SMART DIGITAL MONITORING SYSTEMS FOR OCCUPATIONAL SAFETY AND HEALTH: OPPORTUNITIES AND CHALLENGES

The role of digital OSH monitoring systems

Digital systems and technologies are transforming the world of work for employers and workers alike. Their emergence also influences the management and improvement of workers' occupational safety and health (OSH) in the workplace, as well as the nature, location, and organisation of work.

OSH monitoring systems are increasingly using digital technologies (ICT, cameras, wearables, smart personal protective equipment, artificial intelligence, etc.) to collect and analyse data on OSH.[1]

These new types of digital OSH monitoring systems offer a vast range of opportunities for substantive OSH improvements, including: enhancing workers' safety, and health awareness; improving task and shift allocation; preventing and reducing accidents; increasing wellbeing; tailoring solutions to specific needs; decreasing occupational stress or injuries; minimising consequences of accidents; and control over decisions, etc. Despite their many known and potential benefits, new OSH monitoring systems can trigger or increase physical health and safety risks, psycho-social risks, a blurring of OSH responsibility, or certain limitations regarding training.

European workplaces are increasingly using digital OSH monitoring systems, in particular in industries in which workers are exposed to higher levels of OSH risks due to specific (hazardous) environments, but overall, their uptake continues to be relatively slow and limited.[2] Factors such as the extent of technological advancement and digital transition, company size, legislation and standardisation in relation to technological changes and OSH implications, and organisational factors influence the uptake of digital OSH monitoring systems.

Notwithstanding these underlying conditions, scarcity of evidence about the use and effectiveness of these systems and the technologies they rely on constrains employers from making informed decisions about whether and which systems they can use in their organisation to improve workers' OSH.

This policy brief discusses some of the key opportunities and challenges of the new OSH monitoring systems and outlines key takeaways for policy- and decision-makers to enhance the benefits of these systems and minimising the potential drawbacks of their use at organisational level. The policy brief draws on research findings from a EU-OSHA' s report on Digital OSH monitoring systems and OSH.

Detection and prevention of harm (proactive approach)

Digital OSH monitoring systems can support harm prevention through the collection of accurate and comprehensive data, which can be analysed and used for workplace adjustments aimed at improving workers' OSH – for example, through measuring exposure to ergonomic hazards and identifying plant- and premises-related hazards. Digital OSH monitoring systems can also prevent harm by identifying hazardous worker behaviour and supporting personalised training to enable better use of these systems. They can also identify poor individual health and wellbeing and support online risk assessments and remote inspections. Key types of opportunities for preventing harm that OSH monitoring systems can bring to the workplace and remote locations are summarised in the table below.

[1] EU-OSHA – European Agency for Safety and Health at Work, *Smart digital monitoring systems for occupational safety and health: uses and challenges, 2023.* Available at: https://osha.europa.eu/en/publications/smart-digital-monitoring-systems-occupational-safety-and-health-uses-and-challenges.

[2] European Agency for Safety and Health at Work, *Drivers and barriers to the adoption of new OSH monitoring systems*, 2023, n.d..

Table 1. Types of opportunities linked to the use of digital OSH monitoring systems

Types of opportunities	Brief description of the potential benefit	Examples of OSH monitoring systems and technologies
Measuring individual or collective harmful exposure and environmental levels	Digital OSH monitoring systems can **support harm prevention by measuring** routine and non-routine **harmful individual and collective workers' exposure**, including remotely (in sectors such as mining, tunnel construction and chemical plants).	• Wearables and smart PPE (smart glasses, hard hat sets, smart bands, smart shoes, and protective clothing, with smart electronics parts linked to smartphones and smartwatches), or heat cameras can **measure** individual **hazardous exposure in real time** (e.g. gas[3], mercury[4], UV radiation[5], high heat levels[6]). • Badges with sensors linked to the Internet of Things (IoT) may enable the capture of **radiation levels**, alert workers and advise them to move away from a given area. • Wireless sensor networks[7] and drones[8] can **detect harmful environmental conditions** such as poisonous dust in poorly ventilated areas, explosive gases, radiation leaks, chemicals and biological agents, and high humidity.[9]
Measuring exposure to ergonomic hazards	Digital OSH monitoring systems may help prevent **work-related musculoskeletal disorders** (WRMSDs) and repetitive strain injuries (RSIs), which may result from poor posture. This applies to different types of jobs and sectors (e.g. in offices or when teleworking, construction, mining, manufacturing, shipbuilding, agriculture, farming, waste management, hotel and restaurants, transportation and	○ Wearables using accelerometers, the IoT, mobile apps and exoskeletons are able to measure the number of movements, their speed, type, and appropriateness, in order to **detect unsafe or harmful movements**, provide **real-time biofeedback** to the user, and prevent long-term serious health conditions. ○ Wearables can also warn that a worker needs to **stop a certain activity** for which a given threshold has been reached: for instance, stopping dynamic lifting.[11] As a result, measures can be designed to **eliminate or reduce exposure to risk** factors. ○ Machine-learning algorithms that use kinematic data may be used to **increase reliability in distinguishing correct and incorrect postures**.[12]

[3] Binajjaj, A., Sheltami, T., Aliyu, F., & Kaosar, M. (2018). Design and implementation of a wearable gas sensor network for oil and gas industry workers. *Journal of Computers, 13*(3), 300-308. https://doi.org/10.17706/jcp.13.3.300-308
[4] Mattoli, V., Mazzolai, B., Raffa, V., Mondini, A., & Dario, P. (2007). Design of a new real-time dosimeter to monitor personal exposure to elemental gaseous mercury. *Sensors and Actuators B: Chemical, 123*(1), 158-167. https://doi.org/10.1016/j.snb.2006.08.004
[5] Bongers, C. C., Hopman, M. T., & Eijsvogels, T. M. (2015). Using an ingestible telemetric temperature pill to assess gastrointestinal temperature during exercise. *Journal of Visualized Experiments*, (104), Article 53258. https://doi.org/10.3791%2F53258
[6] Banerjee, S., Hoch, E. G., Kaplan, P. D., & Dumont, E. L. A. (2017). A comparative study of wearable ultraviolet radiometers. In *2017 IEEE Life Sciences Conference (LSC)* (pp. 9-12). IEEE. https://doi.org/10.1109/LSC.2017.8268131
[7] Cheung, W. F., et al, (2018). A real-time construction safety monitoring system for hazardous gas integrating wireless sensor network and building information modeling technologies. *Sensors, 18*(2), Article 436. https://doi.org/10.3390/s18020436
[8] Burgués, J., & Marco, S. (2020). Environmental chemical sensing using small drones: A review. *Science of The Total Environment, 748*, Article 141172. https://doi.org/10.1016/j.scitotenv.2020.141172
Hollenbeck, D., Zulevic, D., & Chen, Y. (2021). Advanced leak detection and quantification of methane emissions using sUAS. *Drones, 5*(4), Article 117. https://doi.org/10.3390/drones5040117
[9] Bakke, B., Stewart, P., Ulvestad, B., & Eduard, W. (2001). Dust and gas exposure in tunnel construction work. *American Industrial Hygiene Association, 62*(4), 457-465. https://doi.org/10.1080/15298660108984647
Muduli, L., Mishra, D. P., & Jana, P. K. (2018). Application of wireless sensor network for environmental monitoring in underground coal mines: A systematic review. *Journal of Network and Computer Applications, 106*, 48-67. https://doi.org/10.1016/j.jnca.2017.12.022
[11] Ranavolo, A., Draicchio, F., Varrecchia, T., Silvetti, A., & Iavicoli, S. (2018). Wearable monitoring devices for biomechanical risk assessment at work: Current status and future challenges—A systematic review. *International Journal of Environmental Research and Public Health, 15*(9), Article 2001. https://doi.org/10.3390/ijerph15092001
[12] Conforti, I., Mileti, I., Del Prete, Z., & Palermo, E. (2020). Measuring biomechanical risk in lifting load tasks through wearable system and machine-learning approach. *Sensors, 20*(6), Article 1557. https://doi.org/10.3390/s20061557

Types of opportunities	Brief description of the potential benefit	Examples of OSH monitoring systems and technologies
	storage, and health and social care).[10]	
Identifying plant and premises-related hazards	A number of OSH monitoring systems can detect and notify workers when they are **entering a hazardous area**. Hazards may relate to slips, trips, and falls, forklifts, collisions and accidents when using and/or interacting with machinery or vehicles.	Sensors (GPS, WSN[13]) can be used to **identify proximity, measure whether speed is above safety thresholds, or activate emergency stop buttons**. • Wearables may detect voltage hazards and places with the most near-miss falls, by analysing historical data.[14] • Vision systems mounted on smart clothing can be used to avoid human/machine collision[15] as can drones and wireless sensor networks (WSNs), for example in precision agriculture.[16]
Identifying hazardous worker behaviour and supporting personalised training	Digital OSH monitoring systems also provide the opportunity to train workers on the correct use of equipment, and target and **tailor training to workers** whose records show that they may, on average, **adopt unsafe behaviour.** These systems can be applied across many different sectors, including, for instance the manufacturing, metal, construction, mining, chemical, and transport sectors.	• CCTVs, wearables, smart PPE, RFID and video cameras can be used to **detect or even predict unsafe behaviour** that can cause injury and also facilitate the identification of safe practices. • RFID[17] and deep learning[18] allow equipment (e.g. working tools or head, ear, and foot protection) to be checked or enable checks on whether the (protective) equipment is correctly worn. • Wearable-based OSH monitoring systems are used in transport, mining, and construction to detect early **signs of physical, muscle, and mental fatigue**, **stress, drowsiness, low alertness and reaction times**, or **impaired decision-making**.[19] • Wearable movement sensors and biomechanical analysis can provide workers with information on **correct posture**[20].

[10] Khakurel, J., Melkas, H., & Porras, J. (2018). Tapping into the wearable device revolution in the work environment: A systematic review. *Information Technology & People, 31*(3), 791-818. https://doi.org/10.1108/ITP-03-2017-0076
Zhu, Z., Dutta, A., & Dai, F. (2021). Exoskeletons for manual material handling – A review and implication for construction applications. *Automation in Construction, 122*, Article 103493. https://doi.org/10.1016/j.autcon.2020.103493
Ziaei, M., Choobineh, A., Ghaem, H., & Abdoli-Eramaki, M. (2021). Evaluation of a passive low-back support exoskeleton (Ergo-Vest) for manual waste collection. *Ergonomics, 64*(10), 1255-1270. https://doi.org/10.1080/00140139.2021.1915502

[13] Wireless sensor networks (WSNs).

[14] Baka & Uzunoglu (2016) and Yang & Shen (2015) in: Khakurel, J., Melkas, H., & Porras, J. Tapping into the wearable device revolution in the work environment: A systematic review. *Information Technology & People, 31*(3), 791-818. https://doi.org/10.1108/ITP-03-2017-0076

[15] See: https://www.retenua.com/en/products/emitrace/

[16] Popescu, D., Stoican, F., Stamatescu, G., Ichim, L., & Dragana, C. (2020). Advanced UAV–WSN system for intelligent monitoring in precision agriculture. *Sensors, 20*(3), Article 817. https://doi.org/10.3390/s20030817

[17] Mahmad, M. K. N., MAZ, M. R. R., & Baharun, N. (2016). Applications of radio frequency identification (RFID) in mining industries. In *IOP Conference Series: Materials Science and Engineering* (Vol. 133) (Article 012050). IOP Publishing. https://doi.org/10.1088/1757-899X/133/1/012050
Dachry, W., & Bensassi, B. (2021). Toward a real-time personal protective equipment compliance control system based on RFID technology. In F. Saeed, T. Al-Hadhrami, F. Mohammed, & E. Mohammed (Eds), *Advances on Smart and Soft Computing* (pp. 553-565). Springer. https://doi.org/10.1007/978-981-15-6048-4_48

[18] Nath, N. D., Behzadan, A. H., & Paal, S. G. (2020). Deep learning for site safety: Real-time detection of personal protective equipment. *Automation in Construction, 112*, Article 103085. https://doi.org/10.1016/j.autcon.2020.103085
Fang, Q., Li, H., Luo, X., Ding, L., Luo, H., Rose, T. M., & An, W. (2018). Detecting non-hardhat-use by a deep learning method from far-field surveillance videos. *Automation in Construction, 85*, 1-9. https://doi.org/10.1016/j.autcon.2017.09.018

[19] Jung, S.-J., Shin, H.-S., & Chung, W.-Y (2014). Driver fatigue and drowsiness monitoring system with embedded electrocardiogram sensor on steering wheel. *IET Intelligent Transport Systems, 8*(1), 43-50. https://doi.org/10.1049/iet-its.2012.0032
de Naurois, C. J., Bourdin, C., Stratulat, A., Diaz, E., & Vercher, J. L. (2019). Detection and prediction of driver drowsiness using artificial neural network models. *Accident Analysis & Prevention, 126*, 95-104. https://doi.org/10.1016/j.aap.2017.11.038
Lee, B. G., Lee, B. L., & Chung, W. Y. (2015). Smartwatch-based driver alertness monitoring with wearable motion and physiological sensor. In *2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)* (pp. 6126-6129). IEEE. https://doi.org/10.1109/EMBC.2015.7319790
Li, J., Li, H., Umer, W., Wang, H., Xing, X., Zhao, S., & Hou, J. (2020). Identification and classification of construction equipment operators' mental fatigue using wearable eye-tracking technology. *Automation in Construction, 109*, Article 103000. https://doi.org/10.1016/j.autcon.2019.103000
Aryal, A., Ghahramani, A. and Becerik-Gerber, B., 2017. Monitoring fatigue in construction workers using physiological measurements. *Automation in Construction, 82*, 154-165. https://doi.org/10.1016/j.autcon.2017.03.003

[20] Svertoka, E., Saafi, S., Rusu, A., Burget, R., Marghescu, I., Hosek, J., & Ometov, A. (2021). Wearables for industrial work safety: A survey. *Sensors, 21*, Article 3844. https://doi.org/10.3390/s21113844

Types of opportunities	Brief description of the potential benefit	Examples of OSH monitoring systems and technologies
Identifying poor individual health and wellbeing	Digital OSH monitoring systems create opportunities to collect and analyse data that can assess a person holistically.	• The use of accelerometers as part of the SurPASS project, which aims to **evaluate an e-system that measures the daily (24/7) physical behaviour** (physical activity, sedentary behaviour and sleep) at work and during the non-working time of working adults.[21] Similar projects have been initiated , for instance for measuring **occupational and leisure time UV radiation**.[22]
Supporting online risk assessments and remote inspections	Some digital OSH monitoring systems focus specifically on **digital and dynamic risk assessments and inspections**. [23]	• OiRA is an EU-level online **interactive risk assessment tool** that enables risk forecasting.[24] There are other similar comprehensive tools at national level, such as: BeSmart.ie; Rie.nl; and Prevencion10.es. There are tools for specific risk factors, such as noise or chemicals.[25] • Sensor networks and AR enable **remote inspections**, for example in agriculture and forestry, oil and gas, mining and construction.[26]
Applications during the COVID-19 pandemic	Smart OSH monitoring systems that rely on wearables, IoT, artificial intelligence (AI) and machine learning (ML), or tracking devices, can help to ensure safer workplaces in situations in which measures to counter the transmission of diseases are needed.	• These systems can **measure temperatures and other early warning signs** of possible infections and ensure that appropriate preventative hygiene measures are adopted by workers and that environmental aspects such as air quality and ventilation are measured and addressed. • **The wearing of masks** can be enforced more easily by methods of face mask detection.[27] Facial recognition could also help identify those who, for example, should be quarantined due to the COVID-19 pandemic.[28]

Minimising consequences of accidents and improving investigation and reporting (reactive approach)

Digital OSH monitoring systems present a range of opportunities for minimising the consequences of accidents or emergencies by enabling quick interventions and the reporting and investigation of accidents. These systems may minimise harm by signalling an emergency and sending accurate location data, suggesting to workers how

[21] See: https://nfa.dk/da/forskning/strategiske-forskningsomraader/om-msb/om_msb_researchers

[22] Strehl, C., Heepenstrick, T., Knuschke, P., & Wittlich, M. (2021). Bringing light into darkness—Comparison of different personal dosimeters for assessment of solar ultraviolet exposure. *International Journal of Environmental Research and Public Health, 18*(17), Article 9071. https://doi.org/10.3390/ijerph18179071

[23] EU-OSHA – European Agency for Safety and Health at Work, *The development of dynamic risk assessment and its implications for occupational safety and health*, 2021. Available at: https://osha.europa.eu/en/publications/development-dynamic-risk-assessment-and-its-implications-occupational-safety-and-health

[24] See: https://oiraproject.eu/en
OSHWiki, *OiRA and other online risk assessment tools in national OSH strategies and legislation*, 2021. Available at: https://oshwiki.osha.europa.eu/en/themes/oira-and-other-online-risk-assessment-tools-national-osh-strategies-and-legislation

[25] EU-OSHA – European Agency for Safety and Health at Work, *The development of dynamic risk assessment and its implications for occupational safety and health*, 2021. Available at: https://osha.europa.eu/en/publications/development-dynamic-risk-assessment-and-its-implications-occupational-safety-and-health

[26] EU-OSHA – European Agency for Safety and Health at Work, *Digitalisation and occupational safety and health - An EU-OSHA research programme*, 2019. Available at: https://osha.europa.eu/en/publications/digitalisation-and-occupational-safety-and-health-eu-osha-research-programme - EU-OSHA – European Agency for Safety and Health at Work, *Impact of artificial intelligence on occupational safety and health*, 2021. Available at: https://osha.europa.eu/en/publications/impact-artificial-intelligence-occupational-safety-and-health
Howard, J., Murashov, V., & Branche, C. M. (2017). Unmanned aerial vehicles in construction and worker safety. *American Journal of Industrial Medicine, 61*(1), 3-10. https://doi.org/10.1002/ajim.22782.

[27] Loey, M., Manogaran, G., Taha, M. H. N., & Khalifa, N. E. M. (2021). A hybrid deep transfer learning model with machine learning methods for face mask detection in the era of the COVID-19 pandemic. *Measurement, 167*, Article 108288. https://doi.org/10.1016/j.measurement.2020.108288

[28] European Trade Union Confederation. (2020). *COVID-19 Watch ETUC briefing on new technologies allowing more surveillance at work*. https://www.etuc.org/sites/default/files/publication/file/2020-12/20200930_covid-19%20Briefing%20on%20surveillance%20technologies.pdf

they should behave in a dangerous situation. They also help to investigate accidents quickly, safely, and effectively, and enable the reporting of accidents efficiently and with less stigma.

Signalling and localising emergencies

OSH monitoring systems based on GPS tracking allow workers, who would otherwise be at risk of fatality or serious harm, to be **located quickly and accurately and brought to safety**. This can be used, for example, for truckdrivers in distress, for firefighters entering a hazardous rescue area with fire, smoke and high temperatures, or miners and construction workers who are trapped or who have fallen.

The OSH monitoring systems allow the **automatic signalling of an emergency**, for instance through fall detection using accelerometers. They can also send automatic panic alerts, even when the worker is unable to make an emergency call. As workers can be located accurately, **rescue operations can take less time**.[29]

There are new **wearable** solutions for workers in isolated working environments, which have a **man-down feature** integrated into a digital earpiece to use in the case of a loss of consciousness or disabling injury.[30] **Mines connected through WSNs** also allow workers to be located promptly and an assessment to be made as to whether or not they are moving. This real time surveillance is made possible by Bluetooth, WiFi stations, and underground Wi-Fi or 5G. **Unmanned aerial vehicles (UAVs)** also offer significant capabilities in terms of search and rescue, both overground and underground. Autonomous drones can navigate hazards in underground mining environments[31] or can be used in the petrochemicals industry to identify and locate victims.[32]

Responding to emergencies or accidents

Digital OSH monitoring systems may also help when dealing with emergencies or accidents. **Wearables** and **AR** enable **information** (video, audio, images, text) **to be delivered** quickly and accessed easily, for example through smart glasses, so a worker can come to a more informed decision on how to best respond to the situation in which they find themselves.

In the case of firefighters, **smart PPE** has **active cooling systems**. While immersing the hand and forearm in cool water is the most simple and effective way to reduce heat strain[33], automatic cooling systems are among the preferred features for the smart PPE of the future.

Drones can not only provide the location of workers during search and rescue operations, it can also detect defects in equipment being used. This will be helpful for those devising ways to minimise the potential for harm, and also in **delivering new equipment** that may be needed, such as breathing apparatus for workers in a mining emergency.[34]

Accident investigation and reporting

Digital OSH monitoring systems can support accident investigation by providing **data** regarding where the accident occurred, who was present, and who the victims were, what actions and/or conditions led to it, and what happened during the accident and the subsequent rescue operations (when needed). This can help to establish a chain of events.[35]

Accurate and unbiased accident data can be obtained **quickly and efficiently** through the use of digital OSH monitoring systems, which can be sufficient for investigative purposes or can provide a good basis for further investigation, or to supplement it. Data can be gathered on exposure to various types of hazards through

[29] Lawson, F. (2020, July 31). *How apps with GPS tracking ensure worksite safety*. Industry Today. https://industrytoday.com/how-apps-with-gps-tracking-ensure-worksite-safety/
Khakurel, J., Melkas, H., & Porras, J. (2018). Tapping into the wearable device revolution in the work environment: A systematic review. *Information Technology & People, 31*(3), 791-818. https://doi.org/10.1108/ITP-03-2017-0076

[30] Guilbeault-Sauvé, A., De Kelper, B., & Voix, J. (2021). Man down situation detection using an in-ear inertial platform. *Sensors, 21*(5), Article 1730. https://doi.org/10.3390/s21051730

[31] Hennage, D. H., Nopola, J. R., & Haugen, B. D. (2019). *Fully autonomous drone for underground use*. Paper presented at the 53rd U.S. Rock Mechanics/Geomechanics Symposium. OnePetro.

[32] Gamulescu, O. M., Rosca, S. D., Panaite, F., Costandoiu, A., & Riurean, S. (2020). Accident sites management using drones. In *MATEC Web of Conferences* (Vol. 305) (Article 00004). EDP Sciences. https://doi.org/10.1051/matecconf/202030500004

[33] Giesbrecht, G. G., Jamieson, C., & Cahill, F. (2007). Cooling hyperthermic firefighters by immersing forearms and hands in 10°C and 20°C water. *Aviation, Space, and Environmental Medicine, 78*(6), 561-567. https://www.ingentaconnect.com/contentone/asma/asem/2007/00000078/00000006/art00004
Barr, D., Reilly, T., & Gregson, W. (2011). The impact of different cooling modalities on the physiological responses in firefighters during strenuous work performed in high environmental temperatures. *European Journal of Applied Physiology, 111*, 959-967. https://doi.org/10.1007/s00421-010-1714-1

[34] Hennage, D. H., Nopola, J. R., & Haugen, B. D. (2019). *Fully autonomous drone for underground use*. Paper presented at the 53rd U.S. Rock Mechanics/Geomechanics Symposium. OnePetro.

[35] Probst, T. M., Bettac, E. L., & Austin, C. T. (2019). Accident under-reporting in the workplace. In R. J. Burke & A. M. Richardsen (Eds), *Increasing occupational health and safety in workplaces* (pp. 30-47). Edward Elgar Publishing. https://doi.org/10.4337/9781788118095.00009

dosimeters, radiometers, accelerometers, WSNs, or **AR**. Data can also be in the format of **geo-localisation, images, sounds, and movement**.

Data collected through digital OSH monitoring systems can also provide insights into **how rescue operations can be improved** in terms of response time and action taken.

Digital OSH monitoring systems also provide the **possibility for quick and accurate reporting**[36]**.** For example, (smartphone) apps can substitute burdensome paper-based reports, which are also easier to archive and retrieve. This is also the case for audio and visual recordings from the accident scene, which can be sent to the responsible OSH officer automatically.[37] Without digital technology, this is often a lengthy and burdensome process, which may add to the stress of having experienced or witnessed an accident.

Under-reporting, which may be due to the lengthy and burdensome process of reporting. As , stigma and shame attached to being involved in an accident, can be mitigated by digital technology as a consequence of on-the-spot and/or automatic reporting.[38]

Potential challenges to the use of digital OSH monitoring systems

Despite the many recognised and potential benefits of the use of digital OSH monitoring systems, challenges remain. These arise from the potential trade-offs that must be made between the benefits and risks of these systems. Their use has implications for data collection and protection, how OSH monitoring systems work in real-life environments, working relationships, and OSH responsibilities and boundaries.

Physical risks

The use of monitoring by exoskeletons, which, by reducing pressure in some parts of the body can modify the redistribution of effort, can result in the emergence of new biomechanical constraints and risk factors for musculoskeletal disorders (MSDs).[39] Exoskeletons might also hinder movement and lead to collisions because of their bulky structure, they may cause discomfort, skin irritation, increase cardiovascular load and stress, or make workers over-confident in their abilities, giving them a feeling of invulnerability that could result in accidents.[40] VR and AR may cause disorientation, motion sickness (also called cybersickness) and eye strain, owing largely to hardware, content, and human-related factors.[41]

Challenges related to how OSH monitoring systems work in real-life environments

Even when technologies are certified, their **accuracy for collecting accurate data is first assessed in laboratory-type environments** that may not accurately replicate adverse working conditions.[42] This is particularly the case in **working environments that may limit sensor accuracy** or in settings where technologies may face unexpected challenges: for example, thermal cameras in drone systems may not be able to locate a worker.[43] Human-machine interfaces (face, gestures, voice, eye movement, brain signals) could misinterpret corrupted or low-strength signals – for example due to batteries running low or interference.[44]

New digital technologies may malfunction. Batteries may not only be inefficient or stop working in difficult environmental situations, they may also overheat, catch fire, or explode[45]. A **sensor-based vest** may be vulnerable to water penetrating its electrical areas, which can cause short circuits or electric shocks. **UAS** can be

[36] See: https://osha.europa.eu/en/blog/world-day-safety-and-health-work
[37] Hussin, M. F. B., Jusoh, M. H., Sulaiman, A. A., Abd Aziz, M. Z., Othman, F., & Ismail, M. H. B. (2014). Accident reporting system using an iOS application. In *2014 IEEE Conference on Systems, Process and Control (ICSPC 2014)* (pp. 13-18). IEEE.
[38] Black, K. J., Munc, A., Sinclair, R. R., & Cheung, J. H. (2019). Stigma at work: The psychological costs and benefits of the pressure to work safely. *Journal of Safety Research, 70*, 181-191. https://doi.org/10.1016/j.jsr.2019.07.007
[39] INRS. (2020). *Using exoskeletons at work : The message of prevention*. https://en.inrs.fr/news/exoskeletons-6-critical-points.html
[40] EU-OSHA – European Agency for Safety and Health at Work, *Digitalisation and occupational safety and health - An EU-OSHA research programme*, 2019. Available at: https://osha.europa.eu/en/publications/digitalisation-and-occupational-safety-and-health-eu-osha-research-programme
[41] Chang, E., Kim, H. T., & Yoo, B. (2020). Virtual reality sickness: A review of causes and measurements. *International Journal of Human–Computer Interaction, 36*(17), 1658-1682. https://doi.org/10.1080/10447318.2020.1778351
[42] Khakurel, J., Melkas, H., & Porras, J. (2018). Tapping into the wearable device revolution in the work environment: A systematic review. *Information Technology & People, 31*(3), 791-818. https://doi.org/10.1108/ITP-03-2017-0076
[43] Burke, C., McWhirter, P. R., Veitch-Michaelis, J., McAree, O., Pointon, H. A., Wich, S., & Longmore, S. (2019). Requirements and limitations of thermal drones for effective search and rescue in marine and coastal areas. *Drones, 3*(4), Article 78. https://doi.org/10.3390/drones3040078
[44] EU-OSHA – European Agency for Safety and Health at Work, *Foresight on new and emerging occupational safety and health risks associated with digitalisation by 2025*, 2018. Available at: https://data.europa.eu/doi/10.2802/515834
[45] EU-OSHA – European Agency for Safety and Health at Work, *Smart personal protective equipment: intelligent protection for the future*, 2020. Available at: https://osha.europa.eu/en/publications/smart-personal-protective-equipment-intelligent-protection-future/view

a safety risk to workers nearby due to system malfunction or cyber-attacks. This is particularly true for semi-autonomous or autonomous UAVs not operated by humans.[46]

OSH monitoring systems may also **intensify work** and thereby potentially cause harm to workers. As OSH monitoring systems have financial implications: some companies might want to combine their OSH functions with functions to increase productivity and thus reduce costs (e.g. by dismissing or not hiring workers)[47]. In such cases, an existing worker might have to deal with additional workload.

Challenges related to data collection and protection

Digital monitoring systems can support OSH improvements through accurate data collection and meaningful analysis of trends at aggregate levels but can also be perceived as an invasion of privacy by workers, which can be stressful, and lead to alienation at work.[48]

There are a number of important questions with regards to **data privacy, ownership and security**, linked to the design and use of OSH monitoring systems, as digital devices collect vast amounts of data, which can be sensitive personal data (e.g. related to ethnic origin, health, genetic, and biometric data). Therefore, for workers and worker representatives it is important to understand who has the right to see and use the data, what type of data are collected, how they are stored and transferred to third parties, such as external service providers, and how or when data will be deleted. Further, there is also the risk of data breaches and theft. It is important for workers to understand what types of security measures are in place to protect them against unauthorised access to data and for them to be included in processes that decide the use of digital OSH monitoring systems in the workplace or in remote locations.

Another aspect to consider is the purpose for which the data are used. There are instances, for example, of digital surveillance linked to **work intensification**.[49] Workers and their representatives sometimes perceive that management is using OSH monitoring systems to increase control over workers' performance in the context of increasingly challenging targets.[50] OSH monitoring systems for teleworkers may also include risks and challenges related to performance monitoring. On the basis of the data collected, employers may be able to know where workers are, what they are doing, how (tired) they are feeling, or whether they are sleeping. They may also be able to find out how long someone spends on a toilet break.[51] This can generate anxiety and stress due to an **always-on culture**[52] **and anticipatory surveillance fear**,[53] for example, in cases where digital technology frequently sends alerts, warnings, and reminders, which can be stressful as it gives a sense of constant oversight.

AI, ML, deep-learning, and algorithms may also have **adverse effects** on workers. For example, when an accident is about to happen, AI may be tasked with making choices that may save lives, it is therefore important

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[46] EU-OSHA – European Agency for Safety and Health at Work, *Summary - Foresight on new and emerging occupational safety and health risks associated with digitalisation by 2025*, 2018. Available at: https://osha.europa.eu/en/publications/summary-foresight-new-and-emerging-occupational-safety-and-health-risks-associated-1
EU-OSHA – European Agency for Safety and Health at Work, *Cobots, robots and drones: the impact of digital technology on OSH in agriculture and forestry*, 2021. Available at: https://osha.europa.eu/en/publications/cobots-robots-and-drones-impact-digital-technology-osh-agriculture-and-forestry
Howard, J., Murashov, V., & Branche, C.M. (2017). Unmanned aerial vehicles in construction and worker safety. *American Journal of Industrial Medicine, 61*(1), 3-10. https://onlinelibrary.wiley.com/doi/abs/10.1002/ajim.22782

[47] Ecorys interviews conducted for this study, from November 2021 to February 2022.

[48] Carpenter, D., McLeod, A., Hicks, C., & Maasberg, M. (2018). Privacy and biometrics: An empirical examination of employee concerns. *Information Systems Frontiers, 20*, 91-110. https://doi.org/10.1007/s10796-016-9667-5
EU-OSHA – European Agency for Safety and Health at Work, *Monitoring technology: The 21st century pursuit of well-being?*, 2017. Available at: https://dspace.library.uu.nl/bitstream/handle/1874/369002/VandenBroek17_Workers_monitoring_and_well_being.pdf?sequence=1&isAllowed=y
European Commission, European Political Strategy Centre, & Servoz, M. (2019). *AI, the future of work? : Work of the future! : On how artificial intelligence, robotics and automation are transforming jobs and the economy in Europe*. Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/096526d7-17d8-11ea-8c1f-01aa75ed71a1

[49] European Commission, Joint Research Centre, & Ball, K. (2021). *Electronic monitoring and surveillance in the workplace : Literature review and policy recommendations*. Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/1cbf6cdf-1c19-11ec-b4fe-01aa75ed71a1/language-en/format-PDF

[50] European Trade Union Confederation. (2018). *Digitalisation and workers participation. What trade unions, company level workers and online platform workers in Europe think*. https://www.etuc.org/sites/default/files/publication/file/2018-09/Voss Report EN2.pdf

[51] Bender, G., & Söderqvist, F. *How to negotiate an algorithm: A case study on voice and automation in Swedish mining*. Blekinge Institute of Technology (forthcoming).

[52] Ecorys interviews conducted for this study, from November 2021 to February 2022

[53] Samek Lodovici, M. et al. (2021). *The impact of teleworking and digital work on workers and society*. Policy Department for Economic, Scientific and Quality of Life Policies, European Parliament. https://www.europarl.europa.eu/RegData/etudes/STUD/2021/662904/IPOL_STU(2021)662904_EN.pdf

that these systems have reliable, accurate, and unbiased data; that they have adequate 'intelligence' to achieve complex goals; and that they are able to reduce risks without causing more harm.[54]

For company management, the vast amount of data collected and in need of interpretation may result in **cognitive overload** unless the process is automated.[55] This also applies to workers who may receive a high volume of data/content, when using VR/AR.[56]

Challenges related to working relationships

The shift to **algorithmic management** may impact working relationships, communication, and trust. AI management can reduce contact between management and workers, as well as between co-workers. It can therefore undermine workplace connections and motivation. The reduced scope for task rotation and variety may also lead to increased job dissatisfaction, for example in the case of workers assigned to lonely, monotonous, and repetitive work. In addition, algorithmic decision-making that is not transparent and open may lead to the perception of injustice and alienation and may, as a result, curb creativity and autonomy.[57] The use of digital OSH monitoring systems can create **frustration and a fear of technology malfunctioning** or not being comfortable or easily customisable.[58]

Blurred OSH responsibility and boundaries

In practice, digital OSH monitoring systems may blur responsibility for OSH and the boundary between private and work life in in several ways.

- Employers may become **increasingly reliant** on them at the **expense of other OSH measures**.
- Employers may not carry out **adequate risk assessments or adopt corrective measures** on the basis of the data gathered through digital technology, which could create a false sense of safety at work.
- There may be **more emphasis on personal OSH monitoring measures than on collective measures**: collective protective measures protect all workers rather than only one at a given time, but these two levels of protective measures are complementary rather than mutually exclusive, with personal control measures adding an additional layer of protection for *residual risks*[59].
- **Blurred boundaries between private and work life:** the use of wearables may blur the distinction between private and work life if data is recorded 24/7. Wearables can warn workers that they are sleep deprived and related wellbeing programmes may point to individual measures that can be taken (e.g. a better diet, going to bed early, drinking less coffee, being more physically active, etc.) when occupational (or even public health) measures may be required instead.
- **Absence of adequate training**[60] of workers and management to enable effective use of OSH monitoring systems in the workplace can limit potential benefits and even increase the risk of harm.

Boosting the benefits of digital OSH monitoring systems: Key takeaways for policy- and decision-makers

Digital OSH monitoring systems can contribute extensively to identifying and assessing OSH risks, prevent and/or minimise harm, and promote occupational safety and health. They can, therefore, be an essential tool to help organisations improve workers' OSH, safety of equipment and processes, and health management systems. Further evidence about their practical

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[54] Eliot, L. (2020, July 27). AI ethicists clash over real-world aptness of the controversial trolley problem, but for self-driving cars it is the real deal. *Forbes*. https://www.forbes.com/sites/lanceeliot/2020/07/27/ai-ethicists-clash-over-real-world-aptness-of-the-controversial-trolley-problem-but-for-self-driving-cars-it-is-the-real-deal/?sh=18f7754a5095 Eliot, L. (2020, March 7). If AI has human rights, some are worried that self-driving cars might turn on us. *Forbes*. https://www.forbes.com/sites/lanceeliot/2020/03/07/if-ai-has-human-rights-some-are-worried-that-self-driving-cars-might-turn-on-us/?sh=e6c3b344548e See: https://www.aitrends.com/ai-insider/self-driving-car-mother-ai-projects-moonshot/ Castelvecchi, D. (2020). Is facial recognition too biased to be let loose? *Nature*. https://www.nature.com/articles/d41586-020-03186-4

[55] Hosman, A. (2017, July 17). *How wearables could disrupt workplace safety*. EHS Today. https://www.ehstoday.com/ppe/article/21919117/how-wearablescould-disrupt-workplace-safety

[56] EU-OSHA – European Agency for Safety and Health at Work, *Digitalisation and occupational safety and health - An EU-OSHA research programme*, 2019.: https://osha.europa.eu/en/publications/digitalisation-and-occupational-safety-and-health-eu-osha-research-programme

[57] European Trade Union Confederation. (2020, July 13). *Resolution on the European strategies on artificial intelligence and data*. https://www.etuc.org/en/document/resolution-european-strategies-artificial-intelligence-and-data
Zednik, C. (2021). Solving the black box problem: A normative framework for explainable artificial intelligence. *Philosophy & Technology, 34*, 265-288. https://doi.org/10.1007/s13347-019-00382-7

[58] Ecorys interviews conducted for this study, from November 2021 to February 2022.

[59] HASpod. (2019). Residual risk: How to manage the risks you can't stop. Available at: https://www.haspod.com/blog/management/residual-risk.

[60] European Commission, European Political Strategy Centre, & Servoz, M. (2019). AI, the future of work? : Work of the future! : On how artificial intelligence, robotics and automation are transforming jobs and the economy in Europe. Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/096526d7-17d8-11ea-8c1f-01aa75ed71a1

use and adaptation in different organisational, sectoral, and legal contexts will enable a deeper understanding of their impact on OSH, including concrete benefits and remaining challenges.

Against this background, the following key takeaways are offered with a view to enhancing the benefits of digitalOSH monitoring systems and minimising the potential drawbacks linked to their use.

Takeaway 1: Develop evidence-based standards within the EU digital single market that encourage take-up

The use of digital OSH monitoring systems is often driven by compliance with existing legal standards. Legislative developments, however, often lag behind technological developments. Standardisation of smart OSH monitoring systems presents a range of challenges which are acting as a potential barrier to their adoption at organisational level. Establishing standards in the EU digital single market that provide an adequate framework and boundaries but do not lag behind the fast pace of technological developments is challenging, but efforts should continue. This will provide a suitable legal environment for designers to continue to innovate and for employers to use digital OSH monitoring systems to drive OSH improvements.

Takeaway 2: Adapt digital OSH monitoring systems to companies' and workers' needs

Decisions to use OSH monitoring systems should also be informed by existing needs and the desire to improve workers' safety, health and well-being at work, not just legal requirements. While generic OSH monitoring systems may prove adequate for use across some sectors or types of jobs, tailoring solutions to the workplace and workers' needs may increase their effectiveness and maximise positive impacts. One way to increase the effectiveness of such systems is to consider specific needs at the design stage, and the potential positive and negative impacts of the adoption of digital OSH monitoring systems.

Takeaway 3: Ensure adequate support for organisations, in particular SMEs

Concrete examples of the effectiveness of these systems and how adaptations can be made to further increase their benefits would provide the necessary evidence for decision-makers to adopt such systems. This evidence is reliant on current designers and users collecting, reviewing, and publicly sharing information about the impact of OSH monitoring systems and the adaptations that enable higher effectiveness. Extensive sharing of good and promising practices could further the take-up of these systems. Such endeavours can however be costly, alongside the design and adaptation of the monitoring systems, which present significant challenges to employers, and in particular SMEs.

Public policy measures to support the design, acquisition, and evaluation of the use of digital OSH monitoring systems (attached to financial support instruments) may improve the use of these systems and strengthen the evidence base in terms of their impact in preventing or reducing OSH risks and adjustments that need to be made.

Takeaway 4: Consult relevant parties and agree how smart OSH monitoring systems are to be used (employers, worker representatives, OSH professionals)

Before OSH monitoring systems are put into place, employers, employee representatives, and OSH professionals should discuss and reach agreement on how the systems are to be used, and the employees must be properly consulted and informed. This is an essential step in order to raise awareness, secure buy-in, and enable a productive, effective and efficient use of these systems, targeted at specific OSH needs at organisational level.

Takeaway 5: Properly inform and train company management and workers in using digital OSH monitoring systems

Limited evidence about the concrete impact on workers' OSH, and safety processes at organisational level across different sectors, types of jobs, and in countries with different OSH cultures can limit the propensity of employers to design and/or use OSH monitoring systems. This is amplified by inadequate information about short- and long-term costs necessary for designing, implementing, and adjusting these systems. Limited evidence of the impact on OSH can equally reduce workers' trust levels in such tools.

Adequate information and awareness-raising campaigns can contribute to a wider and deeper understanding of these tools. Workplace resources (e.g. training guides, company policies) and regular communication about the lessons learned as a result of the use of these systems can support a better understanding of the benefits and limits of these systems. They can also ensure their alignment with pre-existing risk monitoring and other risk assessment processes, such as occupational health screening.

Takeaway 6: Digital OSH monitoring systems have limitations, which should be clearly determined and communicated

Smart or digital OSH monitoring systems are tools to improve and promote OSH through workplace adaptations, adjustments, corrective measures, worker training, and a reinforced culture of trust and participation. Monitoring technologies can be optimised and adapted to their intended use in different organisations, but have inherent limitations related to the technology being used, the extent to which risks can be prevented or limited, how data is collected and interpreted and potential errors stemming from the process.

OSH monitoring systems provide information about predetermined parameters and are primarily aimed at *supporting* systems making decisions about OSH at organisational level. They do not act autonomously or replace decision-makers, given that monitoring technology cannot account for external or contextual factors that influence the interpretation of the collected data and any decisions about corrective actions.

Takeaway 7: Consider data collection and protection implications and adequately inform workers

Contemporary data management and analytics bring significant benefits to decision-making processes at organisational level, including those aimed at improving OSH, and can lead to more effective risk reduction at work. There is a need for clarity, transparency, and data protection protocols about how the data collected by these systems is used, what type of data is used, who can access it, for what purposes, and how robust data security is ensured.

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