

IMPROVING WORKPLACE SAFETY USING ADVANCED INDUSTRY 4.0 TECHNOLOGIES

Marija Savković¹, Marica Dašić², Marko Đapan¹, Arso Vukićević¹, Ivan Mačužić¹,
Miladin Stefanović¹

¹ University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, Kragujevac, Serbia,
e-mail: marija.savkovic@kg.ac.rs

² AMM Manufacturing d.o.o., Aleja Milanović bb, 34325 Kragujevac

Abstract: Taking into account the fact that safety and health at work is one of the main components of financial success in all contemporary industrial systems that operate on lean principles, special attention is paid to the continuous improvement of safety and health of workers. A comprehensive transformation of industrial production and complete automation and digitalization of production processes is supported by Industry 4.0. Industry 4.0 is characterized by intelligent networking of physical objects over the Internet, interactions, communications and data exchange between all physical entities and the application of modern advanced technologies (collaborative robots, artificial intelligence, nanotechnology, virtual reality, augmented reality, Internet of Things, big data, cloud computing, 3D printers, drones and autonomous vehicles). It creates significant changes in production, work organization, and the way how workers perform their activities. Moreover, Industry 4.0 has a significant impact on workplace safety.

The paper presents the connection between workplace safety and Industry 4.0 through the analysis of the most important research papers in this field. Also, the paper presents the most significant modern advanced digital technologies of Industry 4.0 that have applications in the field of safety and health of workers (sensors and wearable technologies, exoskeletons etc.). Special attention in the paper is paid to emphasizing the positive effects and benefits of the application of these modern advanced technologies. The main goal of the application of these modern innovative technologies is to improve workplace safety through the prevention of injuries at work, occupational diseases and deaths and to improve the general health and well-being of workers. The paper is a part of research activities in the field of research of possibilities for improving the effectiveness of production processes by applying modern advanced technologies of Industry 4.0.

Keywords: *Advanced technologies, Collaborative robots, Exoskeleton, Industry 4.0, Workplace safety, Safety 4.0*

INTRODUCTION

Taking into account the fact that improving safety and health at work is one of the main indicators of an organization's financial success, contemporary industrial systems operating on lean principles strive to achieve the highest level of occupational safety and health at work (OSH). Minimizing injuries at work and achieve such work conditions in which workers would have a sense of satisfaction directly contribute to increasing productivity, reducing costs and increasing product quality. Injuries at work and occupational diseases lead to a reduction or in certain situations loss of working ability and reduction of life activities and often cause absence from work, which further causes downtime in production, increased costs and expenses.

Industry 4.0 represents a new production paradigm that causes changes in production, work organization, the way on work activities are performed, and this is increasingly reflected in the safety and health of workers. Real-time networking and information exchange, big data, collaborative cooperation of operators and robots, remote detection, real-time process monitoring and control, autonomous digital technologies are becoming the basic characteristics of modern industrial systems.

The research paper points out the connection between workplace safety and Industry 4.0 entitle as Safety 4.0. The main purpose of scientific research is to through critical analysis and synthesis of conclusions from scientific research papers in the OSH field and Industry 4.0 answer questions about how Industry 4.0 affects the safety and health of workers and how the application of innovative technologies Industry 4.0 can lead to improved safety and health of workers.

Automated systems, collaborative robots, exoskeletons and smart machines, smart personal protective equipment, autonomous vehicles have a positive impact on occupational safety and health. It improves general health and welfare of workers since these entities replace workers in performing daily complex and precise monotonous activities and enable workers to perform these tasks in a more efficient,

productive, flexible and safer way and enable monitoring of parameters in the work environment that affect the process, [1], [2], [3], [4].

Industrialization has undergone great transformations since its beginnings in the 18th century, and all these changes have affected the safety and health of workers. During the first industrial revolution, child labor was a common occurrence and the work environment was extremely dangerous. Also, in this period, the application of OSH laws was very limited, [5]. The increase in the number of workers during the second revolution led to small investments in companies in programs for improve safety and health at work. OSH laws have begun to be applied in a many countries. A turning point in the adoption and implementation of laws in the field of safety and health at work was the Act passed in Great Britain in 1974, which required employers to take certain measures to increase the safety and health of workers, [5], [6]. During the third industrial revolution, a new occupational safety and health strategy called the OSH 3.0 strategy was created. The novelties in this strategy are related to the implementation of risk assessment in the workplace and the introduction of preventive measures to protect workers, reduce injuries at work and occupational diseases, improve workplace conditions and promote "total" health [5], [6]. Special emphasis in this period was placed on increasing the safety of machines. The new occupational safety and health strategy related to the fourth industrial revolution aims to promote, improve and enhance OSH in line with the specifics of Industry 4.0. This includes the use of new technologies (mobile devices, wearable technologies and sensors) and the application of new tools to predict the occurrence of OSH risks. The paper is structured as follows: After the introductory part and defining the concept of Industry 4.0, the paper presents the most significant modern advanced digital technologies of Industry 4.0 that have applications in the field of occupational safety and health (collaborative robots, sensors and wearable technologies, exoskeletons, augmented reality) and this paper points out the positive effects and benefits of applying these modern advanced technologies. Concluding remarks are made in the conclusion.

MATERIAL AND METHODS

Industry 4.0 is a very important area that is attracting increasing attention from researchers and experts in many fields. This can be concluded on the basis of a large number of scientific research papers written in this field. A detailed review of the literature concludes that a small number of scientific research papers have been written that indicate the link between Industry 4.0 and occupational safety and health.

McKinsey defines Industry 4.0 as the next phase in the digitalization of the manufacturing sector, characterized by a sharp increase in data and an increasing role for analytics and business reporting, comprehensive networking of facilities, and a collaborative form of cooperation between workers and collaborative robots. Industry 4.0 is based on connecting the real and virtual world, connecting modern innovative technologies and traditional production processes. Everything within the smart company (products, semi-finished products, machines, equipment, tools, workers and collaborative robots, etc.) and around the company (suppliers, distributors, customers, etc.) is digitally networked. All entities communicate with each other and exchange data in real time. Connecting entities via the Internet to the network enables the exchange of data and facilitates their control and monitoring. All objects within the cyber physical system have the ability to make decentralized decisions, take the initiative and independently control.

Industry 4.0 implies full automation and digitalization of production through the application of modern digital technologies, and transformation of production in such a way that isolated production cells are interconnected and integrated into a smart system, [7], [6], [8]. It changes traditional relationships externally between suppliers, manufacturers and customers and internally between workers and collaborative robots, machines and components, [9]. Highly automated smart companies are characterized by virtualization, interoperability, modularity, production process optimization, decentralized decision making, service orientation through creating new value and providing innovative customer service and independent process management. The key features of Industry 4.0 are horizontal integration, vertical integration and system-wide integration, and digitization of information during the product life cycle (end-to-end engineering). Of particular importance in smart enterprises are artificial intelligence, nanotechnology, biotechnology, the Internet of Things, big data,

cloud computing, 3D printers, collaborative robots and autonomous vehicles, [10]. The primary goal of applying these technologies is to improve operational performance, efficiency and productivity.

Industry 4.0 technologies that have an impact on workplace safety

Collaborative robots are a special type of robot that cooperates collaboratively with workers in a shared workspace and assists them in performing daily activities to perform activities more efficiently, flexibly, and safely. Increased interaction and collaborative cooperation between workers and robots is the foundation of Industry 4.0, [11]. Collaborative robots are embedded with sensors that allow them to perceive the environment, react to dynamic conditions, and recognize objects in their vicinity, [11], [3]. These autonomous robots are very intelligent, perform activities faster and more accurately than robots, and take up less space, [12].

Exoskeletons are mechanical devices that workers carry and that have the role of supporting workers in performing difficult, manual and physically demanding work tasks that cannot be automated (such as lifting loads and handling loads).

Knowledge-based smart machines equipped with sensors and cameras have the ability to self-monitor and self-control and independently predict errors and dysfunctions that could occur during their operation, [13]. Rapid advances in robotics, artificial intelligence, computer vision, and edge computing capabilities are resulting in smart machines that can potentially think, see and move more deftly than workers. These autonomous machines are self-maintained by sending information to diagnostic centers to determine whether additional interventions related to the maintenance of these machines are necessary, [6], [14]. In this way, it is possible to determine in real time on which machine the failure occurred and to redirect the products to another machine.

Mobile smart wearable digital technologies (eg smart bracelets, smart glasses) and mobile miniature devices built into smart personal protective equipment (helmets, hats, protective suit or hand straps) enable continuous monitoring of workers' activities and health parameters and working environment conditions in real time [15].

Augmented reality is a combination of the physical and digital worlds, in which digital elements (image, text, animation or sound) complement the physical world. Augmented reality allows real-world information to be accompanied by computer-generated data (images, text) that are combined into one unit displayed on computer screens or mobile phones, or computer-generated images are projected onto real objects in real time.

The Internet of Things (IoT) is a network of physical objects, with built-in sensors and actuators, that are connected via the Internet. IoT technologies allow plant facilities to exchange data with each other. These technologies enable the collection of data on the plant and the processes, and based on the processing of this data in the cloud and the processing results, production management can be corrected.

Another characteristic of smart companies is the rapid growth of the amount and variety of unstructured data that come from different sources (smartphones, tablets, sensors built into various devices, machines, tools, plants) and must be collected, processed and analyzed in real time. Big data represents data whose size exceeds the capabilities of traditional databases and software to collect, process, analyze, and store data.

The continuous need to process, analyze and store large amounts of data has led to the increasing use of cloud computing. Cloud computing is the outsourcing of IT infrastructure (hardware and software) using the Internet and its use as needed. Cloud computing enables the use of various IT services on physically remote servers with the help of network infrastructure and appropriate Internet protocols. Every machine, device and component in a smart enterprise generates data stored in the cloud, then this large data collected within the enterprise and value chain is processed so that real-time performance can be monitored and analyzed, compared with historical data and institutions problems that may arise, [16].

Virtual reality represents the use of information technology for the exact and realistic representation of environment scenarios such as work situations and their properties. Virtual reality embeds the workers in the virtual world and permits interaction with this environment in real time.

Artificial intelligence is the branch of computer science which deals with the study and design of intelligent agents that perceives environment, speech recognize, learn, plan and problem solve.

Artificial intelligence represents the simulation of human intelligence processes by machines, especially computer systems.

Autonomous vehicles represent a new form of self-driving vehicles that can move independently and can operate independently with video camera, radar sensors and laser rangefinders on the basis of which he can "see" others objects in plant. Autonomous vehicles possess the capabilities to recognize and maneuver around obstacles. These smart cars perceive environment using technologies such as radar, GPS, artificial intelligence and machine vision. Advanced control systems interpret the collected sensors information to identify appropriate navigation paths, as well as obstacles and relevant signaling.

RESULTS AND DISCUSSION

Positive effect of advanced industry 4.0 technologies application on occupational health and safety

Collaborative robots, exoskeletons, artificial intelligence, virtual reality, augmented reality, the Internet of Things, big data, cloud computing and autonomous vehicles contribute to improving the safety and health of workers.

Collaborative robots contribute to the improvement of the health of workers by replacing workers in complex, dangerous and physically demanding activities and facilitate the performance of precise, monotonous, repetitive activities (such as assembly work). These modern autonomous robots are characterized by less complexity and easy control. Unlike conventional robots that operate on the principle of pre-programmed commands, collaborative robots have built-in sensors that allow them to recognize and analyze workers' intentions and adapt their activities to workers' abilities. In this way, stress, burnout and annexation in workers are reduced and their health condition is improved. Also, collaborative robots have the ability to self-control by reducing or increasing speed depending on the proximity of the worker. Collaborative robots are safe to work with workers and do not have to be fenced like classic robots. They are programmed to stop work when the worker enters in the shared workspace and continue to work when the workspace is vacated, [17]. Also, if a person enters in the zone of action of collaborative robots, it can change activities, reduce the speed of work and thus not endanger the occupational safety of workers.

Exoskeletons have the role of enhancing the physical abilities of workers (eg strength and endurance), reducing the compression of force on the lower back, shoulders, elbows and joints and thus protecting workers from injuries that may occur on these parts of the body. The use of exoskeletons reduces fatigue and physical exertion and improves the general health of workers. They provide support to the body of the worker during positioning or use of tools, handling of objects etc. Active exoskeletons use actuators to support the movement and activities of workers who perform fatigue activities (pushing, lifting, pulling, etc.) for an extended period of time in an incorrect position, giving them extra strength and increasing their performance, [18]. The active exoskeleton for the upper body in Fiat in Italy was used to provide support to the hands of the workers so that the workers could lift the load without any difficulties. In this way, the load on the joints and muscles is reduced and the health condition of the workers is improved. The passive exoskeleton for the lower part of the body has the role of being set as a "chair" and is applied when workers often change positions or stand for a long period of time. The application of this exoskeleton reduces the load on the legs and facilitates the adoption of correct positions on the one hand, while maintaining flexibility and mobility on the other hand, [17].

Smart exoskeletons are a special type of exoskeleton that incorporates sensors that have the role of monitoring the health parameters of workers in real time and indicate non-ergonomic movements and body positions and in that way improve the health of workers. The benefits of the application are reflected in the reduction of muscle fatigue, avoidance of tension, stretching and bending, and reduction of injuries to the operator.

In October 2018, Hyundai Motor Group at the North American plant Hyundai-KIA began testing the Hyundai Vest Exoskeleton (H-VEX), (which aimed to reduce pressure on workers' necks and backs) and the Hyundai Chairless Exoskeleton (H-CEX) which is set up as a "chair" and is used by workers who have to stand for a longer period of time during the performance of activities. After the

application of these exoskeletons, injuries at work and occupational diseases were reduced and the efficiency and productivity of workers was increased.

The use of exoskeletons also contributes to improving the health of workers and reducing injuries of workers who perform repetitive activities up to 8 hours a day continuously in an incorrect position (eg with arms raised above the head) and reduce pain in the neck, shoulders, back (most common in these workers).

Smart machines have the ability to perform advanced analysis and prediction of potential hazards that may occur and the ability to manage unexpected situations that may occur during operations, thus preventing accidents and injuries to workers, [16], [6]. Some smart machines can accurately interpret the emotions and intentions of workers and in this way increase the safety and health of workers.

Mobile smart wearable digital technologies identifies and monitors hazardous situations that can cause accidents [19]. In this way, the safety and health of workers is ensured and improved. The benefits of applying these new technologies are reflected in real-time risk assessment and decision-making on the preventive and corrective measures (taking into account his health condition) to eliminate accidents and reduce injuries at work, [20].

The sensors monitor the movement of the worker, the location of the worker, the number of steps the worker has taken, the activities he performs, the position he occupies etc. Monitoring the basic health parameters of workers (heart rate, pulse, temperature, stress level, fatigue, concentration) can indicate the physical and cognitive load of the operator, anti-ergonomic movements and body positions, reduces worker stress, reduces cognitive and physical load and avoids work injuries.

Palazon et al. suggest that innovative technologies play a significant role in improving working environment conditions, [4]. These innovative digital devices enable workers to remain safe in environments such as with high temperatures, toxic gases, harmful chemicals and high noise levels by indicating abnormalities that can adversely affect on OSH, [21].

By applying innovative technologies, it is possible to determine whether OSH procedures and rules are followed, to identify which workers are particularly at risk, which workers should attend additional training in the field of safety and health at work in order to perform activities in a safer way. Moreover, training instructors in this way can adapt the training in the OSH field to each worker individually in accordance with his situation.

By connecting sensors to smart technologies (accelerometer sensor, gyroscope sensor, magnetometer, dust sensor, smoke sensor, gas sensor etc.), workers receive warnings about potential exposure to hazards and harms, and allow the injured worker to seek help if needed, [22], [2], [23].

Augmented reality finds great application during employee training by increasing operator flexibility, shortening the time required to learn a new task and reducing the number of mistakes made by the worker, which further improves worker safety and health, [5].

Virtual reality finds application in risk assessment of workplaces and work equipment. Also, virtual reality enables more efficient implementation of employee training. The dangers and risky situations that may arise can be practically presented by applying virtual reality. Martinetti et al. tested the application of virtual reality for the training of vehicle maintenance technicians and pointed out the benefits of applying this technology in the field of OSH, [24].

According to Heinrich's safety pyramid every accident and serious accident is preceded by a large number of omissions, uncertain actions and other events. Therefore, the most effective way to prevent accidents and incidents is to collect data. Mattsson et al. believe that the collection, integration, and analysis of big data from workplaces in intelligent work environments has a positive impact on worker safety and health through improved performance, stress reduction, and accident prevention, [2]. The collected data indicate the possibility of accidents and harmfulness in the workplace. In this way, it is possible to eliminate and control hazards before an accident happens. Combining data collected from sensors in the previous period with real-time data facilitates decision-making and it has a positive impact on worker safety.

Artificial intelligence plays an important role in improving OSH and wellbeing of workers. Artificial intelligence-based digital technologies enable workers to be tracked and directed based on the collection of large amounts of data in real time via mobile devices, control devices worn on clothing, or embedded in personal protective equipment, or the workers body. The application of artificial intelligence methods enables timely decision-making and risks and dangers are recognized and prevented, [25].

Autonomous vehicles replace workers in performing activities. In this way, OSH is improved. Cameras monitor the movements and activities of workers and detect any irregularities that may occur in real time.

The fourth industrial revolution led to the appearance of significant changes in production, work organization, and the way workers perform their activities as well as on safety and health of workers. All these innovative technologies of Industry 4.0 contribute to workplaces in contemporary industrial systems be safer, more ergonomic and more comfortable, and this will further increase the economic effects - productivity and efficiency of workers (Table 1.).

The benefits of applying the innovative technologies of Industry 4.0 are reflected in the overall improvement of the health and safety of workers. Continuous monitoring and supervision of parameters from the work environment and monitoring the health of workers in real time in combination with analytics achieves safer working conditions, eliminates accidents and deaths, reduces injuries at work and occupational diseases and creates a basis for the application of personalized preventive measures.

Table 1. Advantages of applying the basic components of Industry 4.0, [25]

Component	Application benefits
Big data	unlimited data collection reducing uncertainty improving capacity for vital parameter analysis and error prevention
Internet of things	improving machine/equipment interactions and detecting anomalies and dysfunctions that may occur
Cyber-physical systems	improving process monitoring and control remote monitoring and control
Collaborative robots	improves human-robot interaction improves safety and health of workers
Artificial intelligence	learning and quickly recognizing dangers real-time decision making
Simulation	improving assessment prevention at source

CONCLUSION

The application of innovative Industry 4.0 technologies improves OSH by enabling the detection and elimination or reduction of hazards that may endanger the life and health of workers. By improving working conditions, reducing occupational injuries, occupational and work-related illnesses, preconditions are created for the physical, mental and social well-being of employees and the improvement of economic indicators - efficiency and productivity.

The application of innovative Industry 4.0 technologies allows workers to perform activities in a safer and more flexible way. The application of these technologies contributes to reducing the occurrence of occupational diseases and injuries at work and improving the health of workers by reducing repetitive/monotonous work activities, reducing stress and creating a better work-private life balance, reducing the risk of occupational diseases by monitoring basic health parameters of workers (monitoring muscle and brain activity using EMG and EEG sensors placed in personal protective equipment) in real time and showing warnings to workers about the occurrence of danger or harm, facilitating the implementation of preventive measures and improving working conditions through continuous monitoring of parameters in the work environment in real time (humidity, noise, lighting, etc.) and reducing or eliminating their negative impact.

In intelligent work environments, workers are given the opportunity to qualitatively enrich their work activities and reduce the performance of heavy physical work and monotonous repetitive precision work activities, since these activities are mostly performed by collaborative robots. Workers are

involved in performing activities that add value - creative activities that require reasoning, decision-making and solving problem situations in case of unforeseen events. Workers in smart companies monitor automated machinery and equipment, make decisions independently and take the initiative, manage and solve problems if unforeseen situations arise that could endanger their health or life and thus improve OSH. Workers are less exposed to stress because they can organize their activities independently, and achieve a greater degree of autonomy and self-development. Flexible working conditions in intelligent work environments enable workers to achieve a better balance between work and private life and between personal and professional development, which further leads to increased worker satisfaction and motivation to work, and reduced physical and cognitive load.

Worker-machine integration has a positive effect on OSH through the reduction of accidents and injuries at work, improving worker safety and improving ergonomic aspects in the workplace. The combination of digital wearable technologies, smart personal protective equipment, cameras, artificial intelligence can predict the potential dangers that may occur in the workplace, and this further enables the prevention of accidents and injuries to workers.

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