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Occupational health and safety in a robot blended workplace[**]

Introduction

The aim of this paper is to introduce the basic elements of the readaptation of occupational safety and health (hereinafter: OSH) regulations to different generations of robots. It will discuss the pros and cons of AI-driven robots in the context of OSH and the challenges of robot generations for OSH measures.[1]

Inevitably, the new generations of AI-driven robots are becoming mobile, smart and collaborative. While the old generation (industrial) robots generally used to perform unsafe, hazardous, highly repetitive, and unpleasant tasks, intelligent machines are taking over a wide range of notjust manual but also cognitive tasks previously done only by humans. Workers are increasingly overseen by monitoring technologies and algorithms, to the extent that in the future they could be managed by intelligent machines.The 24/7 globally interconnected economy requires evermore flexible work organisation and has given rise to new forms of work, such as online platform work and humanoid (human-robot twinning) work. In this context, psychosocial and organisational risk factors deserveparticular attention, as they may give rise to higher levels of work-related stress and poor mental health. New safety and ergonomic challenges are emerging as well, including risks of functional safety associated with cybersecurity. Digital technologies and new forms of work present challenges for the application of OSH regulations.[2]

At the very beginning, a widespread misconception should be queried that robots will completely replace human workers and they will completely take away work from the human beings, therefore the need for OSH will evaporate. While replacing human activity is a major factor in how robotics traditionally impacts workplace safety, this replacement is

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[**] This research was supported by the project nr. EFOP-3.6.2-16-2017-00007, titled Aspects on the development of intelligent, sustainable and inclusive society: social, technological, innovation networks in employment and digital economy. The project has been supported by the European Union, co-financed by the European Social Fund and the budget of Hungary.
[1] NB: The responsibility of robots for work accident will be analysed in a different article.
[2] Digitalisation and occupational safety and health (OSH) An EU-OSHA research programme European Agency for Safety and Health at Work, 2019 https://osha.europa.eu/en/emerging-risks/ developments-ict-and-digitalisation-work (14. 12. 2020).

far from absolute or permanent. Rather, the replacement function of robots primarily focuses on removing the human factor from otherwise dangerous or fatal workplace tasks. From a safety standpoint, the implementation of robotics means removing workers from doing those demanding and dangerous jobs that put them at risk.[3]

Inevitably, OSH is deeply embedded into Western culture. OHS saves millions of lives, but more and more workplace tasks are automated, which impacts the prospect of the occupational health and safety measures and the profession itself. In the past, many things threatened OSH – deregulation, public opinion, corporate greed, atypical work, – but recently the most unavoidable impact for health and safety at work is artificial intelligence (AI) and its creation, robotics. However, robotisation is a double-faced development (see pros and cons later). Traditional and AI-driven robots affect many aspects of traditional work, such as carrying out manual work (labour), monitoring employee health and safety, making management decisions, etc. It is changing warehouses, construction sites and facilities worldwide as technology becomes more accessible and advanced.

The hypothesis of this article is that advanced AI-driven robotics offers vast potential to meet growing demand and increase productivity, but could be detrimental to workers' mental and/or physical health and necessarily modifies OSH measures.

I. Impacts of robotisation on occupational safety and health: pros and cons

1. Pros for OSH

Robotisation improves workplace productivity and safety. In the long run, the benefits of increasing robot installations remain the same: rapid production and delivery of customized and quality products at competitive prices.

From the point of view of OSH, further advantages of using robotic systems in production are as follows:

a) Prevention. Improving the health and safety of workforce: better monitoring of workers' safety and health condition. Studies indicate that many robot accidents occur during non-routine operating conditions, such as programming, maintenance, testing, setup, or adjustment. During many of these operations, the worker may temporarily be within the robot's working envelope where unintended operations could result in injuries.[4]

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[3] There are supporting opinions from practice: 1. "Instead of having the worker expose his/her life or limbs to the hazards of moving sheet metal in and out of a 300-ton stamping press, a robot can assume that 'risk.'" 2. "Changing the operation to a 'no-touch' environment can dramatically improve the safety of workers by reducing their exposure." 3. "Replacing operators in these environments allows companies to reduce or maybe even eliminate workers' long-term exposure (to high-risk environments and tasks)." ; JACK BURTON: (2020) *Rise of the robots, Technology increasingly assuming risks of most dangerous tasks*. https://www.ohscanada.com/features/rise-of-the-robots/ (14. 12. 2020.)

[4] BARBARA WELTMAN: *During many of these operations, the worker may temporarily be within the robot's working envelope where unintended operations could result in injuries.* 2019. https://bigideasforsmallbusiness.com/idea/robots-and-workplace-safety/ (17. 12. 2020.)

b) Increasing work safety. Making work safer and profitable regardless of working conditions. The AI-driven robots might remove workers from hazardous jobs. Taking over many jobs can diminish both types of human overload: a) cognitive overload due to increasing technological complexity or performing repetitive and dangerous tasks (with a high chance of fatigue and making mistakes and accidents due to tiredness) and b) physical overload due to work intensification in thecase of repetitive tasks. The AI-driven workplace produceshigh accuracy of work – reduced errors, waste and accidents.Work can be delivered in confined, dark, cold spaces, which would not be fit for human workers. Work can be performed 24/7, leading to higher production and reprogrammability or flexibility.[5]

c) Decreasing human error. Human factors play a huge role in workplace safety, with repetitiveness, monotonous work or high level attention and stress readily contributing to accidents. So, one major benefit of AI-driven robotsistheir inability to get stressed, tired or unwell. In other words, AI safety can scale down human factors in the workplace.[6]

2. Cons for OSH

Despite the clear benefits that accompany AI and AI-driven robots in the workplace, it does come with disadvantages.The main disadvantages of using robotic systems in production are the following: 1. expertise needed to operate such systems; 2. training of workers required in both operation and maintenance; 3. high initial capital cost;[7] 4. permanent monitoring of workers (makes them nervous and has a Big Brother effect); 5. performance pressure for human being employees; 6. lack of awareness (it means that the AI is not completely error free).[8] Inevitably, robots still cause accidents even though the capabilities of robots are in many ways outstanding, and they stand to deliver even greater efficiencies in the near future. However, the complexities of robotics introduce serious workplace hazards: collisions, crushing, unexpected restarts, and electrical shocks, etc.

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5 *Robotics, Occupational Safety and Health Administration.* https://www.osha.gov/robotics (19. 12. 2020.)

6 One example: Launched in 2018, AI-SAFE (Automated Intelligent System for Assuring Safe Working Environments) cleverly detects if employees are wearing the correct PPE for each working area by blending video footage, innovative algorithms and machine learning. If a worker is not suitably dressed, AI-SAFE sends an alert and restricts access. In old practice PPE checks are typically conducted by a staff member, human error can come into play. AI safety reduces this risk.

7 RUTH TRUMPOLD: *Sustainable.* innovationhttps://www.ruthtrumpold.id.au/destech/?page_id=376 (15. 12. 2020.)

8 One argument is that autonomous systems like driverless cars and robots are taught by virtual training scenarios which do not match real-life environments.

According to the US OSHA's[9] technical manual, typically these hazards arise from: 1. human error,[10] 2. control errors,[11]3. unauthorized access, 4. mechanical failures, 5. environmental sources,[12] 6. power systems,[13] or 7. improper installation.[14,15]

In sum, as robots are basically so safe, so efficient and error-proof, when they become cheaper than humans, it will spell human workforce decline. As a result, there will be fewer human-related risks to be managed, and fewer people to get hurt. In the final stage – it is impossible to predict when, but that day will surely come – there will be no human employees in the majority of the workplaces,[16] only robots.[17,18]

II. Typology: generations of robots and OSH

1. Awareness of robots: occupational robotics as a new field in OSH

Rapid advancements in technology have introduced many types of physical robotic systems in the workplace. The range of industrial robots continues to expand – from traditional caged

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[9] United States Department of Labour Occupational Safety and Health Administration.

[10] By far, the most common cause is human error. Workers get comfortable with the equipment and are sometimes complacent about the dangers. They may place themselves in unsafe areas when programming or performing maintenance on a robot, for instance.

[11] Robots require complex programming to operate, and accidents can also result from a human-introduced programming error.

[12] Industrial robots are capable of powerful movements across a large area, even beyond the base of their unit. Changes to the materials or the environment may affect the preprogrammed movements of the robot. The use of physical barriers typically protects workers from industrial robot hazards – but accidents do happen.

[13] One concrete example: an employee working for an automobile parts manufacturer leaned through a light curtain to change a welding tip on a robot. Another robot unexpectedly energized. The robotic arm struck the employee who sustained a fracture and dislocation of his left hip, requiring hospitalization.

[14] Other hazards may result from improper installation, failure to properly maintain equipment, and malfunctions in the hydraulic and electrical systems.

[15] The Robots are Here. How Do We Work Safely with Them? https://ohsonline.com/articles/2019/11/19/the-robots-are-here-how-do-we-work-safely-with-them.aspx?m=1 (03. 12. 2020.)

[16] On the one hand, automation is a great and mighty thing, making it possible to reduce costs, waste and defects and, at the same time, to increase production speed. But, on the other hand, it is not able to replace the cognitive added value given by the human being, the only one — at the moment — able to innovate, add, transform and create. Manufacturing, like most of the world of work in other industries, will automate all repetitive and low value-added work and instead preserve and even emphasize the specific value of human beings. (Luca Mascaro: Robots work in the dark; https://medium.com/sketchin/robots-work-in-the-dark-96206d299461) (19. 12. 2020.)

[17] For example, the dark factories, one of those that employ only robots and no human workers. Robots work in the dark; they do not need light to see and complete their tasks. A factory without people — populated only by robots and a few human supervisors who live far away from the production lines — is not a good or bad thing in itself, nor is it necessarily the future of manufacturing. Surely there are some controversial opinions. Toyota had automated almost all the lines, but it is slowly reversing its course so that the most advanced production lines employ only human labour and the machines are all assembled by hand, piece by piece. The reason for this choice is cultural and is well explained by the words of the company's Vice President: "Such a [fully automated] factory would always remain stuck at the same stage of development. Robots cannot improve processes. Only people can, which is why they are always the focus of our attention. (LUCA MASCARO (2020): *Robots work in the dark.* https://medium.com/sketchin/robots-work-in-the-dark-96206d299461) (19. 12. 2020.)

[18] HANNAH STEWART: *Will Health and Safety Ever Die?* https://www.pro-sapien.com/blog/will-health-and-safety-ever-die/?hsCtaTracking=a9f64eda-5eb1-46ad-95bf-4d2a5c29c9e5%7C47f5228c-c4b1-47f4-bf76-3a0235325b90

robots (in our categorisation: industrial robots) capable of handling all payloads quickly and precisely, to new collaborative robots that work safely alongside humans, fully integrated into workbenches.

The introduction of robots in the 21st century workplace are creating three basic different types of work: (1) human work; (2) robot work; and (3) collaborative (blended[19] or boosted[20]) work. The increased complexity of work that is emerging in the 21st century with regard to the traditional occupational safety and health concept of "worker" requires the occupational safety and health system to broaden the traditional scope of risk management. Similar to another emerging technology, nanotechnology, any discussion of the emerging field of occupational robotics should include a discussion of the methods needed to do robotic hazard assessment and risk management, as well as managing the ethical issues impacting a workplace where human workers may be in the minority.[21]

In this study the three basic categories/generations of robots will be discussed: (1) industrial robots; (2) service robots (professional and personal service robots); and (3) collaborative robots (cobots). A new and largely experimental category of robot workers is emerging, called managerial[22] robots.[23,24]

2. Industrial robots

2. 1. Features of industrial robots

The initial wave of industrial robots was introduced in the 1970s when they began to be used in the manufacturing sector for assembling automobiles. There are many definitions of industrial robots. The well-accepted approach by the International Organization for Standardization (ISO) defines the industrial robot as "an automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications".[25]They are programmable, mechanical devices used in place of a person to perform dangerous or repetitive tasks with a high degree of accuracy.That simple definition, however, opens up the huge world of robotics, from large, intricate systems to the small parts, cables, guarding,

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19 Blended work when a human worker works with any kind of cobots (collaborative robots).

20 Human workers equipped with performance-enhancing robotic devices such as robotic prostheses and exoskeletons.

21 Schulte Pa, Salamanca-Buentello F.: *Ethical and Scientific Issues of Nanotechnology in the Workplace.* Env Health Persp. 2007. 115(1): pp. 5–12.

22 The development of robots with increasingly sophisticated decision-making and social capacities is opening the door to the possibility of robots carrying out the management functions of planning, organizing, leading, and controlling the work of human beings and other machines.

23 Matthew Gladden: *Managerial Robotics: a Model of Sociality and Autonomy for Robots Managing Human Beings and Machines.* 2004. https://www.researchgate.net/publication/273461810_Managerial_Robotics_a_Model_of_Sociality_and_Autonomy_for_Robots_Managing_Human_Beings_and_Machines

24 Vladimir Murashov, Frank Hearl And John Howarda: *Working Safely with Robot Workers: Recommendations for the New Workplace.* J Occup Environ Hyg. 2016 Mar; 13 (3): pp 61–71. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4779796/ (10. 12. 2020.)

25 International Organization for Standardization (ISO) Robots and robotic devices – Vocabulary. Geneva, Switzerland: ISO. 2012. (ISO 8373: 2012.)

grippers, and components that make up these machines.[26]Industrial robots are characterized by high strength, endurance and precision and are widely used for welding, painting, assembling, moving, and testing.[27]Making the picture more complex, industrial robots can be custom programmed to handle a variety of tasks and applications for many industries, there are really five main categories of industrial robotics. The tasks needing completion determine which type of robot is necessary. Industrial robot categories include: 1. Cartesian robots, 2. Gantry robots, 3. SCARA robots, 4. Articulated arm robots and 5. Human-assist robots.[28] Due to the limited space they are not discussed in this article.

2. 2. Hazards of industrial robots

While industrial robots are proving their utility across industries, there are real hazards to be considered. Most of the industrial robots are unaware of their surroundings, therefore, they can be dangerous to workers. As a main rule, the workers must obey some safety rules and usually physical protection (fence, yellow or red painted roads on the floor, etc.).

The US OSHA's technical manual identifies four typical categories of accidents that can occur when employees are working with industrial robots: 1. *Impact or collision accidents* resulting from unpredicted movements, component malfunctions, or unpredicted program changes related to the robot's arm or peripheral equipment can occur. 2. *Crushing and trapping accidents* of workers' limbs or other body parts caught between a robot's arm and other peripheral equipment can happen, or the individual may be physically driven into and crushed by other peripheral equipment. 3. *Mechanical part accidents* resulting from the breakdown of the robot's drive components, tooling or end-effector, peripheral equipment, or its power source constitute mechanical accidents. These include the release of parts, failure of a gripper mechanism, or the failure of end-effector power tools (e.g., grinding wheels, buffing wheels, deburring tools, power screwdrivers, and nut runners).[29] 4. *Accidents from leaking high-pressure lines*, arc flash, metal spatter, dust, electromagnetic, or radio-frequency interference can also occur.[30]

From different aspects, industrial robots can pose several types of hazards based on their origin: 1. mechanical hazards such as those arising from unintended and unexpected movements or release of tools; 2. electrical hazards such as contacts with live parts or connections or exposure to arc flash; 3. thermal hazards such as those associated with hot surfaces or exposure to extreme temperatures; 4. noise hazards; and 5. other hazards such as vibration, radiation, and chemicals.[31]

[26] Defining the Industrial Robot Industry and All It Entails; https://www.robotics.org/robotics/industrial-robot-industry-and-all-it-entails (22. 12. 2020.)

[27] International Organization for Standardization (ISO) Robots and robotic devices – Vocabulary. Geneva, Switzerland: ISO. 2012. (ISO 8373: 2012.)

[28] Defining The Industrial Robot Industry and All It Entails; https://www.robotics.org/robotics/industrial-robot-industry-and-all-it-entails (22. 12. 2020.)

[29] The Robots are Here. How Do We Work Safely with Them? https://ohsonline.com/articles/2019/11/19/the-robots-are-here-how-do-we-work-safely-with-them.aspx?m=1 (20. 12. 2020.)

[30] The Robots are Here. How Do We Work Safely with Them? https://ohsonline.com/articles/2019/11/19/the-robots-are-here-how-do-we-work-safely-with-them.aspx?m=1 (20. 12. 2020.)

[31] *International Organization for Standardization (ISO) Safety requirements for industrial robots – Part 1: Robots.* Geneva, Switzerland: ISO. 2011. (ISO 10218-1: 2011). [Standard].

Furthermore, there are two main categories of worker injuries from working around industrial robots: 1. those due to engineering errors and 2. human errors.

1. Engineering errors include errors in the robot's mechanics (e.g., loose connections across parts, faulty electronics), errors made by the controller (e.g., programming bugs, faulty algorithm). As a consequence, robots might, for example, fail to stop, or a robot arm might achieve high, uncontrolled speed, abrupt motion or acceleration.[32]

2. *Human sources* of injuries such as errors in programming, interfacing peripheral equipment, connecting input/output sensors, can all result in unpredicted movement or action by the robot which can result in personnel injury or equipment breakage. Human errors in judgment result frequently from incorrectly activating the teach pendant or control panel. The greatest human judgment error results from becoming so familiar with the robot's redundant motions that personnel are too trusting in assuming the nature of these motions and place themselves in hazardous positions while programming or performing maintenance within the robot's work zone.[33]

2. 3. Potential solution to avoid hazards

The main issue regarding industrial robot safety is the maintenance of a safe distance between human workers and operating robots through the creation of "guarded areas." Worker entrance into the safeguarded area would require the shutdown of the robot. The shutdown of one robot for safety reasons, in an assembly line of robots, can impair productivity and may be a disincentive to achieving the highest level of safety for the human worker.[34]

More detailed recommendations regarding the design of industrial robotic systems, the training of workers, and their supervision can be found in the NIOSH publication, "Preventing the Injury of Workers by Robots."[35] For the design of industrial robotic systems, the NIOSH recommended that robotic systems include: 1. physical barriers that incorporate gates with electrical interlocks and backup sensors stopping robots when the gate is open; 2. barriers between robotic equipment and any freestanding objects to eliminate pinch points; 3. adequate clearance distances around all moving components of the robot; 4. remote diagnostic equipment; 5. adequate illumination around the robot working area; and 6. clearly visible marks on working surfaces or floors that indicate the zones of maximum robot movement.

Safety training and refresher courses specific to the particular robot in question should be provided to human workers who will be programming, operating, or maintaining robot workers. Supervisors should ensure that workers do not enter the operational area of a robot without first putting the robot on "hold," in a "power down" condition, or at a

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[32] VASIC M, BILLARD A.: *Safety Issues in Human-Robot Interactions.* 2013 IEEE Int. Conf. Robotics Automation (ICRA); Karlsruhe, Germany. May 6–10, 2013. New York, N.Y: IEEE. 2013. pp. 197–204.

[33] U.S. Occupational Safety and Health Administration (OSHA). Chapter 6 – Robotics in the workplace. Available at https://www.osha.gov/Publications/Mach_SafeGuard/chapt6.html.

[34] JIANG BC, GAINER CA.A: *Cause-and-Effect Analysis of Robot Accidents.* J Occ Accidents. 1987:9; pp. 27–45.

[35] *U.S. National Institute for Occupational Safety and Health (NIOSH) Preventing the injury of workers by robots.* U.S. National Institute for Occupational Safety and Health; Dec, 1984. DHHS (NIOSH) Publication Number 85–103.

reduced operating speed mode, and ensure that workers doing automated tasks are closely supervised (e.g., video monitored).

There are several reasons why human workers enter robot worker operating areas such as to set up a job, to re-program the robot, to inspect the robot operational system, or for routine maintenance. The injuries which have occurred to human workers have happened most frequently when corrective maintenance was being done. The NIOSH technical report, "Safe Maintenance Guidelines for Robotic Workstations," describes approaches for preventing injury due to unexpected or unintended robot motion to workers whose job is to correct problems with the normal operation of robotized industrial systems.[36]

One recommended systematic approach to selecting safeguards and setting safety procedures is the Structured Analysis and Design Technique (SADT). This is a general problem-solving tool relying on a box-and-arrow diagramming methodology for organizing and analysing complex problems. In SADT the analysis of any robot worker problem, such as achieving the goal of robot maintenance intervention without human worker injury, is carried out according to a descending, modular, hierarchic, and structured logic. SADT models include both objects (documents, products, information, and data) and activities (performed by people, machines, or programs).[37]

In sum, while industrial-type robots have historically driven workplace safety by isolating employees from high-risk tasks, collaborative technologies diversify robotics' influence on workplace safety through the opposite means, by integrating human and robot labour.[38] Despite improvements in the safety of industrial robots, injuries and fatalities caused by industrial robots still occur.[39]

3. Service robots (professional and personal)

3. 1. Features of service robots

The second robot wave took off at the turn of the 21st century with the introduction of service robots. The main task of service robots is providing services to humans rather than performing the traditional manufacturing tasks in an industrial environment. This has created the need to focus on safety issues arising from the new service robots' intended purposes because this requires (generally) close proximity to humans to perform their tasks, whereas the previous industrial robots have been designed on the basis of

[36] *U.S. National Institute for Occupational Safety and Health (NIOSH) Safe maintenance guidelines for robotic workstations.* U.S. National Institute for Occupational Safety and Health; Mar, 1988. DHHS (NIOSH) Publication. Number 88–108.

[37] DAVID A. MARCA CLEMENT I. MCGOWAN: *Structured Analysis and Design Technique*. (SADT) McGraw-Hill (1987) p. 392.

[38] JACK BURTON: *Rise of the robots, Technology increasingly assuming risks of most dangerous*. taskshttps://www.ohscanada.com/features/rise-of-the-robots/ (14. 12. 2020.)

[39] VLADIMIR MURASHOV, FRANK HEARL AND JOHN HOWARDA: *Working Safely with Robot Workers: Recommendations for the New Workplace.* J Occup Environ Hyg. 2016 Mar; 13(3). pp. 61–71. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4779796/

keeping humans and robots separated while the robots are operating.[40] It was facilitated by the increasing autonomy and sensory capabilities of robots coupled with decreasing cost and size of microprocessor controllers, which led to the development of mobile robots capable of autonomous operation in unfamiliar environments such as disaster zones ("drones"). With the availability of relatively inexpensive service (preliminary cooperation with human) robots capable of working in direct contact with people and also robotic workers operate alongside human workers and symbiotic workers, i.e., human workers equipped with performance-enhancing robotic devices such as robotic exoskeletons and other capacity-enhancing prostheses.

The ISO defines a service robot as one that performs useful tasks for humans or equipment excluding industrial automation applications. Basically there are two types: 1. professional and 2. personal service robots.

1. Professional service robots are further differentiated as a service robot used for commercial tasks, usually operated by a properly trained operator,[41] while personal service robots are used for non-commercial tasks. Similar to industrial robots, professional service robots manipulate and navigate their physical environments. However, unlike industrial robots, professional service robots operate mostly outside industrial settings in unstructured and highly unpredictable environments without people such as disaster areas or with people present such as hospitals.[42]

2. Personal service robots have been classified into three classes: a) mobile servants, b) physical assistant robots, and c) person carriers robot. a) *mobile servant robots*: travelling in buildings while avoiding collisions with objects in their environment to perform pose-to-pose motions or full area coverage, interaction with humans including object exchange, handling of small and medium sized objects for grasping, manipulating, transporting, placing tasks and handling large objects possibly having constraints, e.g., opening a door/window, which may include travelling to extend the workspace. b) *physical assistant robots*: exoskeleton or other strap-on robotic devices for applying cooperative control forces on human limbs designed in order to do the following: (i) to help comfortable walking, (ii) to help in carrying heavy loads, (iii) to reduce loads on parts of the body, (iv) to allow fine manipulation, etc. c) *person carrier robots*: physically transporting a person from one location to another autonomously in various environments (flat 2D surfaces, 3D unstructured areas, etc).[43]

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[40] GURVINDER SINGH VIRK,SEUNGBIN MOON: *Safety for Emerging Service Robots.* Conference Paper January 2012. https://www.researchgate.net/publication/268484216_SAFETY_FOR_EMERGING_SERVICE_ROBOTS/link/5687805608ae1e63f1f6f030/download (14. 12. 2020.)

[41] *International Organization for Standardization (ISO) Robots and robotic devices* – Vocabulary. Geneva, Switzerland: ISO; 2012. (ISO 8373: 2012.); [Standard].

[42] NB: this paper excludes the issue of drones, which might be the subject of a separate study.

[43] GURVINDER SINGH VIRK, SEUNGBIN MOON (2012). https://www.researchgate.net/publication/268484216_Safety_for_Emerging_Service_Robots/link/5687805608ae1e63f1f6f030/download (14. 12. 2020.)

3. 2. Hazards of service robots

One of the key differences between traditional industrial robots and the service robots is the close robot-human interactions which must be included to allow for the provision of the needed assistance to persons. It is because of this that the safety standard for personal care robots is being formulated so that close robot-human interactions, as well as robot-human contacts, are allowed while the robot is operating. It is clear that, as with industrial robots, the new personal service robots will still be regarded as "machines", and as such will be regulated in Europe under the Machinery Directive,[44] which requires all machines to be "safe"; how such close robot-human interactions will be allowed while maintaining human safety is a major challenge.

According to the DIS (Draft International Standard),[45] some specific hazards have been indentified by giving particular consideration to: a) unexpected travel surface conditions in the case of mobile robots; b) uncertainty of objects to be handled in the case of mobile servant robots; c) conformity to the human anatomy and its variability in the case of physical assistant robots; d) normal but unexpected movement of the personal care robot; e) unexpected movement of humans, animals and other objects and f) unintended movement of the personal care robot.

In this way, clauses have been formulated to reduce risk due to the following reasons: a) hazards related to charging battery, b) energy storage and supply, c) hazards due to robot shape, emissions, electromagnetic interference, stress, posture and usage, d) hazards due to robot motion, e) insufficient durability, f) incorrect autonomous actions and g) contact with moving components. Each hazardous area has been looked at via the three step risk reduction process to ensure an acceptable level of safety is achieved.[46]

3. 3. Potential solution to avoid hazards of service robots

A) Professional service robots. Physical proximity between professional service robots and human workers are much more common than between industrial robots and workers since they often share the same workspace. Therefore, worker isolation from the professional service robot is no longer an option as the main safety approach. Furthermore, more complex environments in which professional service robots must operate dictate much higher degree of autonomy and mobility afforded to professional service robots. This autonomous and mobile behavior can result in dangerous situations for workers. Therefore robot designers must consider physical, social and ethical implications of such autonomy.[47,48]

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44 EU Directive 2006/42/EC – New machinery directive.

45 National Information Standards Organization https://www.niso.org/international-standards (14. 12. 2020.)

46 GURVINDER SINGH VIRK, SEUNGBIN MOON (2012). https://www.researchgate.net/publication/268484216_Safety_for_Emerging_Service_Robots/link/5687805608ae1e63f1f6f030/download (14. 12. 2020.)

47 ROGERS E.: *Introduction to Human-Computer Interaction (HCI).* RAS/IFRR Summer School on "Human-Robot Interaction". Volterra, Italy. July 19–23, 2004. Available at http://www.cas.kth.se/ras-ifrr-ss04/material/rogers-hci-intro.pdf. (17. 12. 2020.)

48 REEVES N, NASS C.: *The Media Equation: How People Treat Computers.* Television and New Media Like Real People and Places. Cambridge. Mass: Cambridge University Press; 1996. pp. 54–67.

Professional service robots such as tele-operated robots commonly interact unidirectionally with their human operators. In this mode of interaction, the operator controls the robot which sends back information about its environment and its task.[49] For such professional service robots their interaction with workers is very limited and the inactivation of the robot for servicing can be used to minimize risks during maintenance.

Most professional and personal service robots operating autonomously are equipped with collision detection and avoidance systems,[50] which reduce the possibility of a harmful physical contact during unplanned encounters with human workers. Other approaches to minimizing the risks of service robots are reducing their weight, size and operating speeds and forces. However, these approaches cannot completely eliminate collisions, and other methods for improving safety are necessary.[51] In addition to engineering and human sources of injuries, adverse environmental factors such as extreme temperature, poor sensing in difficult weather or lightning conditions can lead to incorrect response by service robots and can be a source of injury.[52]

B) Personal service robots. It is clear that the different personal care robot applications will have different safety requirements, e.g., speeds of operation, maximum forces which can be applied to various parts of the body, etc., although it is too early to state these at the current time. It is also clear that such safety requirements will also need to include more complete safety-related numeric information for different categories of people (children, elderly persons, pregnant women, etc.), which will need major international cooperation to determine if it is to be acceptable normative design data for personal care robots.

Safety-related control systems for personal care robots have also been considered, especially the stopping functions since these need to comply with more complex safety requirements than industrial robots so that hazards are not caused by the stopping functions themselves. Another interesting clause that has been developed considers different operational modes of the personal care robot (manual, autonomous and some mixture), and their implications on safety.[53]

In sum, despite the proliferation of safety concerns involving service robot workers in the same workplace as human workers, no international standards have yet been developed to address human worker safety in maintaining or operating professional and personal service robots.[54]

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49 THRUN S.:*Toward a Framework for Human-Robot Interactions.* Human-Computer Interaction. 2004;19(1–2):9–24.

50 SIEGWART R, NOURBAKHSH IR, SCARAMUZZA D.: *Introduction to Autonomous Mobile robots. 2.* Cambridge, MA: The MIT Press; 2011. p. 472.

51 ZINN M, KHATIB O, ROTH B, SALISBURY JK.: *Playing it safe. IEEE Robotics & Automation Magazine.* 2004, Jun. 12–21.

52 VASIC M, BILLARD: *A. Safety Issues in Human-Robot Interactions.* 2013 IEEE Int. Conf. Robotics Automation (ICRA); Karlsruhe, Germany. May 6–10, 2013. New York, N.Y: IEEE. 2013. pp. 197–204.

53 GURVINDER SINGH VIRK, SEUNGBIN MOON (2012). https://www.researchgate.net/publication/268484216_Safety_for_Emerging_Service_Robots/link/5687805608ae1e63f1f6f030/download (14. 12. 2020.)

54 VLADIMIR MURASHOV, FRANK HEARL AND JOHN HOWARDA: *Working Safely with Robot Workers: Recommendations for the New Workplace.* J Occup Environ Hyg. 2016, Mar. 13(3): pp. 61–71. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4779796/ (17. 12. 2020.)

4. Collaborative robots

4. 1. Features of collaborative robots (cobots)

The ISO has defined a collaborative robot as "*a robot designed for direct interaction with a human*".[55] Depending on the application area, collaborative robots could be any of the two types of robots described previously, industrial and service (professional, or personal) robot.[56]

Collaborative and smart robots, so-called cobots, will become a familiar presence in the workplace as highly developed sensors make it possible for people and robots to work together.[57] Most cobots are equipped with self-optimising algorithms, allowing them to learn from their human „colleagues". With the increasing use of AI, robots will be able to carry out not only physical tasks but also increasingly cognitive tasks. Robots are already able to perform a variety of cognitive tasks autonomously, such as supporting legal casework or medical diagnoses, and will also become commonplace in customer-facing jobs. This means that the use of smart robots is expected in many different sectors and settings, such as in the care sector, hospitality, agriculture, manufacturing, industry, transport and services.[58]

However, the growing proportion of mobile, smart robots in the workplace may increase the risk of accidents, as injury could occur from direct contact with robots or from the equipment they use. As smart robots are constantly learning, although efforts are made to factor in all possible scenarios in their design, they may behave in unanticipated ways. Workers having to keep up with the pace and level of work of a smart cobot may be placed under a high level of performance pressure. This may have negative impacts on workers' safety and health, particularly mental health. Increased working with robots will also significantly reduce contact with human peers and social support, which is also detrimental to workers' mental health.[59]

There are many categorisations of cobots. Here we distinguish between their two basic types: 1. classical collaborative robots and 2. managerial cobots.

1. Classical collaborative robots strive to combine the dexterity, flexibility and problem-solving skills of human workers with the strength, endurance and precision of mechanical robots. In 2007, Pilz GmbH & Company launched a multi-camera computer

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55 *International Organization for Standardization (ISO) Robots and robotic devices* – Vocabulary. Geneva, Switzerland: ISO; 2012. (ISO 8373: 2012).

56 For example, the ISO Draft Technical Specification (DTS) 15066 "Safety requirements for industrial robots – Collaborative operation" defines industrial collaborative robots as operating within a defined collaborative workspace, where the collaborative workspace is defined as a workspace within a safeguarded space where the robot and a human worker can perform tasks simultaneously during production operation.

57 For example, Amazon already has 100,000 AI-augmented cobots supporting its distribution activities.

58 Digitalisation and occupational safety and health (OSH) An EU-OSHA research programme European Agency for Safety and Health at Work, 2019 https://osha.europa.eu/en/emerging-risks/developments-ict-and-digitalisation-work (19. 12. 2020.)

59 Digitalisation and occupational safety and health (OSH) An EU-OSHA research programme European Agency for Safety and Health at Work, 2019. https://osha.europa.eu/en/emerging-risks/ developments-ict-and-digitalisation-work (19. 12. 2020.)

system that monitors the area surrounding robots and adjusts their behavior accordingly. The system, called SafetyEYE, allows a robot to perform tasks without sectioning off the entire area from human workers. Thus, this system allows robots to perform their tasks collaboratively with human workers in the same workspace. A robot equipped with such a system can move around freely, but can slow its movements if a worker approaches or, if the robot gets too close to the human worker, stop altogether without disrupting the activities of the entire workspace.[60]

2. *Managerial cobots*. A new field of collaborative robotics is managerial robotics. Instead of being relegated to mundane, repetitive, and precise job tasks, researchers are increasingly wondering if robots with their perfect memories, internet connectivity and high-powered computers for data analysis can also keep "a perfect record of project progress, provide real-time scheduling and decision support, and hold perfect recall (and remind others) of complex policies and procedures, all while communicating with people in a natural, social way."[61]The correlations between autonomy and sociality for collaborative robots could lead to robots succeeding in particular management roles.[62] Their development is still in an early stage.

4. 2. Hazards of collaborative robots

As more robots, especially those who are mobile, come into direct contact with workers, concerns about the safety profile of the worker-robot interaction space has increased. Collaborative robots, which have one or more mechanical arms, provide workers with a (literal) extra set of hands.

The design work environment (wider than workplace) of collaborative robots should ensure that the motions of the robot are predictable to humans and do not cause any unpleasant reactions like fear, shock, or surprise. The ability to read human emotions is a capability which would not only improve the functionality of collaborative robots, but also improve their safety profile. Several methods are being investigated such as behavior pattern recognition, on-skin sensors or other similar methods that would enhance the ability of a robot to "read" human emotion.[63]

Cognitive interactions between a robot and a human worker can lead to mental health risksfor the human worker. As the definition implies, collaborative robots interact bi-directionally with their human collaborators. In this new mode of interaction, the information exchange between human workers and robots flows in both directions and is on an equal level of importance with regard to work processes for both workers – human and robot.

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[60] Economist. Working with Robots: Our Friends Electric; The Economist. 2013 Sep. 7. Available at http://www.economist.com/news/technology-quarterly/21584455-robotics-new-breed-robots-being-designed-collaborate-humans. (17. 12. 2020.)

[61] YOUNG J, CORMIER D.: *Can robots be managers, too?* Harvard Business Review. 2014. Apr. 2.

[62] GLADDEN ME.: *Managerial robotics: a model of sociality and autonomy for robots managing human beings and machine.* Int J Contemp Management. 2014. 13(3): pp. 67–76.

[63] ROH E, HWANG BU, KIM D, KIM BY, LEE NE.: *Stretchable, Transparent, Ultrasensitive, and Patchable Strain Sensor for Human-Machine Interfaces Comprising a Nanohybrid of Carbon Nanotubes and Conductive Elastomers.* ACS Nano. 2015. 9(6): pp. 6252–6261.

As workplace risks are addressed proactively,[64] international safety standards for collaborative robots are being developed in parallel with their rapid introduction into the workplace. Specifically, while the published ISO 10218 provides some specific guidelines for collaborative robots, ISO TC 184 SC 2 is also developing the 15066 standard on collaborative operation as a Technical Specification (TS), which is one level below an International Standard (IS). This is a reflection of the nascent nature of collaborative robots in the workplace, as more application knowledge is needed before publishing this standard as an IS. Some of the issues being standardized in this TS include guidance on the maximum force with which a robot worker may strike a human worker ("power and force limiting"), and guidance on "speed and separation monitoring," which allows for correlation in real-time of increasing danger in robot actions with decreasing distance between people and the robot.[65] The latter issue was not covered in another standard developed by ISO, TC 184 SC 2 and published in 2014, ISO 13482 "Robots and robotic devices – Safety requirements for personal care robots."[66]

4. 3. Potential solution to avoid hazards

Since robots are working alongside human workers, isolation as a safety measure is no longer an option, and other safety approaches must be developed and implemented (e.g., proximity sensors, appropriate materials, software tools, and similar controls).[67] Workspace sharing without any resultant harm to human workers (and to the robot itself) has been the goal of research in the domain of physical and cognitive human robot interactions. The research on the physical safety of human and robot workers in the collaborative space falls into three categories:[68] 1. interaction safety assessment and the quantitative description of the human-robot safety concept; 2. interaction safety through design, such as lightweight manipulators, passive compliant systems, safe actuators, and passive robotic systems; and 3. interaction safety through planning and control, such as navigation and collision avoidance in an environment shared by human and robot through proactive safety systems and control of the stiffness/pliability to reduce the impact force during collisions.[69]

Another example of novel approaches to improve the emotional safety profile of collaborative robots is the ability of certain models of collaborative robots "to act like a human worker." For example, the robot could have an "eye" looking in the direction of the human worker and be able to react to the human worker's facial expressions indicating

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[64] MURASHOV V, HOWARD J.: *Essential features for proactive risk management. Nature Nanotech.* 2009;4:467–470.

[65] KUHN S, GECKS T, HENRICH D.: *Velocity control for safe robot guidance based on fused vision and force/torque data.* IEEE Int. Conf. on Multisensor Fusion and Intelligent Systems; Heidelberg, Germany. September 2006; New York, N.Y: IEEE; 2006. pp. 485–492.

[66] *International Organization for Standardization (ISO) Robots and robotic devices* – Safety requirements for personal care robots. Geneva, Switzerland: ISO; 2014. (ISO 13482:2014). [Standard]

[67] VASIC M, BILLARD A.: *Safety Issues in Human-Robot Interactions.* 2013 IEEE Int. Conf. Robotics Automation (ICRA); Karlsruhe, Germany. May 6–10, 2013; New York, N.Y: IEEE; 2013. pp. 197–204.

[68] PERVEZ A, RYU J.: *Safe physical human robot interaction – past, present and future.* J Mech Sci Tech. 2008. 22: pp. 469–483.

[69] RIBEIRO L, BARATA J, BARREIRA P.: *Is ambient intelligence a truly human-centric paradigm in industry? Current research and application scenario.* Ent Work Inn Studies. 2009. 5: pp. 25–53.

danger, distress or fear. Though such capabilities also bring new safety issues with them, e.g., human workers might unintentionally attribute non-existent "reasoning" or "recognition" capabilities to robots.[70]

Another practical solution is the self-expression robot, which says loudly and continuously what it will be doing. It means that coworkers can be aware of the action of the robot-machine.[71]

Humanoid robots, by virtue of their appearance and behavior, appeal to people differently than other robots.[72] A 2004 study of cognitive interactions suggests that humanoid robots may be appropriate for settings in which people have to delegate responsibility to robots or when the task is too demanding for a human worker to do.[73] Machine-like robots, as opposed to humanoid robots, however, may be more appropriate when robots are expected to be unreliable, are less well-equipped for the task than people are, or in other situations in which personal responsibility should be emphasized.

In sum, what collaborative robotics brings to workplace safety is a technological transition – a shift that transforms the workplace robot from a proxy into a peer. Emerging from this new collaborative relationship between robots and workers is not only the possibility for safer workplaces, but also safer (and smarter) workers.[74]

III. Summary

The research question of this study was whether the rapid development and spread of AI-driven robots will abolish OSH or not. All things considered, it might be predicted that OSH will not disappeardue to the AI-driven robotsin the forthcoming couple of decades ahead. Even if robots and AI were to take over the world, driving humans to extinction, they would still need a piece of software to detect and investigate when something got ill or injured whilst doing its job.[75]

Digital technology itself is neither good nor bad. Maintaining a balance between the challenges and the opportunities presented by digitalisation depends on the proper application of technologies and how they are managed and regulated in the context of social, political and economic trends, such as workforce demographics, the state of the economy, social attitudes, governance and skills. Examples of OSH strategies that could help to mitigatethe OSH, challenges presented by digitalisation include: a) the development of an ethicalframework for digitalisation, codes of conduct and proper governance; b) a strong 'prevention through design' approach that integrates human

[70] Nourbakhsh Ir.: *The Coming Robot Dystopia.* Foreign Affairs. 2015. Jul–Aug. 23–28. Available at https://www.foreignaffairs.com/articles/2015-06-16/coming-robot-dystopia. (16. 12. 2020.)

[71] Vladimir Murashov, Frank Hearl and John Howarda (2017): *Working Safely with Robot Workers: Recommendations for the New Workplace.* J Occup Environ Hyg. 2016. Mar. 13 (3): pp. 61–71. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4779796/

[72] Fong T, Nourbakhsh I, Dautenhahn K.: *A survey of socially interactive robots.* Rob Auton Sys. 2003. 42 (3-4): pp. 143–166.

[73] Hinds Pj, Roberts Tl, Jones H.: *Whose Job Is It Anyway? A Study of Human-Robot Interaction in a Collaborative Task.* Human-Computer Interaction. 2004. 19: pp. 151–181.

[74] https://www.ohscanada.com/features/rise-of-the-robots/ (19. 12. 2020.)

[75] https://www.pro-sapien.com/blog/will-health-and-safety-ever-die/ (14. 12. 2020.)

factors and worker-centred design; c) the involvement of workers in the design and implementation of any digitalisation strategies; d) collaboration between academics, industry, social partners and governments on research and innovation in digital technologies to properly take account of the human aspects; e) a regulatory framework to clarify OSH liabilities and responsibilities in relation to new systems and new ways of working; f) an adapted education system and training for workers and g) the provision of effective OSH services to all workers of the digital world of work.[76]

The on-going introduction of advanced industrial, professional service and collaborative robots working alongside of human workers requires occupational safety and health professionals to take a proactive approach to the assessment and management of the risk profile of occupational robotics. The elements of a proactive approach include: 1. qualitative risk assessment; 2. the ability to adapt strategies and refine requirements; 3. an appropriate level of precaution; 4. global applicability; 5. the ability to elicit voluntary cooperation by companies; and 6. stakeholder involvement.[77]

Furthermore, to ensure that human workers are protected, the following measures are recommended for occupational robotics: 1. occupational safety and health professionals should be directly involved in the development of international standards aimed at ensuring safety of workplaces with human and robot workers; 2. workplace safety standards for maintenance, operation, and interaction with human workers, of professional, personal service and collaborative (including managerial) robots should be developed, and 3. proactive approaches for establishing risk profiles of robotic workplaces should be developed. These measures, and others discussed earlier in this article, should be examined now before millions of potentially unsafe robots enter the 21st century workplace.

HAJDÚ JÓZSEF

A MUNKAHELYI EGÉSZSÉG ÉS BIZTONSÁG ÚJ KIHÍVÁSAI EGY ROBOTOKKAL VEGYES MUNKAKÖRNYEZETBEN

(Összefoglalás)

Abban már nincs semmi újdonság, hogy a modern munkahelyeken robotokat használnak és ezek a munkavállalókkal együtt végzik a munkát. Míg azonban ezeket a gépeket eleinte csak egyszerű feladatok ellátására építették, mára a mesterséges intelligencia már oda jutott, hogy a robotok bizonyos értelemben „gondolkodni” is tudnak. Ebben a cikkben

[76] Digitalisation and occupational safety and health (OSH) An EU-OSHA research programme European Agency for Safety and Health at Work, 2019 https://osha.europa.eu/en/emerging-risks/ developments-ict-and-digitalisation-work (19. 12. 2020.)

[77] MURASHOV V, HOWARD J.: *Essential features for proactive risk management.* Nature Nanotech. 2009;4:467–470. and VLADIMIR MURASHOV, FRANK HEARL, and JOHN HOWARD: *Working Safely with Robot Workers: Recommendations for the New Workplace.* J Occup Environ Hyg. 2016. Mar. 13(3): D61–D71.

ismertetjük a robotok és intelligens gépek jelenlegi használatát, felvázoljuk a robotika széles körű alkalmazásának jövőképét és azt, hogy mindez milyen következményekkel jár a munkahelyi biztonságra és egészségvédelemre. Szisztematikusan mutatjuk be a robotok három fő generációját (ipari robotok, szolgáltató robotok és kollaboratív robotok), a velük kapcsolatos specifikus munkahelyi kockázatokat és a jelenleg ismert munkabiztonsági standardokat. A történelmi tapasztalatok azt mutatják, hogy az új technológiák az új előnyök mellett új költségekkel, lehetőségekkel és veszélyekkel is járnak. A robotok új kihívásokat jelentenek a munkavédelem és a munkaügyi egészség modernizálása számára. Utalás történik arra, hogy a világ számos helyén folynak kísérletek a robotok és az emberek közötti munkavégzés biztonsági standardjainak a kidolgozására. Válaszolva a bevezetésben feltett kérdésre, kijelenthető, hogy a robotok alkalmazása – középtávon biztosan – nemhogy megszüntetné a munkavédelem és a munkaegészségügy iránti igényt, sőt egyre újabb megoldandó feladatok elé állítja.