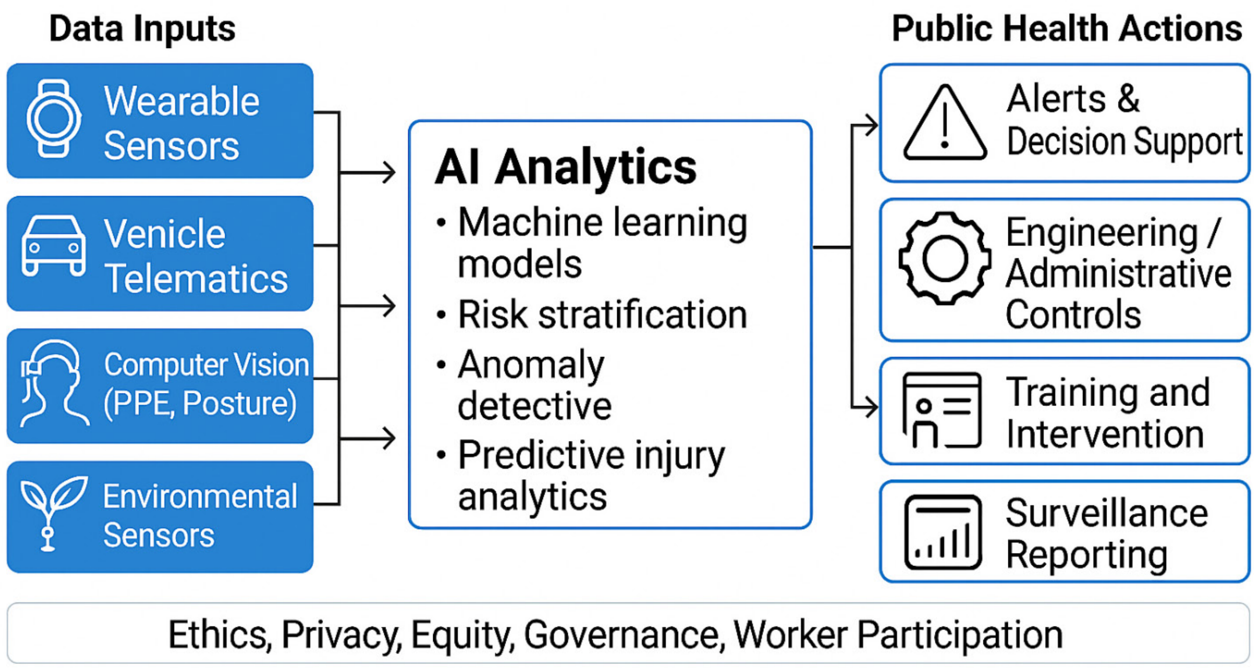


**Figure 1.** Conceptual framework for AI-based occupational hazard surveillance as a digital public health intervention.

### Core applications of AI-Based occupational surveillance

**Fatigue and cognitive risk detection:** Fatigue is a well-established determinant of occupational injury, particularly in work involving prolonged driving, early morning schedules, and physically demanding labor. AI enabled fatigue detection systems integrate physiological indicators, behavioral metrics, and task level performance data to assess fatigue risk in near real time [7,8]. Compared with proxy measures such as hours worked, AI driven approaches enable individualized exposure assessment and targeted intervention.

From an occupational epidemiology perspective, real time fatigue monitoring represents a shift toward dynamic exposure assessment, reframing fatigue as a modifiable occupational hazard rather than an unavoidable characteristic of certain jobs.

**PPE compliance and unsafe act monitoring:** Computer vision-based AI systems are increasingly deployed to detect PPE usage, unsafe postures, and proximity to moving equipment. Studies suggest that these systems can enhance compliance beyond what is achievable through periodic safety audits alone [6,9]. However, continuous observation introduces concerns regarding worker privacy and autonomy, emphasizing the need for transparent governance and participatory implementation.

**Predictive injury analytics:** Predictive models integrating historical injury data, near miss reports, task characteristics, and environmental conditions allow organizations to stratify injury risk across jobs, locations, and time periods [7,8]. While promising, such models require rigorous epidemiologic validation to avoid spurious associations, misclassification, and unintended inequitable impacts. Predictive analytics should be deployed as decision support systems rather than deterministic predictors of injury.

**Applications in the waste management industry:** The waste management sector presents a uniquely complex occupational risk profile characterized by mobile operations, heavy vehicle interaction, manual material handling, and exposure to biological and chemical hazards. AI based surveillance technologies are increasingly adapted to these conditions.

AI enabled vehicle telematics systems analyze driving behavior, route complexity, and fatigue indicators to identify elevated collision risk and support real time intervention [10]. Motion tracking systems and wearable sensors can identify unsafe lifting mechanics and cumulative ergonomic strain, supporting musculoskeletal injury prevention [9,11]. Computer vision-based PPE detection and environmental monitoring systems further support exposure prevention in settings where direct supervision is limited [6,12].

Together, these applications demonstrate the potential for AI based surveillance to address gaps left by conventional occupational health monitoring approaches in the waste sector.

## Discussion

### Ethical, legal and equity considerations

The prevalence AI based occupational surveillance raises significant ethical challenges. Continuous monitoring may undermine worker trust if perceived as punitive or disciplinary rather than protective. Concerns regarding data ownership, secondary use, and surveillance creep are particularly salient in lower wage and frontline occupations [11,13].

Algorithmic bias represents an additional risk. AI models trained on incomplete or skewed datasets may disproportionately classify certain worker groups as "high risk," reinforcing existing occupational inequities [13]. Addressing these concerns requires governance frameworks grounded in transparency, proportionality, informed consent, and human oversight. Occupational health professionals play a critical role in ensuring that AI systems align with prevention and equity goals rather than productivity surveillance.

### Implications for public health research and practice

AI based occupational surveillance should be understood as a digital public health intervention. Future research priorities include prospective evaluations linking AI deployment to injury and illness outcomes, standardized reporting of algorithm performance, and assessment of psychosocial impacts associated with continuous monitoring. Advances in explainable AI and privacy preserving methods may further support ethical integration into occupational health practice [5].

## Conclusion

AI enabled surveillance systems offer a transformative opportunity to shift occupational hazard detection from retrospective documentation to proactive prevention. In high risk industries such as waste management, real time fatigue detection, PPE monitoring, and predictive injury analytics may substantially reduce preventable injury. Realizing this potential requires rigorous epidemiologic validation, ethical governance, and sustained worker engagement. When implemented responsibly, AI can strengthen rather than erode the public health mission of occupational health surveillance.

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