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SYSTEMIC SHAPING OF OCCUPATIONAL SAFETY AS A FACTOR FOR THE FUNCTIONING OF INDUSTRY 4.0 (I4.0)

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Purpose: The aim of this article is to indicate the possibilities of reducing the burdens related to the lack of safety, occurring in I4.0 enterprises.
Design/methodology/approach: The study links the guidelines for the systemic management of occupational safety, indicated in the ISO 45001 standard, with the conditions of operation of I4.0 of enterprises.
Findings: The study indicates key factors that determine the efficient functioning of Industry 4.0. The diagnosis showed that taking into account OHS guidelines may be an important condition for ensuring the efficient operation of machines and technical devices. This condition also occurs when a person only performs support functions related to maintenance.
Research limitations/implications: It seems reasonable to specify the existing relationships, e.g. the positive and negative impact of the industrial revolution on the consequences related to the state of occupational safety should be determined. It is necessary to consider the impact of new technologies on individual groups of employees.
Practical implications: The obtained results indicate the need to take into account safety issues in order to ensure effective implementation of the I4.0 guidelines. This should be considered as important information for people (entities) involved in purchasing, launching technical devices and ensuring the maintenance of machines used in I4.0.
Originality/value: The limitations affecting the effective use of technical equipment were identified. It was indicated that the improvement could be based on the guidelines of the systemic management of occupational health and safety. The obtained indications are addressed to people in I4.0 enterprises who make decisions related to the purchase and use of machines and technical equipment.
Keywords: operation of technical equipment, Industry 4.0 (I4.0), improving the conditions of use of technical devices, work safety, occupational safety management.
Category of the paper: Research paper.

1. Introduction

Ensuring safety at work constitutes a crucial factor in the effective functioning of industrial enterprises. It can be perceived as a way to reduce losses due to the lack of provided working conditions for efficient performance of occupational duties. Most often, such losses are the consequence of incidents that were that were the effect of existing hazards or lack of supervision over the performed tasks.

Based on the characteristics of severity of incidents, it can be clearly concluded that the most serious consequences are generated by contact with technical equipment (Górny, 2024a; Singh, et al., 2025). Usually, such injuries are characterized by a high level of consequence, causing significant burden to all the parties of the realized workflows. It also refers to an environment that involves the use of technical equipment, if its proper functioning requires human involvement.

When implementing improvement measures, it is necessary to acknowledge their purpose, effectiveness, nature, existing interrelationship, possibility to make ongoing changes and the competence requirements determining the realization of production tasks according to the guidelines adopted within the organization in scope of its functioning. In this sense, it is particularly important to take into consideration the solutions which reduce the number and severity of incidents. The areas for improvement can be determined through the application of systemic work safety management. This will ensure the proper choice of technical equipment, with the acknowledgment of the possibility to implement production-related tasks and, at the same time, minimize the existing burden. In order to ensure efficiency of the adopted solutions, it is necessary to identify the needs and indicate the validity as to their choice.

In particular, incidents play a major role in the shaping of the economic position of the enterprise. It is estimated that losses related to accidents at work amount several percent of the day-to-day operating costs of enterprises. When analyzing the existing losses, one should also take into consideration the employer's civil liability for the resulting losses. In the recent years, the size of the losses has not change in any significant way, despite of the implemented automation and robotization. However, the reasons for incidents have changed. Usually, they are the consequence of employees' improper behavior in the area where technical equipment is being used. A considerable proportion of the losses is constituted by situations related to inadequate choice of technical equipment.

2. The role of issue description

The aim of the elaboration is to indicate the crucial issues determining the ensured safety of employees in conditions of functioning and development in line with the provisions of new paradigms regarding technical development of companies. This is particularly important in the case of companies which utilize technical equipment and reduce the scope of tasks performed directly by humans, i.e., companies that apply solutions according to the I4.0 guidelines.

This dissertation characterizes the proposed sustainable safety management at a I4.0 organization. This elaboration has been based on a proceeding methodology in line with the need to ensure safety, realized on a systemic basis, taking into consideration the conditions in which an industrial organization operates.

The dissertation has been concentrated on the discussion concerning the possible application of the guidelines of systemic occupational safety management in I4.0, indicating the key conclusions for managers and decision makers, employees of OH&S departments as well as researchers.

3. Theoretical background

3.1. Safety in the operation of Industry 4.0

The end of the 20th century and the beginning of the 21st century determine a period characterized by a rapidly increased pace of technological development. Due to the changes, the mechanization of work positions and the realized processes has increased and is still growing. One of the methods to extend automation of labor is by implementing the solutions provided for in Industry 4.0. It is a new concept of realization of production-related tasks as part of which the efficiency of conducted processes is increased through automation and digitization (Arana-Landín et al., 2023). The intended effect is accomplished with digitization and integration, undertaken vertically, horizontally and comprehensively (Ghobakhloo, 2018; Wang et al., 2023). This involves the need to introduce changes in production systems, IT and communication technologies, utilization of the Internet of Things and machines used in cyber-physical systems (CPS), which then allows for the required integration (Lu, 2017; Pandey et al., 2024). The process creates possibilities in the scope of optimized operations, reduced costs and faster response to the market demand (Singh et al., 2025). The I4.0 approach allows for establishing an intelligent factory where cyber-physical systems control physical processes, creating virtual (digital) copies of the real world and making decentralized decisions. What is more, the said systems, with the use of the Internet of things, communicate and cooperate with humans and with one another (Wang et al., 2023). At the same time, they ensure

performance of internal services and interoperations thanks to cloud processing (Yin et al., 2018). The implemented processes are becoming more and more complex, leading to new security risks in the scope of the performed tasks (Aceto et al., 2020; Charalambous et al., 2015).

Based on the loss analysis, a significant proportion of such hazards is generated by behavior of the employees and situations resulting from an inadequate choice of technical equipment. The problem becomes more and more evident in companies that increase the use of technical equipment while reducing the scope of tasks performed directly by people.

The ensured safety, acknowledged in the guidelines for the functioning of I4.0, should be understood as the lack of situations leading to disruptions, limiting the effective performance of tasks through the related technical facilities. However, in any case when people participate in any scope of the realized tasks, the said state must be also considered with regard to the human factor (Górny, 2024a).

The changes should be associated with automation of work stands and implemented processes. Humans are no longer the performers – they become verifiers of the proper operation of technical equipment, monitoring its proper functioning. Thus, it is necessary to provide the employees with conditions characterized by efficient implementation of the new type of professional duties. Usually, it results in the need to care for the safety of persons working with technical equipment and realizing tasks that are to maintain the proper level of efficiency of such technical equipment. It becomes crucial to identify the key factors concerning humans and affecting the effectiveness of implementation of new technologies. The basic axiom of the conducted activity, i.e., the need to limit the burdens, including losses related to machine downtime and accident rate remains the same (Górny, 2024a).

In this scope, safety requirements determine the possible functioning of a human being that is a user and operator of technical devices. Safe realization of tasks assigned to humans should be considered as an important condition of the efficiency of the conducted production-related duties (Górny, 2024a). The literature provides the reasons for the risks and their impact on the identified state of work safety that has been associated with the I4.0 implementation guidelines (Arana-Landín et al., 2023; Badri et al., 2018; Górny, 2024a; Otitolaiye, Abd Aziz, 2024). The most commonly acknowledged limitations in efficient operations include:

- Functional lack of preparation of the operator and other people involved in the exploitation of technical equipment and functional ambiguity.
- Actions performed under time pressure and stress connected with the need to make complex decisions.
- Disruption of the operator's work time rhythm.
- Psychosocial burden being the consequence of an excessive amount of information.
- Excessive strain on the musculoskeletal system, partially due to the pace of the performed tasks.
- Environmental hazards related to the impact of physical factors.

- Mechanical hazards generated by direct contact with technical equipment.
- Electrical hazards connected with the use of technical equipment powered with electricity.

It has been indicated that many hazards can be prevented through the application of protective measures that take into consideration the nature of the existing hazards and instructions on how to adjust the working conditions to the needs of the participants in the conducted processes (Demir et al., 2019; Sadłowska-Wrzesińska et al., 2016; Keshvarparast et al., 2024). Technological development allowed for automatization of tasks which had been carried out by humans, reducing the entailed occupational hazards (Fantini et al., 2020; Kumar, 2024). However, the applied solutions, if implemented incorrectly, may lead to new hazards, usually related to the required presence in the environment with the used technical equipment. It needs a clear specification of the risk related to the conducted operations as well as the indication of possible improvements. When undertaking improvement actions, one must pay attention to the relations between the realized tasks, the employees and the technical equipment.

3.2. Systematic occupational safety principles related to Industry 4.0 (I4.0) guidelines

The rapid growth of automation and robotization requires solutions which will result in the effective collaboration between humans and technical equipment, ensuring safe realization of the assigned tasks. At the same time, it becomes necessary to prevent waste and losses. The production capacity of machines and the potential of people functioning in a synergetic environment should be prioritized (Górny, 2023; Jagódka, 2024). Safety in such an environment is a by-product of efficient implementation of tasks (Arana-Landín et al., 2023; Górny, 2024a). The well-being of people present in the center of production systems should be deemed as a necessity (Górny, 2023). The nature of the undertaken action, taking into account the specificity of the existing hazards, must ensure:

- Inclusion of safety requirements at all stages of the lifecycle of technical facilities, equipment and the conducted processes.
- The use of modern technical solutions which increase the efficiency of safety measures and the effectiveness of actions aimed at reducing the size of possible losses.
- Streamlining the analysis of incidents connected with the exploitation of technical equipment.
- Improving the safety culture, e.g., through increasing the work safety competence, including aspects beyond the legal requirements, and through encouraging employees to report incidents and irregularities and drawing improving conclusions.

The acknowledgment of own experience and benchmarking is an indispensable part of the undertaken action. It allows identifying problems characteristic for the type of operations and, at the same time, take into consideration the opportunities to reduce losses. The used solutions must be in line with the safety guidelines, limiting the chance of risks at their source.

When it is impossible to eliminate risks, it obligates to conduct a risk assessment to identify the most adequate methods of use of the technical equipment. Solutions based on the results of risk assessment must ensure:

- Reduction of the consequences of risks resulting from the nature, scope and way of performance of occupational tasks and exploitation of technical equipment.
- Adjusting the conditions and course of work to the individual capabilities (and limitations) of employees.
- The application of solutions eliminating the need for use of hazardous devices that are inconsistent with the desired level of technical safety.
- Prioritizing the use of collective technical protection measures over other possible protective solutions that can be implemented.

The undertaken actions should have regard to the guidelines of the adopted preventive policy and be consistent with each other.

By undertaking systemic solutions in favor of improved working conditions, it is necessary to ensure that they take place within a system of mutually related actions that increase the chances of success of the assumed objectives. The management system must ensure proper functioning of technical equipment. The elements of such system must take into consideration:

- The structure of the organization functioning according to I4.0 guidelines.
- The role and responsibility of people appointed to perform specific tasks related to exploitation of technical equipment.
- Operational activities related to ensuring the possibility of ongoing realization of manufacturing tasks.
- Training that allows for obtaining or increasing competence required to perform the assigned tasks.
- The assessment of undertaken actions, confirming the relevance of the used solutions and indicating the area of further improvements.

Providing the proper flow of information can be considered as the key action that allows reducing the impact of risks (Arana-Landín et al., 2023). The undertaken actions result in achieving compliance with systemic requirements that were previously deemed necessary. Such actions should be included in the structure of continuous improvement in order to increase the chance of gaining advantage. This requires them to be measurable in order to compare them with the determined needs.

4. Research methodology and results. Objectives and guidelines for developing systemic safety requirements in I4.0 organizations

The application of systemic management rules related to the standard risk assessment methodology is possible in the case of acknowledgment of provisions provided for in ISO 45001 and ISO 31010 standards. The standards highlight the need to comprehend the nature of the existing risks and opportunities which affect the organization's performance in the scope of creating work safety in conditions integrating new technologies. In particular, they indicate that hazards and risks should be minimized and the opportunities for improvement – maximized. This is particularly important in the case of the need for integrating I4.0 with business processes, transformation of working conditions and other conditions that directly influence the risk and need for the implementation of new solutions. An important part of the undertaken actions is the possibility of eliminating incidents or reducing their consequences.

Detailed guidelines for the realization of requirements regarding work safety management which are crucial in the analyzed situation depend on the nature of the performed tasks. The choice of the procedure option depends on the intended goals, the desired level of complexity, and the accessibility and reliability of the used data. The applied technologies must be adequately adjusted to the context of the operations and allow for clear, traceable, reproducible, and verifiable results. This also refers to ensuring the realization of tasks as part of I4.0. In order to provide safe use of technical equipment, it is necessary to acknowledge the requirements provided for in the applicable legal and technical regulations which refer to individual categories of technical equipment. For instance, due to the fact that the implementation of I4.0 is most often associated with investments in robotization of labor, it must take into consideration the possibility of involving collaborative robots (so-called cobots) (9). It is equally important to acknowledge the scope of performed tasks by people responsible for:

- The integration and commissioning of technical equipment.
- Maintaining the workflow and efficiency of technical equipment.
- Carrying out ongoing exploitation, including collaboration of employees.
- Maintaining organization and proper organization of work.

The issues in scope of I4.0 should be a part of the identification of the organization's operations. Selected guidelines for the realization of systemic work safety management depend on the nature of the carried-out tasks. Their scope has been presented in Table 1.

Table 1.
Systemic occupational health and safety management guidelines which are relevant to ensure safety at I4.0 enterprises

Scope of requirements	Guidelines for realization of requirements
Realization of systemic requirements	- Realized activities based on the adopted policy and objectives as well as processes and actions that allow achieving the pre-determined goals in the scope of implementation and use of technical equipment. - Inclusion of the aspects indicated by all the participants in the realization of I4.0 in the management system. - Acknowledgment of the relations between the human factor and the technical aspect of the conducted operations.
Identification of risks and risk assessment	- Acknowledgment of the functioning context of a I4.0 organization in the carried-out activities. - Acknowledgment of all potential hazards (e.g. mechanical, physical, mental) and their influence on the health and safety of the employees. - Implementation of solutions aimed at eliminating or reducing the impact of hazards.
Control and supervision	- Regular inspections of the technical condition of machines, devices and installations and the influence of technical solutions on the employees
Documentation and revisions	- Implementation of a system for reporting and monitoring of irregularities. - Keeping records of undertaken actions after a situation that led to limited functioning of technical equipment.
Ensuring protective measures	- Providing access to proper protective measures and implementation of solutions that ensure their proper use during the performed occupational tasks.
Training and awareness raising	- Acknowledgment of problems regarding safe exploitation of technical equipment in training programs. - Promoting culture of safety and involvement undertaken to increased comfort at work.
Accident and critical situation management	- Implementation of solutions that allow for fast reaction to all dangerous situations. - Keeping a log of accidents and incidents at work to analyze and eliminate (reduce) their cause.
Shaping of safety culture	- Supporting the involvement of employees in caring for the safe use of technical equipment. - Acknowledgment of the employees' opinions on improvement activities. - Promoting responsibility for own actions and their influence on the co-workers' safety.
Ensuring compliance of procedures with regulations of law	- Compliance with the labor law, OH&S norms and standards. - Monitoring of changes in the applicable regulations and adjusting the procedures to the new guidelines.
Ensuring continuous improvements	- Ensuring sharing experience and best practices with other entities in the scope of task performance conditions. - Implementation of assessment criteria for the efficiency of undertaken actions. - Regular audits and implementation of improvements based on the results of the conducted analyses.

Source: Source: own analysis based on (Górny, 2024a; 2024b; ISO 45001; Otitolaiye et al., 2024; Wang et al., 2023).

5. Discussion of the results

The application of I4.0 solutions may reduce the number of physical, mechanical and psychosocial hazards and improve the work ergonomics. This refers to the issues that are an integral part of the traditional performance of occupational duties in an environment

involving the use of technical equipment. However, in order to obtain the intended results, a verification of the impact of the used solutions on the potential safety improvement is needed. The application of systemic safety rules requires acknowledgement of the comprehensive nature and complexity of the used solutions, an integration of the used technologies, protection of the available data and information, as well as ensuring the employees' proper conduct.

Full automation of factories allows reducing risk. It is possible since the used machines are more and more frequently facilitated with technical measures for parameter monitoring, which is important for the process flow. Usually, the used solutions make it possible to react immediately after any occurring dysfunction. They are characterized by a self-control capability as well as the ability to monitor the surroundings and send information indicating the need for an intervention (Mattsson et al., 2016). As a result, it is possible to include such new technologies into the system of actions undertaken in order to improve health and safety and increase human efficiency in the working environment. The applied solutions can be treated as contributing to reduced burden connected with the lack of safe conditions for the performed occupational duties.

Nowadays, a large proportion of companies which declare the implementation of the I4.0 rules and solutions identifies this with investments in robots, production management systems, and other dedicated solutions. However, it very often turns out that the above-mentioned components remain unrelated and their functioning is based on the use of human factor. In practice, it means that the information used as the basis for manufacturing activities are generated and introduced by humans. Thus, it can hardly be considered as a complete implementation of the I4.0 principles. One should bear in mind, however, that the acknowledgment of human needs remains the condition for success regardless of the degree of implementation of technical solutions (Górny, 2024a; 2024b). It is impossible to ensure the effective functioning of technical equipment without human involvement, even if people are only used for monitoring and maintenance tasks.

Efforts in order to improve safety (taking into account I4.0) require:

- A verification of the level of integration of human labor with the used technical equipment.
- Conducting an analysis of the impact of existing hazards on the development of social accountability of companies and the effective functioning of new technologies.
- Assessing the consequence of the impact of applied solution on work organization and the existence of psychosocial risks.
- Determining standards of procedure to adjust working conditions to the new reality.
- Applying solutions that distribute tasks among employees and intelligent machines, taking into consideration the physical and cognitive capabilities of the workers.
- Ensuring effective and continuously improved protective measures against an unauthorized access to recorded data and information.

Regardless of the used technical solutions, it is crucial to implement a psychosocial environment based on cooperation. This incorporates:

- Improving specialist knowledge and motivation of the employees, promoting safe collaboration between the employees and the technical equipment.
- Developing adaptive interfaces and emotion sensors that allow monitoring the employees and ensuring their ongoing safety.
- Shaping human behaviors, reactions to stress, difficulties and hesitation.

The undertaken initiatives must combine a virtual task analysis, dynamic risk assessment and a workload analysis (Górny, 2024b).

Regardless of the nature of the adopted solutions, the work environment configuration must be concentrated on people, their security and comfort. This condition is needed for the efficient realization of the tasks assigned to them. Improvement activities must acknowledge the possibility of technical equipment performing the tasks and should be adjusted to the limitations on the human side. The said requirements should be juxtaposed with the nature of tasks carried out by individual groups of employees.

6. Conclusion and future research directions

The efficiency of the used solutions depends on their nature and the reasons for the implementation that must be thoroughly identified as well as on the method of implementation of the requirements. The use of systemic management guidelines helps ensure a safe and friendly working environment. The resulting advantages can have a considerable impact on the efficiency of the I4.0 activities. Their application can lead to lower losses and, consequently, improved conditions of the realized production tasks.

The conducted diagnosis of the problem presented in the title of this elaboration helped identify the conditions for development of manufacturing activities where work safety aspects are recognized as the decisive factor for their successful completion while improvements are introduced through systemic approach guidelines. To assess whether the above-mentioned effects are possible, further in-depth search is needed to determine the existing dependencies and their practical verification, taking into consideration the actual circumstances, existing in industrial in industrial organizations that grow their operations according to the I4.0 guidelines. In particular, it is needed to acknowledge the guidelines of systemic occupational health and safety management during the process of putting technical equipment into operation. It should be considered as assistance in the conducted processes, realized with regard to the efforts aimed at ensuring resources necessary to gain advantage in all the areas of operations of the enterprise.

Acknowledging the existing dependencies, one should determine the positive and the negative impact of the industrial revolution on the consequences connected with the state of work safety. The influence of new technologies on individual employee groups should be analyzed. The characterization of the issues related to the implementation of solutions based on the I4.0 guidelines should not refer solely to problems regarding efficiency, quality and competitiveness. It should acknowledge all the requirements that might have a negative effect on the realization of occupational duties. This includes requirements that relate to ensuring work safety. One should bear in mind that the implemented technology generates its own specific hazards.

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