Management Systems
in
Production Engineering

2026, Volume 34, Issue 1, pp. 127-137

Date of submission of the article to the Editor: 07/2025
Date of acceptance of the article by the Editor: 01/2026

DOI 10.2478/mspe-2026-0013

LOCKOUT – TAGOUT SYSTEM – AS A SOLUTION AIMED AT REDUCING ACCIDENTS AT WORK

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Abstract:
Every day, accidents related to the accidental activation of hazardous energy sources or their failure to secure them are recorded in manufacturing plants. A lockout/tagout system can be a solution to effectively reduce accident-causing activities during the installation, repair, and maintenance of machinery and equipment. As part of the analysis, a bibliometric analysis was conducted to identify research trends in the field of the LOTO system. To identify the accident rate and analyze it, quantitative data on accidents at work during the repair, maintenance, and installation of machinery was compiled. The quantitative data was predicted using the Winters' model with multiplicative trend and multiplicative seasonality. Based on our own research, it was concluded that implementing solutions aimed at reducing occupational accidents in this area is a significant issue. Therefore, a methodical approach was proposed for the effective implementation of technical and organizational solutions aimed at improving occupational safety. In terms of the effectiveness of the LOTO system, special attention was paid to the human factor, whose role was considered at every stage of lockout/tagout system implementation. Effective prevention in reducing accident risk relies on technical and organizational solutions. The LOTO system is a solution whose implementation, monitoring, and improvement can translate into increased awareness of safe behavior among employees. Therefore, employers should implement solutions aimed at improving workplace safety.

Key words: Lockout-Tagout system (LOTO), work safety, legal regulations, improvement of working conditions, forecasting accident at work

INTRODUCTION

The issue of accidents at work in industrial enterprises is a significant topic for both scientific and practical analyses. The repercussions of occupational accidents extend beyond the immediate victims, encompassing both employees and external entities engaged in collaborative endeavors with the enterprise. As is customary, discourse is had regarding the social and economic costs engendered in the case of recording accidents [1, 2]. The fundamental element in this regard is the implementation of solutions that are designed to enhance work safety, a priority that is identified as a means of reducing accidents at work. The most frequently employed solutions are a combination of technical and organizational solutions.

Employers are looking for methods and tools to effectively improve occupational safety in production facilities. One of the solutions that can translate into improved occupational safety, work safety culture, as well as reducing the number of recorded accidents at work can be an efficiently functioning Lockout-Tagout system. The Lockout-Tagout system is a set of measures aimed at reducing accident risk, through the division of tasks, competencies among employees. The basic element is to understand the purpose of the LOTO system, and then to implement its improvement, supervision and auditing, which will improve safety in the workplace. The example goes from the top, so top management should be involved in all activities concerning the implementation of the system at the workplace.

LITERATURE REVIEW

In the accident investigation literature, researchers analyze accident statistics, the effects of occupational accidents [3, 4], study the relationship between accidents and employee absenteeism due to the increasing role of human resources [5], identify occupational hazards related to factors of the work environment, i.e.: physical, chemical, biological, psychophysical [6, 7, 8], analyze the course of an accident event using so-called models for investigating accidents at work [9, 10], and on the basis of their analyses propose measures to prevent their occurrence in the future. One of the solutions to reduce accident risks in enterprises in particular in terms of unexpected, unplanned activation of a source of hazardous energy by unauthorized persons (e.g., kinetic, pneumatic, potential, thermal, electrical, chemical energy), is the Lockout-Tagout system.

The LOTO system was introduced in the late 1980s as Standard 29 CFR 19.10.147 [11] in the USA and was revised in OSHA 3120, a brochure about controlling hazardous energy during servicing or maintenance of machines or equipment [12]. The brochure encourages employers to review standards for controlling hazardous energy [12], the effects of which can negatively impact the health and lives of workers. In publications addressing the issue of limiting sources of hazardous energy and the possibility of applying the Lockout-Tagout system, attention is drawn to the possibility of applying the system during maintenance and machine repair work [13].

The LOTO system combines a lockout, a physical solution installed on the source of dangerous energy, and a tagout, which provides information about the work being performed and allows for the identification of the worker performing the work (e.g., worker from the maintenance department). The system refers to practices and procedures aimed at preventing the release of dangerous energy [14], thereby reducing the occurrence of situations that pose a threat to workers. Therefore, it is crucial to minimize risks and manage risks effectively to control dangerous energy [15, 16, 17].

The LOTO system categorizes employees into three groups: authorized, subordinate, and others. Authorized employees are given special attention. These are the individuals who physically implement the LOTO system by carrying out established work procedures depending on the specifics of the workplace. The UR department is prepared to carry out specific work in terms of competence and can apply this system. These groups may include mechanics and electricians, for example. These groups are important within the framework of the system. They need to be trained and improve their competencies so that the system works efficiently and meets the organization's measurable and non-measurable H&S goals. The LOTO system also provides for subordinate employees and others. Subordinate workers under the system are operators of machinery and equipment in enterprises. The others are, as the name suggests, other persons employed at the workplace. These individuals do not have direct contact with the system's procedures. Their knowledge is usually limited to information about the application of the LOTO system at the workplace.

The lockout/tagout system also requires the development of procedures – written instructions (standards), which can take the form of a photo, table or diagram. In practice, a combination of the above forms is most often used. Developed procedures can include collated energy sources of the area that is the subject of analysis (general procedure), or be dedicated to a specific machine, workstation – specific procedure. The developed procedures provide a visual form of information that is necessary for the proper protection of the source from accidental release of hazardous energy.

Conducting bibliometric analysis, which consists of scientific data mining [18] registers 60 and 31 documents in Scopus, Web of Science databases, respectively, assuming the keyword "Lockout-Tagout system" for the years 2000-2024 (Fig 1).

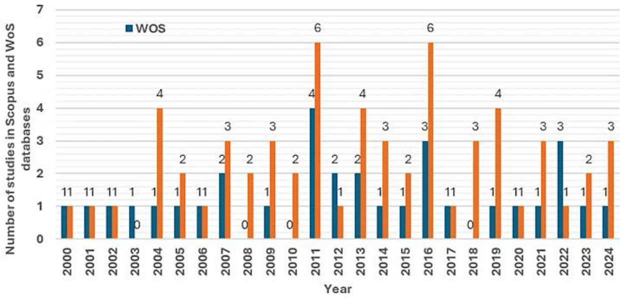

Fig. 1 Quantitative data on the number of publications - "Lockout-Tagout system" for 2000-2024

The time period was determined based on the availability of data in the databases, as well as the timeliness of the studies in question. The largest number of scientific studies is located in the areas, among others:

- Engineering (46 articles), Business, Management and Accounting (8 articles), Medicine (7 articles) – Scopus database,
- Engineering Electrical Electronic (8 papers), Engineering Industrial (8 articles) and 5 articles in the area of Engineering Multidisciplinary and Operation Research Management Science – Web of Science database.

Thus, it can be concluded that most of the articles fall within the fields of engineering and technical sciences. The number of articles indexed in the Scopus database does not exceed four, while the WoS database indexes six articles (Fig. 1). The number of peer-reviewed studies in the field of lockout/tagout application system is not extensive, so it is worth filling the theoretical gap in the subject area and presenting the effects of the implemented, improved system, as well as its impact on improving occupational safety.

Considering the issue at hand on the basis of the analysis of information compiled in scientific and research papers, the authors of the articles pay attention to the protection of workers from uncontrolled activation of sources of dangerous energy. Among other things, the studies (Table 1) refer to issues related to:

Table 1
A review of selected scientific research on the Lockout-Tagout system

Author/Authors (Year of publication)	Journal	Research issue	Research objective
Matsuoka, S., Muraki, M. (2001)	Process Safety Progress	Computer support for planning LOTO programs in the processing industry.	Reduce accident risk by using lockout/tagout system
Parker D.L., Brosseau, L.M., Samant, Y., Xi, M., Pan, W., Haugan D. (2009)	Public Health Reports	The essence of the lockout/tagout system in machine safety in terms of reducing injuries related to the hazards involved. Improving safety in the use of machinery in metal manufacturing companies.	
Emami-Merigani, B., Nadeau, S., Kené, J.P. (2011)	International Journal of Production Economics	A study of the impact of using Lockout-Tagout on production control and labor safety in a production system where machine failures are identified.	
Hong-jie, Z, Zhen-tang, L. (2011)	Procedia Engineering	LOTO system as a form of reinforcement in the field of safety management in the mining industry – reinforcing the zero-accident cults at work.	
Parker, D.L., Yamin, S.C., Brosseau, L.M., Xi, M., Gordon, R., Most, I.G., Stanley, R. (2015)	American Journal of Industrial Medicine	Improving safety in the process of operating machinery by improving safety equipment, as well as improving LOTO procedures. Machine safety checklist as a tool to help evaluate the application of LOTO procedures.	
Badiane, A., Nadeau, S., Kenné J.P., Polotski, V. (2016)	Journal of Quality in Maintenance Engineering	Ensuring work safety while maintaining the achievability of production goals. The role of blocking/marking and the need to supervise their use due to the shortcomings of practical application of the LOTO system.	
Yamin, S.C., Parker, D.L., Xi, M., Rodney, S. (2017)	American Journal of Industrial Medicine	Self-monitoring as part of evaluating and improving LOTO programs, taking action to improve the functioning of the system in the enterprise.	
Boczkowska, K. (2017)	Journal of Management Challenges – JMC	The LOTO system is employed as a method of managing hazardous energy. The following analysis is concerned with the activities during which accident events are recorded. The following paper sets out a number of ways in which sources of hazardous energy may be blocked.	
Dewi, L.T.; Zebua, E.S. (2018)	Journal Teknik Industri	In-depth analysis of the study of documents relating to accidents caused by the failure of LOTO procedures, in the process of operating machinery.	
Ravi, M., Sridharn, P., Sentkikumar, V.K. (2018)	International Journal of Applied Science and Engineering	Implementation of the Lockout – Tagout system in electrical switchgear to minimize risks and severity of consequences in the paper industry.	
Karimi, B., Chinniah, Y., Burlet-Vienney, D., Aucourt, B. (2018)	Safety Science	Improvement of the LOTO system (audit, training), the use of alternative methods, risk assessment as part of improving occupational safety.	
McNinch, M., Parks D., Jacksha R., Miller A. (2018)	Mining, Metallurgy and Exploration	The role of the proper application of the LOTO system as an element of reducing accidents in the process of machine operation.	
Illankoon, P. et al. (2019)	Safety	The need to involve employees in risk assessment activities. Avoiding accidental energy activation by increasing employee awareness of the system in use.	
Dźwiarek, M. (2022)	Electric Machines – Problem Papers	Problems of the occurrence of new risks resulting from the implementation of Industry 4.0. Development of guidelines, training materials in support of LOTO procedures in the enterprise.	
Delpla, V., Kenné, J.P., Hof L.A. (2023)	International Journal of Production Economics	Minimizing the cost of production and inventory of finished products while guaranteeing the safety of employees during maintenance activities through the implementation of operational LOTO activities – preventive or corrective maintenance of machinery.	
Poisson, P., Ben Aziza, M.N., Jocelyn, S., Chinniah, Y.A. (2024)	SIAS 2024 Proceedings: Safety of Industrial Automated Systems	LOTO system as a form of effective protection against electrical hazards. Additional consideration of the possibility of zero energy after the LOTO system – the Tryout system.	
Khawi, H.A., Asmary, A.M. (2024)	Society of Petroleum Engineers	The development of employee awareness regarding the LOTO system is a critical component in enhancing occupational safety. The process of monitoring the implementation of interlocks on specific pieces of equipment is of paramount importance. The LOTO system is undergoing a process of digitalization.	

- application of the Lockout-Tagout system in terms of identifying the impact of lockout/tagout on the occurrence of accidents [16, 19, 20],
- strengthening the zero-accident culture through the implementation of the LOTO system in the mining industry, streamlining and strengthening the safety management mechanism [21],
- forming situational awareness (SA) of employees with regard to the implemented system [13],
- error analysis of LOTO system procedures in the maintenance, repair and installation of machinery [14, 22],
- integrating maintenance and lockout/tagout procedures into the production plan while achieving economic results and ensuring worker safety [23],
- ensuring worker safety by providing equipment energy checks before and after preventive or corrective maintenance activities [24],
- reducing the negative impact of hazards and injuries they can cause [25, 26, 27],
- improving the LOTO system by, among other things, self-monitoring [28, 29] and by developing machine safety checklists while including an area dedicated to LOTO procedures [25],
- computer-aided planning of LOTO programs [30],
- the applicability of LOTO in the face of changes resulting from the implementation of Industry 4.0 in enterprises [31, 32].

The research conducted relates to reducing the risk of accidental activation of sources of hazardous energy in various industries (Table 1), in the process of operating machinery. This demonstrates the wide application of the system in improving occupational safety.

The LOTO system is part of organizational (development of procedures), and technical (interlocks) activities aimed at reducing accident risks. In accordance with the provisions of the EU – Directive 2009/104/EC [33], one can find provisions in which the reduction of the risks involved is possible through the use of the lockout/tagout system, which will be presented later. Scientific studies (Table 1) highlight the risks involved, safe work procedures, training and improvement of employees, as well as improvement of the system.

The purpose of this paper is to present the potential application of a lockout/tagout system to meet the requirements specified in the Directive 2009/104/EC, addressed to employers (Fig. 2).

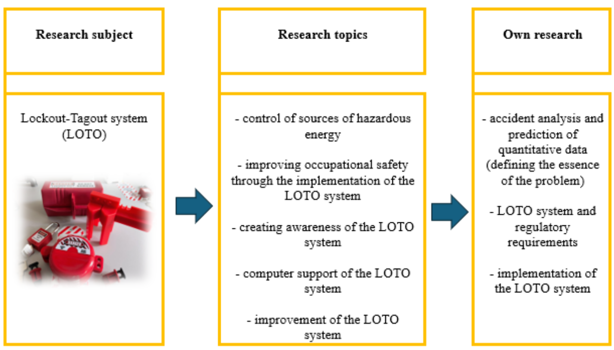

Fig. 2 Research directions for LOTO system and own research

The paper presents step-by-step actions for implementing, using, and improving the lockout/tagout system, aimed at improving occupational safety while simultaneously meeting legal requirements – filling a research gap in this area. Therefore, for the purposes of this study, a hypothesis was assumed that it is possible to improve occupational safety by implementing, maintaining and improving the lockout/tagout system as a technical and organizational solution aimed at reducing accidents at work.

MATERIALS AND METHODS

To achieve the study's stated objective, a three-stage methodology of original work was developed (Fig. 3).

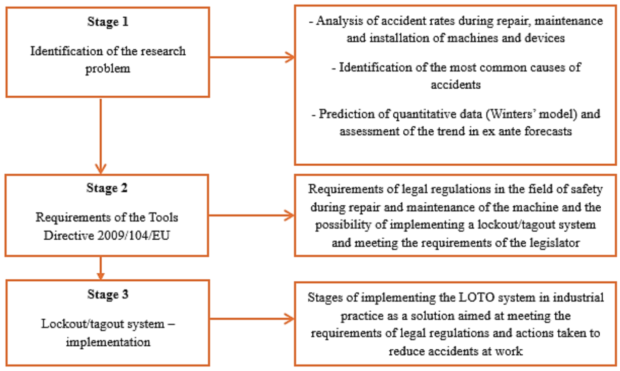

Fig. 3 Three-stage methodology for self-study

The initial stage delineated the crux of the issue, namely, the documented accidents occurring during the installation, maintenance, and repair of machinery and devices in Poland from 2010 to 2023. These data were disseminated by the Statistic Poland [34]. The quantitative data resource was constrained to the year 2023 due to the availability of data publications. A comprehensive data set was also compiled, encompassing the most prevalent causes of accident events. The quantitative data concerning the number of individuals injured in accidents was subjected to a prediction process. In the prediction process, the Winters model with a multiplicative trend and multiplicative seasonality was utilized. The forecasts obtained were then subjected to a qualitative assessment, which entailed an examination of ex-post forecast errors. Additionally, the model was assessed for its validity using the Janus coefficient. The following errors were adopted as measures of forecast acceptability: The following metrics are employed: mean absolute error (MAE), mean absolute percentage error (MAPE), root mean square error (RMSE), and the standard deviation of model residuals, denoted Se. For the purposes of this study, the following assumptions were made MAE ≤ RMSE, RMSE ≤ S_e, and MAPE < 10%. In the context of the Janus coefficient value, the model is deemed admissible under the condition that its value does not exceed one ($J \leq 1$) [35].

The forecast values obtained will be utilized in the analysis of the trend of recorded accident events (increasing, decreasing, or no trend). Consequently, there is justification for employing the prediction process, which enables the assessment of the phenomenon in question in the future while meeting the assumptions regarding forecast errors and the validity of the model. Forecasts also perform specific functions, including warning, information, and advisory roles, which may be a crucial argument in the field of LOTO system application in workplaces.

The second stage of the methodology entailed the compilation of the requirements stipulated in the Directive 2009/104/EC. According to this directive, employers are obligated to ensure safety during the execution of work related to the repairs and maintenance of machines. Consequently, within this stage, the feasibility of implementing the LOTO system was assessed as a solution aimed at meeting the requirements of legal regulations and enhancing work safety.

The third stage of the process entailed a systematic, step-by-step approach that facilitated the implementation of the lockout/tagout system. This system was designed to address the requirements stipulated by the legislator and to enhance employee safety.

RESULTS

The essence of the research problem – analysis of accident rates, causes

It is incumbent upon each company to strive to limit the number of accidents, in view of the considerable costs that ensue from such incidents. The study examined the prevalence of accidents at work during the repair, maintenance, and installation of machinery and devices in Poland. The period covered by the compiled data extends from 2010 to 2023.

The findings of the analyses conducted (Fig. 4) indicate that the alternation of increases and decreases in the number of work-related injuries over the period 2010-2023 does not signify a favourable trend in terms of occupational health and safety.

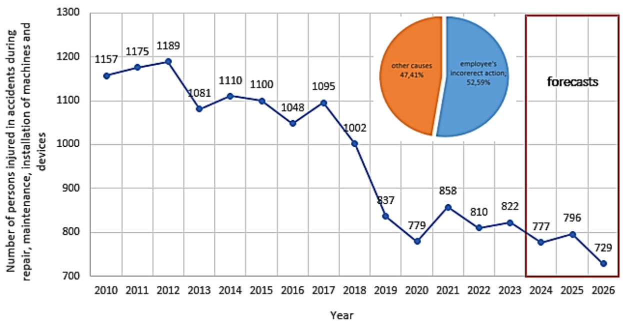

Fig. 4 Number of persons injured in accidents during repair, maintenance and installation of machines and devices in Poland in 2010-2023 and forecasts for 2024-2026 along with their most common causes

The highest recorded value for the number of persons injured in accidents was observed in 2012, with 1,189 cases reported. In contrast, the lowest recorded value was observed in 2020, with 779 cases reported. The decline in the number of registered accidents this year can be attributed to the impact of the SARSCoV-2 virus pandemic.

The fluctuations observed do not appear to offer a reliable indication of accidents at work. Consequently, in order to conduct further analyses of the trend of changes, the possibility of predicting quantitative data was utilised. For the purpose of this study, the Winters' model with multiplicative trend and multiplicative seasonality was utilised. Utilising the model parameter values α = 0.33, β = 0.01, Φ = 0.72 (Table 2) and minimization of the MAPE error (MAPE = 7.94%), ex ante forecasts were determined for the years 2024-2026. The forecast values were respectively: y^*_{2024} = 777, y^*_{2025} = 796 and y^*_{2026} = 729 persons injured in accidents during repair, maintenance, and installation of machines and devices.

Table 2
Ex ante forecasts for the years 2024-2026 of the number of people injured in accidents

Forecasting model	2023	Ex ante forecasts			Model parameters		
		2024	2025	2026	α	β	Φ
Winters' model with a multiplicative trend and multiplicative seasonality	882	777 ↓	796 ↑	729 ↓	0.33	0.01	0.72

The model was also assessed in terms of its validity – the Janus coefficient, where its values did not exceed one (Table 3).

Table 3
Ex post forecast errors, Janus coefficient values

Forecasting model	Ex post forecast errors			
	MAE	MAPE	RMSE	S_e
Winters' model with a multiplicative trend and multiplicative seasonality	71.00	7.94%	98.07	109.65
	Janus coefficient values (J^2)			
	2021	2022	2023	
	0.000	0.003	0.529	

The forecasts demonstrate an absence of decreasing trends, and the fluctuations in question reflect this absence, which is negative information in terms of occupational health and safety.

The data pertaining to the percentage share of causes of accidents, as illustrated in Fig. 4, was presented. This data was broken down according to the number of persons injured in accidents during the repair, installation and use of machines. The remaining 47.41% of cases during the period 2010-2023 were attributable to factors such as inadequate work organisation and unsuitable workstations. In contrast, 52.59% of cases were attributed to employees' improper conduct. Consequently, it can be posited that the adoption of solutions inherent to the LOTO system during repairs, maintenance and the installation of machinery can serve to mitigate improper and arbitrary conduct by employees. This subject will be addressed in a subsequent section of this study.

Lockout/tagout system vs. tool directive requirements

The documentation of unintentional occurrences has been demonstrated to have a deleterious effect on the perception of the company by employees and external entities engaged in collaborative endeavors. The analysis conducted in the domain of accidents in the repair, maintenance, and installation of machinery and equipment reveals the absence of a discernible trend. The ex-ante forecasts determined in advance corroborate the occurrence of a comparable phenomenon over an extended period. The predominant cause of accidents was attributed to improper employee behavior, accounting for 52.59% of the total. Consequently, the requirements of the Directive 2009/104/EC, which pertains to work equipment operated by employees during work, including machinery, were analyzed. As illustrated in Table 4, the implementation of the lockout/tagout system has the potential to enhance occupational safety within specific domains.

These domains encompass the following areas:
- maintenance work on machinery and the activities performed during these activities,
- the equipment used to protect workers, together with worker protection during machine restart,
- the warning signs used that are important for ensuring the safety of workers,
- protection against hazards, including but not limited to fire, explosion, electric current, high and low temperature.

The implementation of a lockout/tagout system necessitates the establishment of standard procedures and the designation of authorized personnel to perform maintenance operations. In the context of maintenance operations, the implementation of interlocks and tags serves to mitigate the risk of hazardous energy sources being activated. This precautionary measure is designed to impede the initiation of the machine, thereby enhancing safety protocols. The tags employed (tagout) furnish information regarding the employees undertaking work on a specific machine.

Table 4
Requirements of Directive 2009/104/EC and the lockout/ tagout system (risk mitigation)

Legal requirement	Lockout/Tagout actions
Work or maintenance places and stations must be suitably adapted to perform these activities related to the repair and maintenance of machines (p. 2.9)	Procedure related to the method of blocking sources of hazardous energy related to the machine (electrical, pneumatic, hydraulic, etc.). Selection of locks within the LOTO system adapted to the identified source of hazardous energy together with the tag. Division of competences between employees performing work within the LOTO system.
Work equipment must be equipped with clearly distinguishable means of disconnection from all energy sources. Reconnection must not constitute a hazard (p. 2.14)	The use of locks and tags as a security solution against accidental activation of energy sources.
Work equipment must be equipped with warning signs and markings that are essential for safety (p. 2.15)	The LOTO system as a form of visualization – it is a visual form relating to the implementation of work on machines.
Employees must have safe access to and presence in all areas necessary for production, set-up and maintenance work (p. 2.16)	LOTO procedures define how to select locks and lockout sources of hazardous energy. The use of locks prevents the machine from starting.
Work equipment must protect employees against the risk of explosion, fire, overheating or the release of gas, liquid, dust, vapour, or other substances produced, used or stored in the equipment (p. 2.17) Work equipment must adequately protect employees against the risk of explosion of the equipment or substances produced, used or stored in the equipment (p. 2.18) Work equipment must protect employees against the risk of direct or indirect contact with electricity (p. 2.19)	Procedures for the LOTO system, employee training, physical barriers preventing the machine from starting, protection against accidental starting of sources in the form of gas, liquid, dust, fumes, produced substances, electricity. LOTOTO system (Lockout-Tagout-Tryout).

Consequently, in the context of the stipulations outlined in Section 2.9 of the Directive 2009/104/EC, the implementation of the LOTO system has been demonstrated to contribute to a reduction in accident risks within the designated area of concern.

The process of disconnection from all energy sources constitutes a critical component in the execution of tasks pertaining to the maintenance and repair of machinery. It is imperative that this type of work be conducted when machines are in a state of standstill. The implementation of the lockout/tagout system is imperative for preventing external parties from initiating the operation of the machinery. The lockout, a security measure employed to restrict access to hazardous energy sources, functions as a barrier to external access. The removal of this apparatus is only possible for the workers who initially installed it. Furthermore, it offers a distinctive approach to deactivating the energy source in question, as detailed in Section 2.14 of the Directive [33]. As illustrated in Fig. 5, a methodology for the elimination of hazardous energy is presented.

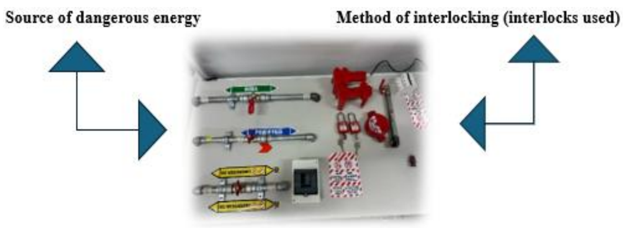

Fig. 5 Training table – o View identification of the source of hazardous energy and selection of solutions within the LOTO system (valve interlocks)

This methodology involves the isolation of water (green) and air (blue).

Maintenance and repairs can be executed in a concurrent manner by multiple workers. Consequently, the LOTO system incorporates group interlocks that pertain to the concurrent obstruction of the energy source by multiple workers. Consequently, the initiation of the machine will be permitted only after the completion of the work and the removal of the locking padlocks by all individuals who participated in the locking procedure.

The LOTO system, which utilizes locks, padlocks, and tags as visual communication tools, facilitates the management of machine work in progress. The visual message conveys information and functions as a warning to other workers (p. 2.15). Visual management constitutes a pivotal component within the framework of occupational health and safety. In this context, the dissemination of information to workers is predominantly facilitated through the sense of sight. The utilization of a lock and tag constitutes a rudimentary yet readily identifiable form of communication, thereby enhancing safety during the operation of machinery.

The implementation and improvement of the LOTO system, as well as the development of procedures (standards) for the use of the system, are essential for ensuring safe work in all areas related to the operation of the machine (p. 2.16). Therefore, the system is also instrumental in enhancing safety in the domain of communication and the establishment of a secure work environment.

As stated in the Directive 2009/104/EC, the legislator acknowledges the occurrence of hazards and dangerous situations associated with explosion, fire, gas release, liquid release, dust, and electricity (pp. 2.17-2.19). The lockout/tagout system is a protocol designed to ensure the secure isolation of equipment or processes whose inadvertent activation could lead to hazardous scenarios. The Directive 2009/104/EC [33] underscores the significance of stored energy. Lockout-Tagout-Tryout is a protocol that aims to ensure that a specific quantity of energy remains within the installation. Consequently, the measures stipulated under LOTO have the potential to enhance safety and align with the legislature's stipulated requirements.

The actions stipulated under the LOTO system are considered good practice, rather than a legal obligation. Consequently, employers are advised to seek effective solutions and good practices to reduce accident risks in enterprises.

Implementation of the LOTO system in industrial practice as an element of improving safety

The legislator's requirements are not specific with regard to the actions that the company (employer) should implement in terms of risk reduction. The application of the LOTO system can be an action that allows reducing the risk of accidents. This reduction can be attributed to two primary factors: technical actions, such as physically cutting off the source of hazardous energy, and organizational actions, including the implementation of procedures and standards of conduct. The implementation of the lockout/tagout (LOTO) system should be initiated subsequent to the identification of these factors. Consequently, it can be posited that the lockout/tagout system constitutes a combination of technical and organizational solutions that facilitate the enhancement of work safety.

The implementation of the LOTO system comprises a series of stages, a point that is also emphasized in relevant literature [16, 20]. For the purposes of this study, the actions were divided into five stages (Table 5), i.e.

- the initial stage of the process entailed the familiarisation of employees with the lockout/tagout system (see Figure 5). At this stage, it is imperative that employees possess a comprehensive understanding of the system's fundamental principles and the objectives underlying its implementation. During the training, a schematic summary of the identified sources of hazardous energy is prepared, lockouts are selected, and a detailed procedure covering all sources of hazardous energy is developed, and the proposed lockouts are physically applied to the identified sources. The final element of the process is a preliminary evaluation of the effectiveness of a given solution (Fig. 6),
- the second stage of implementation of the LOTO system in the manufacturing enterprise is now underway. The LOTO system necessitates the isolation of a group of employees who utilise physical interlocks to secure machinery (authorized employees). It is imperative that this group is allocated the maximum time for training, particularly in later stages related to the functioning and enhancement of the system. As a component of the second stage of the course of action that had been adopted, a layout was developed. This layout delineated the production hall, in which sources of hazardous energy were marked. The team responsible for implementing the system is tasked with the determination of the symbolic marking of sources of hazardous energy. It is imperative to acknowledge that the composition of the team should encompass individuals with a comprehensive understanding of the fundamental principles of the LOTO system. Additionally, the inclusion of departmental managers whose personnel will be engaged in LOTO operations is crucial. Furthermore, the participation of physical workers responsible for the setup of interlocks is essential. Subsequently, procedures should be developed: firstly, general and secondly, specific for machines subject to the interlocking system. It is imperative to acknowledge that the procedures should be comprehensible to employees and adopt a mixed form (table, diagram, photo),
- the third stage of the process is to conduct an audit of the LOTO system. The purpose of the LOTO system audit is to evaluate the effectiveness of the implemented system in terms of occupational health and safety during work related to the repair, maintenance or installation of machinery, where there is a possibility of accidents. The execution of audits necessitates the formulation of a meticulous audit plan, alongside the establishment of audit criteria pertaining to the implemented LOTO system. The documentation pertaining

to the implementation of LOTO encompasses health and safety policy, LOTO procedures, and regulatory requirements. The organization’s employees are responsible for the majority of audits of the LOTO system; therefore, it is also necessary to prepare them to carry out these activities. The selection of an auditor is an individual company's approach to the audit process. It is also possible to use the help of external entities involved in implementation and auditing in the LOTO area,

Table 5
A five-step approach to implementing a LOTO system

First stage (preliminary, training)	**Stage two (implementation in the enterprise)**
The initial phase of the project will entail familiarizing oneself with the fundamental principles of the LOTO system and establishing the rationale behind its implementation.	It is imperative that employees are familiarized with the fundamental principles of the LOTO system, and that the purpose of its implementation is clearly defined (training).
-	The identification of employees is to be conducted in accordance with the LOTO system, utilizing the designated authorized group.
The following diagram illustrates the layout of sources of hazardous energy set on the LOTO training table, which requires protection against accidental activation.	The following diagram illustrates the layout of the production hall, with a view to identifying sources of hazardous energy requiring protection against accidental activation.
The identification of sources of hazardous energy, and the subsequent labelling of said sources, is of paramount importance.	The identification of sources of hazardous energy, and the subsequent labelling thereof, is of paramount importance.
The selection of interlocks for the identified sources of hazardous energy must be undertaken in consideration of the feasibility of implementing the solution.	The selection of interlocks for the identified sources of hazardous energy must be undertaken with due consideration for the feasibility of implementation, as well as the technological profile of the enterprise.
The development of a detailed procedure for sources of hazardous energy is imperative.	The subsequent development of the general procedure is outlined below.
	The development of a detailed procedure is imperative.
The implementation of interlocks on identified sources of hazardous energy is imperative. The present study aims to evaluate the effectiveness of the application in cutting off hazardous energy.	The implementation of interlocks on identified sources of hazardous energy is imperative. The present study aims to evaluate the effectiveness of the application in cutting off hazardous energy.
Stage three (LOTO system audit)	
The following types of audits are to be determined for the LOTO system: internal, external, preliminary and periodic audits.	
The selection of internal auditors.	
Training of auditors.	
The purpose of this audit is to determine the scope of the LOTO system audit, as well as the audit criteria to be employed.	
Internal audit of the LOTO system.	
Improvement of areas for improvement - post-audit activities.	
Stage four (system improvement)	
The present study aims to evaluate the effectiveness of the implemented system.	
Training of employees.	
Stage five (evaluation of effectiveness)	
Evaluation of the effectiveness of the implemented system.	
Training of employees.	

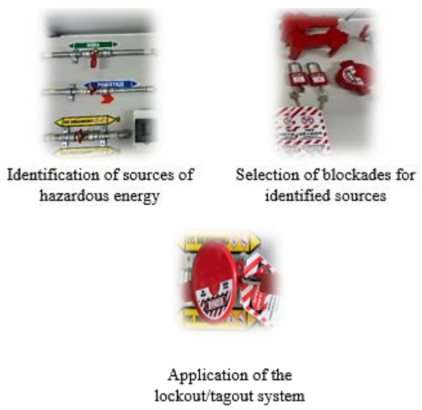

Fig. 6 LOTO system training – initial stage of familiarization with the essence of the system

– the fourth stage of the process is concerned with the enhancement of those areas that have been identified as requiring improvement. It is imperative to acknowledge that the undertakings encompassed within the ambit of the audit are not intended to identify discrepancies within the system; rather, they are aimed at substantiating its efficacious operation. The fundamental objective of the audit is to enhance occupational safety, curtail accidents, allocate competencies, and cultivate a consciousness among employees concerning health and safety. The enhancement of the system is to be founded on the evaluation of implemented solutions and the refinement of existing procedures. Furthermore, the system is to be improved

by enhancing the competence of employees within the LOTO system,
- the fifth stage of the process is the evaluation of the effectiveness of the implemented system in the enterprise. The effectiveness of the implementation can be evaluated by analyzing the registered accidents at work and near misses in the field.

DISCUSSION OF RESULTS AND DIRECTIONS FOR FURTHER RESEARCH

The issue of accidents during repair, maintenance and also installation of machines requires special organization of work in order to provide employees with safe conditions during this work. Analyzing quantitative data on accidents at work does not record a downward trend, but fluctuations, which are not a good prognosis for the subject matter. A visible decrease is recorded in 2020 (779 injured), but this result was probably related to the situation of the SARS-CoV2 virus pandemic. Another important issue is also determining the causes of recorded events, where based on the conducted analyses, it is found that 52.59% were caused by incorrect behavior of the employee. Therefore, when analyzing situations related to accidents, it is necessary to consider what actions can be taken, and what measures to apply in order to reduce the number of recorded accident events in the future. The study refers to the possibility of using technical and organizational solutions in the form of a system based on developed procedures (standards) using physical solutions in the form of locks and information tags. Of course, in industrial practice, only the lockout system can be used. Because each organization decides on its form that it wants to implement. The lockout/tagout system is a form of good practice aimed at reducing risk by shaping competences at various levels of management – the highest level – expressed by the willingness of top management to implement, apply and improve it. Authorized employees who apply established standards and subordinates who are aware of the applied system.

The implemented system is not the end of activities in the field of health and safety; it requires further improvement. Therefore, the study presents a systematic approach aimed at implementing and improving the LOTO system, in which a special role is assigned to improving employee competences.

In the next stages of work devoted to the system, surveys will be conducted to assess employee awareness of the LOTO system. It is also planned to identify its strengths and weaknesses presented by employees of industrial enterprises. The opportunities and threats resulting from its implementation in practice will also be presented.

SUMMARY

The Lockout-Tagout system is a technical and organizational solution that improves occupational safety. Implementing the system reduces accident risk by establishing procedures and allocating responsibilities, as demonstrated in the literature [13, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32]. The aim of this study was to present the potential application of the Lockout-Tagout system as a solution for improving occupational safety during repairs and maintenance of machinery and equipment, as well as technological installations, while simultaneously meeting the requirements of the legal provisions specified in the Directive 2009/104/EC. This complements the scope of ongoing research on the Lockout-Tagout system. The recorded number of accident events does not provide positive information regarding occupational health and safety (OSH) (lack of a trend), therefore, the need to implement safety-oriented solutions becomes apparent. The established ex-ante forecasts clearly fulfill their function by providing information for management and alerting them to the need for OHS actions.

Implementing a Lockout-Tagout system requires an analysis of the current situation in the enterprise and its application capabilities to ensure that its implementation does not hinder the completion of specific tasks. Therefore, a phased approach was presented, emphasizing employee training. Training was planned within each phase to build awareness in this area.

The system's effective operation is possible thanks to the involvement of all employees at various management levels. This system is a solution that can be applied in various industries, such as mining, metallurgy, automotive, and manufacturing.

ACKNOWLEDGMENTS

Silesian University of Technology (Faculty of Materials Engineering) supported this work as a part of Statutory Research BK-201/RM1/2025 (11/010/BK_25/0057).

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