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Review

Exploring Safety of Machineries and Training: An Overview of Current Literature Applied to Manufacturing Environments

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Abstract: A machine is described as an assembly that has a drive system installed or is planned to have a drive system installed and that is constituted of linked elements or components, at least one of which moves, that are connected for a particular application (ISO12100). Different types of risks are present in machines, and exposure to them can cause harm or even death. When risk has been adequately reduced, machinery safety considers a machine's ability to complete its intended duty throughout its life cycle. A literature review was carried out using "safety of machinery" as a keyword, which produced an analysis of 29 papers published from 2008 to 2024. The papers were examined through bibliometric analysis of the year of publication, country, citation statistics, and study of the keywords. These studies were classified into accident analysis papers, papers focused on the normative, papers that addressed risk assessment tools, and papers that conducted quantitative research. In addition, a more in-depth analysis of the articles associated with the keywords with the highest number of occurrences was carried out. Lastly, studies with quantitative analyses were analysed to identify new possible aspects that it is necessary to investigate.

Keywords: safety of machinery; safety; systematic literature review; review

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1. Introduction

The safety of machinery is a specific area in safety studies that considers a machine's ability to complete its intended duty throughout its life cycle when the likelihood of hazards has been sufficiently reduced [1]. As described by Yuvin Chinniah et al. (2019) [2], "Machine safety" integrates design, technical, and procedural measures to ensure the safety of operators with industrial machines. The main objective is to prevent injuries from potential hazards present in machines, such as risky mechanical movements, moving parts, hazardous energies, and chemicals.

An inherently safe design is adopted, with the elimination of sharp edges and the installation of fixed guards and interlocks. At the technical level, safety control systems are properly operated, with practices such as redundancy and continuous monitoring. In the procedural context, safe operating procedures, personnel training, protective devices, and interlock/tag systems are implemented. The overall approach aims to systematically reduce risks during operation and maintenance, considering safety as an integral part of the complete machine system. "Equipment safety" focuses more on the specific elements that make up the machine and their protective measures. Some approaches focus on the design, installation, and safe use of components for industrial machines. This includes the installation of guards, integrated safety devices, and proper maintenance. Operators must be trained in the safe use and the proper labelling of equipment. The goal is to prevent accidents and protect operators during interactions with industrial machinery.

The risk of accidents related to using machines or hand tools appears to be the prevailing danger for the health and safety of workers in over 40% of European companies, as reported in a survey by the European Agency for Safety and Health at Work. Many of these accidents can result in serious injuries or deaths (Third European Survey of Enterprises on New and Emerging Risks (ESENER 2019): Overview Report). Data from national authorities or public and private insurance firms used in a recent study by the European Union [3] using the European Statistics on Accidents at Work (ESAW) framework present statistical findings about indicators for fatal and non-fatal accidents in 2019. During that year, there were 3.1 million non-fatal accidents and 3408 fatal accidents in the EU; these numbers increased by 0.5% for non-fatal accidents and 2.3% for fatal accidents when compared to the previous year. The percentage of non-fatal incidents that harmed the industrial industry was the highest. There were 586,000 non-fatal accidents in 2019 (or 18.9% of all accidents). The construction industry accounted for 22.2% of all workplace fatalities in the European Union (European Statistics on Accidents at Work (ESAW)). It is crucial to understand the interconnection between machinery safety and workplace accidents to briefly contextualise the principles of General Safety Theory and the most recent trends. General Safety Theory emphasises accident prevention, highlighting the need to reduce risks from the design phase of machinery. This approach is grounded in systematic risk management, involving identifying and mitigating potential hazards.

Concurrently, modern trends incorporate new elements to address current challenges. The behaviour-based approach focuses on the awareness and active engagement of operators, promoting safe practices in the workplace. Advanced technologies such as the Internet of Things (IoT) and artificial intelligence are transforming machinery safety through continuous monitoring and automated systems to prevent incidents.

Furthermore, Cheng et al. [4] evaluated 1542 reports of workplace fatalities and injuries in the industry from 2000 to 2009, which were stored in the occupational accident database of the Council of Labour Affairs (Executive Yuan). The analysis shows that the absence of safeguarding or ignoring hazard warning signs have been identified as the most common cause of accidents (43%). The misuse of PPE (Personal Protective Equipment) represented 38%, as can be seen in Figure 1. According to the analysis of the association between accidents and worker type, accidents can be attributed to worker ignorance of risks and the safety protocols required to reduce them [4].

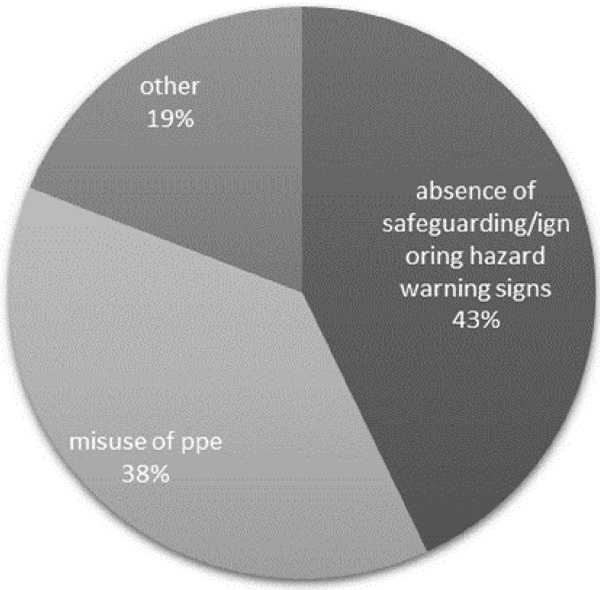

Figure 1. Most common unsafeacts and unsafe conditions reported by Cheng et al. [4].

The wrong use of PPE or the absence of this kind of gear is the most unsafe act and appears to be a systematic violation that leads to injuries and accidents [4,5]. More than 13% of the accidents analysed in 106 accident reports involving moving pieces of machinery in the Canadian province of Quebec from 1990 to 2011 were connected to removing existing guards and circumventing safety mechanisms. Additionally, as shown in Figure 2, it was found that 46% of accidents involved employees with less than five years of experience, and 36% involved employees with less than a year of experience [1].

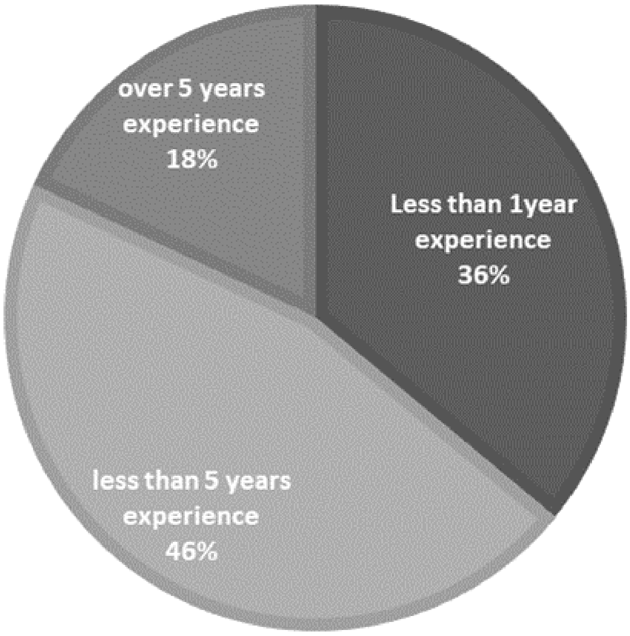

Figure 2. Workers' experience for accidents related to machinery as reported in Quebec from 1990 to 2011 [1].

Considering the overview of the topic and the recent changes in safety of machinery and availability of new tools for risk assessment and training we decided to inform our future research by looking at a literature review of most recent papers to address the following research questions:

RQ1: What are the current research trends in the machinery safety field?
RQ2: How can accidents related to the safety of machines be reduced?
RQ3: What are the current and upcoming prevalent themes in the area?

2. Materials and Methods

This paper looks at the present state of the research and the difficulties surrounding machinery safety. The authors conducted a Systematic Literature Review (SLR) of the available literature in the area and a bibliometric analysis of published articles and review papers. To identify suitable papers, the SCOPUS database was thoroughly searched. The SCOPUS database was selected since it is among the biggest and most well-liked databases and contains many peer-reviewed papers from trustworthy journals. The review used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) technique. PRISMA is a global project created by relevant specialists to solve the persistent problem of a need for more transparent and well-documented review procedures. The objectives of SLR are to study the existing literature and analyse current trends in a field of study. The systematic reviews can develop or assess theories about how or why phenomena occur, answer questions that individual studies would not otherwise be able to answer, identify problems in primary research that should be fixed in follow-up studies, and provide the knowledge state in a field from which future research aims can be identified [6].

Reviewers can identify research gaps and obtain insight into potential new projects using the SLR technique.

2.1. Selection of Databases and Keywords

The first step in a literature review is to choose relevant publications from trustworthy databases. The Scopus (www.scopus.com, last accessed on 19 December 2023) database was chosen for this study to locate pertinent papers in the field of machinery safety. This is one of the largest databases of scientific articles currently available.

The keyword utilised was "safety of machinery" since this work aims to investigate the current state of the art about this topic. The keywords were searched in the papers' titles, keywords. and abstracts. It is important to note that if the search had been extended to all the text of the articles, it would have returned a higher number of results.

The following search string was used for the literature was as follows:

TITLE-ABS-KEY ("safety of machinery") AND (LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2014) OR LIMIT-TO (PUBYEAR, 2013) OR LIMIT-TO (PUBYEAR, 2012)) OR LIMIT-TO (PUBYEAR, 2011) OR LIMIT-TO (PUBYEAR, 2010)) OR LIMIT-TO (PUBYEAR, 2009) OR LIMIT-TO (PUBYEAR, 2008)) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English")).

2.2. Definition of Inclusion and Exclusion Criteria

This study's inclusion criteria (as shown in Table 1) were journal articles or review papers written in the last ten years. In this research, only English materials were considered. Exclusion criteria used for this work were conference proceedings, book chapters, books, trade journals, and articles written in other languages.

Table 1. Eligible criteria.

Publication	**from 2008 to 2024**
Type of paper	Journal article or review paper
Language	English

2.3. Systematic Literature Review

Articles that met inclusion and exclusion criteria in the field of machinery safety were gathered from the SCOPUS database. The recommended SLR methodology flowchart is shown in Figure 3. As can be seen, 121 records were found in the literature search. These records were then examined according to the language, year of publication, and document type by the eligible criteria. Each publication's title and abstract were examined; 32 articles were sought for retrieval, though we could not access the full text for 3 of them. Therefore, 29 articles were determined to be eligible. These chosen articles were then subjected to full-text analysis.

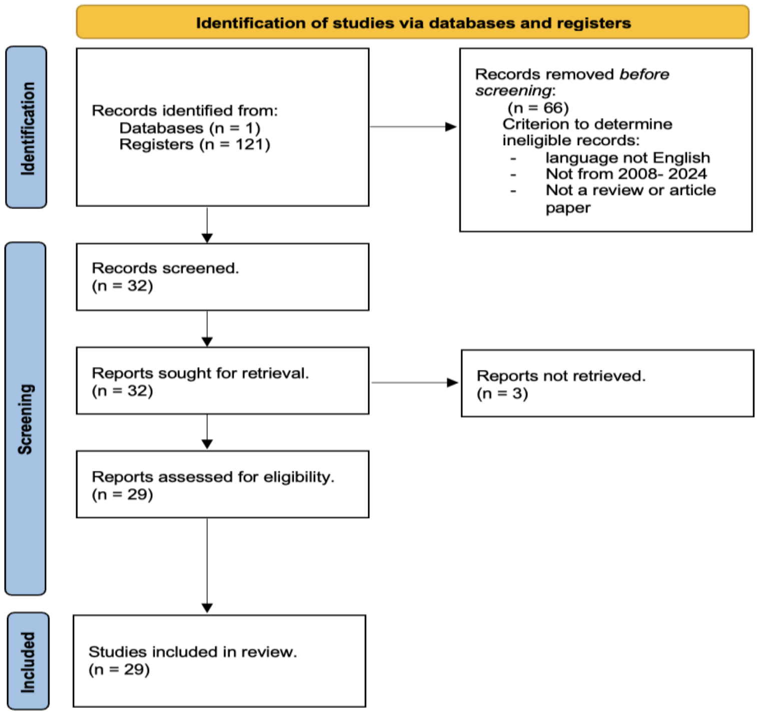

Figure 3. PRISMA flow diagram: selection process of the study records. PRISMA [6].

3. Results

3.1. Bibliometric Analyses

A bibliometric study was carried out to analyse the pertinent contributions of the authors and nations and address the research questions. The studies on the safety of machinery, published from 1 January 2008 to January 2024, were analysed by year of publication, country, number of citations, and keywords. As can be seen from Figure 4, more than 65% (21 out of 29 papers) of the studies reviewed were carried out in the last five years. Despite the increase that has occurred in recent years, however, the number of papers that respond to this topic still needs to grow, regardless of the importance of the topic.

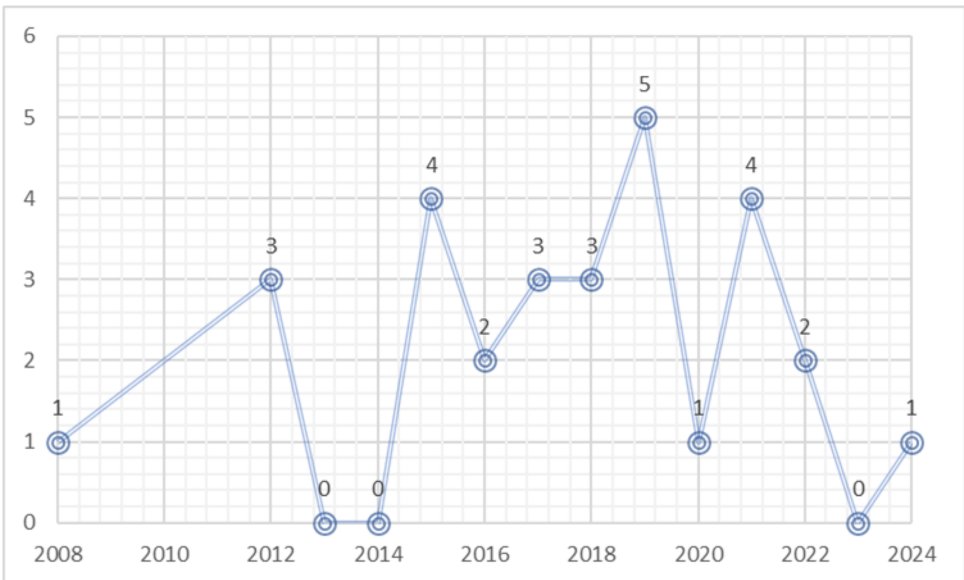

Figure 4. Number of articles published by year.

3.2. Country-Wise Statistics

Information was retrieved from the SCOPUS database to analyse country-wise statistics. Figure 5 presents the contributing countries in the area of safety of machinery. The highest number of studies (47%) were conducted in Canada and 13% of the articles in this work were written in Poland. Russia and China contributed to 9% of the total items, Japan 6%, and the other countries around 3% (Figure 5).

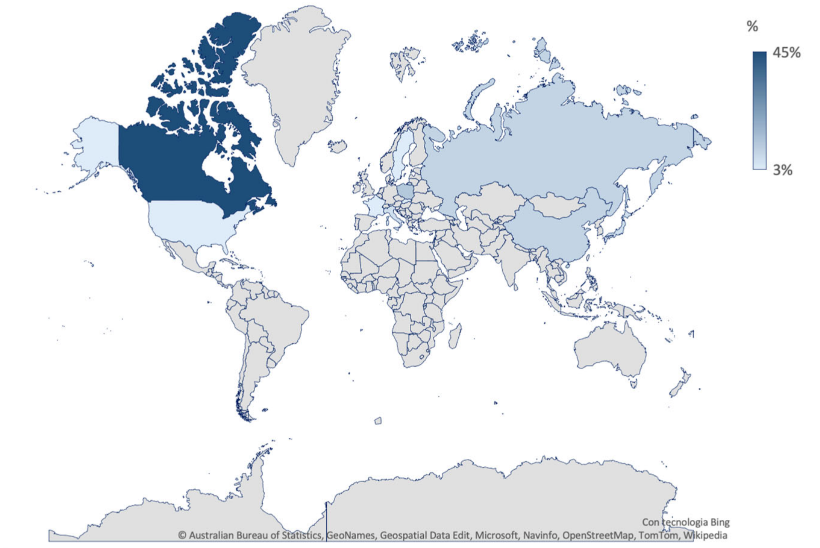

Figure 5. Geographical distribution.

3.3. Citation Statistics

To analyse the citation statistics of the articles, citation information was gathered from the SCOPUS database. The absolute most cited article was written by Chiasson et al., published in 2012 [7], which received 140 total citations, followed by Zhang et al., published in 2017 [8], with 83 citations, and Chinniah, published in 2015 [1], with 66 citations (Figure 6). Looking at the citation per year of the articles, it can be observed that the paper with the highest number of citations was the one written by Qin et al., published in 2019, [9] followed by Zhang et al., 2017 [8], and the third was the one written by Chiasson et al., 2012 [7] (Figure 7).

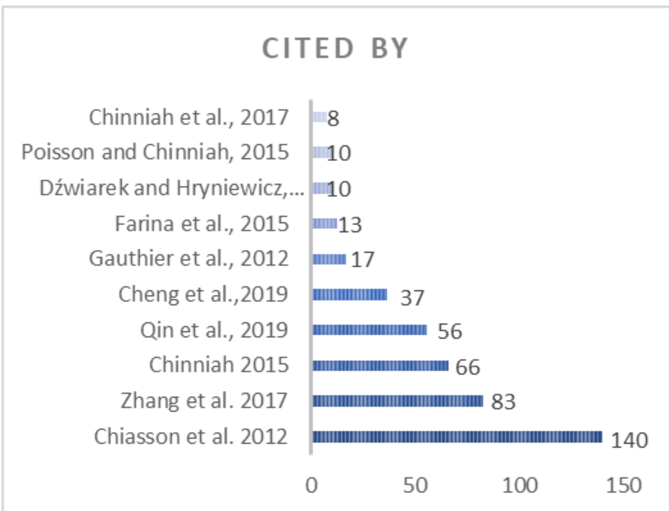

Figure 6. Citations for each of the top citated papers considers in our literature review.

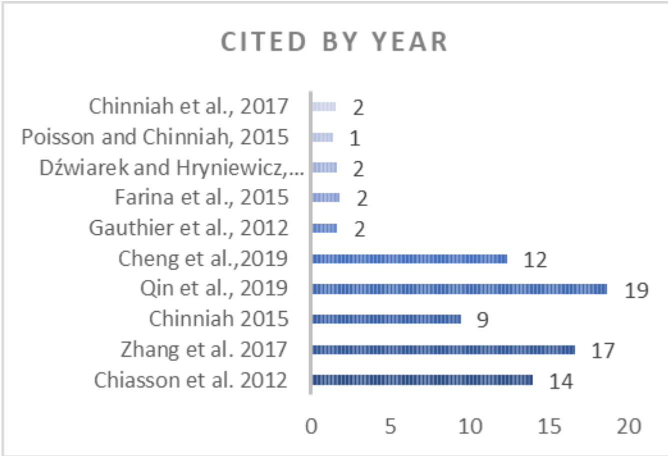

Figure 7. Citation by year for the top cited papers considered in our study.

3.4. Keywords Statistics

The top five most popular keywords from a list of 137 used by authors are shown in Table 2. The frequency analysis of keywords used by the authors showed that, excluding "Safety of Machinery", the keywords with high frequency were "Risk assessment", "Safety Standards", and "Lockout". These three aspects will be discussed in more detail in Section 4. The keyword word cloud used for the safety of machinery is presented in Figure 8.

Table 2. Top five keywords used in the field of safety of machinery.

Keyword	Occurrence
Safety of machinery [a]	16
Risk assessment [b]	13
Safety standards [c]	8
Lockout	6
Safety	5

[a] "Safety of machinery" includes also the keyword "machinery safety"; [b] for more generality, the specific standards used as keywords are included in the "Safety Standards" keyword; [c] the keywords risk estimation, risk analysis, and risk are included in "Risk assessment".

Figure 8. Word cloud safety of machinery keywords.

3.5. Paper Classification

The papers included in this review were classified according to their purpose: papers analysing accidents at work related to the use of machinery, papers that focus on the analysis and limits of international standards and regulations, papers that analyse risk assessment tools and their implementation, papers that aim to improve safety at work through new tools or a different combination of existing tools, and papers where a survey was carried out. Each paper could belong to several categories. The paper classification is shown in Table 3, and the number of papers associated with each category is shown in Figure 9.

Table 3. Paper classification. The presence of an X indicated the main topic(s) covered by each.

Authors	Years	Accidents Analysis	Standards and Regulation	Risk Assessment	New Tools/New Applications	Observations and/or Survey
CHIASSON ET AL.	2012			X		X
GAUTHIER ET AL.	2012			X		
CHINNIAH	2015	X				
SAITO ET AL.	2015		X			X
FARINA ET AL.	2015					X
POISSON AND CHINNIAH	2015					X
JOCELYN ET AL.	2016			X		
ARONSON ET AL.	2016		X			
DŹWIAREK AND LATAŁA	2016	X				
ZHANG ET AL.	2017				X	
CHINNIAH ET AL.	2017				X	X
MACEK	2017		X			
JOCELYN ET AL.	2018			X	X	
KARIMI ET AL.	2018					X
GAUTHIER ET AL.	2018			X		X
TREMBLAY AND GAUTHIER	2018					X
FENO ET AL.	2018				X	
CHINNIAH ET AL.	2018			X		X
KARIMI ET AL.	2019				X	
QIN ET AL.	2019				X	
DŹWIAREK	2019				X	
Y. CHENG ET AL.	2019				X	
CHINNIAH ET AL.	2019		X			
ROSOCHACKI	2019			X		
MAKHUTOV AND GADENIN	2020			X		
HOJO ET AL.	2021		X			
MA AND MAO	2021				X	
GALIK ET AL.	2021				X	
GAUTHIER ET AL.	2021		X			X
BURLET-VIENNEY ET AL.	2021					X
HANNA ET AL.	2022		X			
VAVILIN	2022		X			

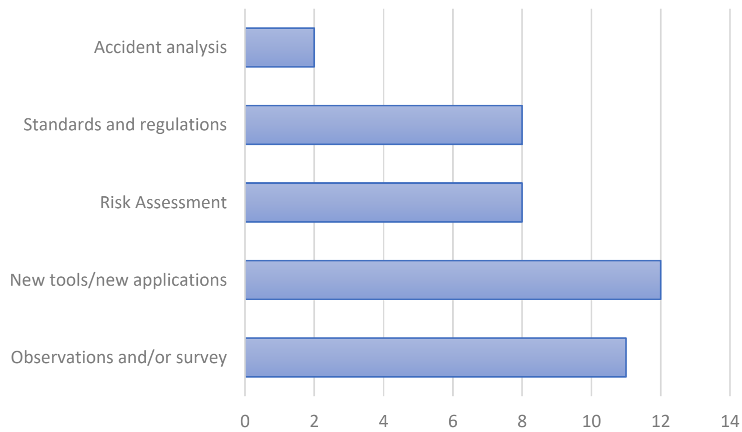

Figure 9. Number of papers in each category.

4. Discussion

4.1. Risk Assessment in the Literature

Assessments of the risk presented by machinery are crucial in maintaining worker safety. The two steps of a machinery risk assessment are risk analysis and risk evaluation. The steps in risk analysis are (i) figuring out the machinery's limits, (ii) identifying potential hazards, and (iii) estimating the risk. Each detected hazard and potentially dangerous circumstance must be subjected to the risk estimating stage. The results will determine how to evaluate the risks and which risk reduction strategies should be used first. According to Chinniah's 2015 examination of 106 accident reports, 104 incidents occurred with no company risk assessment, and no risks were detected [1]. Authors Gauthier et al., 2012 [10], analysed the distribution of the level of risk for 20 scenarios, classified in terms of low-risk to high-risk based on the average result obtained by applying 31 different risk calculation tools. The results of this analysis showed that some tools tend to overestimate low-risk scenarios, while others underestimate high-risk scenarios; in general, a change in the level of risk has been noted about the instrument used. In addition, it was noted that tools configured with two parameters could be considered as effective as those configured with four parameters to estimate the risk associated with industrial machinery. However, these two types of configurations are to be considered favoured over other types of configurations by the standard ISO 12100-2010 [11]. Four of the twenty production activity scenarios developed and validated were used in a two-part study. The chosen scenarios covered the four-value risk scale, ranging from low to high risk. The 25 research participants had adequate levels of training and expertise in machine safety and risk assessment. They were evenly distributed between occupational health and safety (OSH) consultants from industry associations, maintenance employees or safety experts in industries, and engineers with a focus on machinery safety. The first part of the study, conducted by Chinniah et al. 2018 [12], aimed to investigate the flaws in six different risk estimation tools applied to the four production activity situations. The six machine risk estimation tools were selected from the 31 tools considered by them. After the use of a specific tool and the result calculation by the researchers, the professionals were asked to express their degree of agreement with the risk level obtained using a 5-point Likert scale, justifying their answers. A set of classification and distinction criteria, user satisfaction metrics, and convergences of risk levels were used to determine the outcomes for each tool. More than 28% disagreed with the risk level obtained. According to earlier research, architecture that emphasises one parameter can exacerbate divergent outcomes and limit the tool's ability to identify situations correctly [12]. Gauthier et al. (2018) [13] conducted the second phase of the investigation, which tested the effects of flaws in the two risk estimation parameters under consideration: the severity of harm (S) and the probability of harm (Ph). To achieve the aim of the research, we asked 25 experts involved in the study to give feedback on the application of parameters for each scenario. The findings demonstrate that the variables of the risk assessment instruments used in machinery safety can influence the risk estimation procedure. The findings imply that these flaws may contribute to a low convergence of risk levels reached for the same unsafe circumstance by numerous participants and participant dissatisfaction with the effectiveness and accuracy of these instruments. The participants were frequently reported difficulties in selecting the most appropriate level for the severity of harm that best fit a particular circumstance [13]. The use of different risk factor assessment tools associated with musculoskeletal disorders also led to different outcomes, even if considering the same workstation, as shown in [7]. The authors compared eight alternative approaches for identifying risk factors for musculoskeletal problems at work. The Quick Exposure Check (QEC), Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), Ergonomic Workplace Analysis developed by the Finnish Institute of Occupational Health (FIOH), EN 1005-3 standard, OCRA index, and Job Strain Index (JSI) methods were used to assess 224 workstations with 567 tasks. Three risk categories were used to compare the outcomes (low, moderate, high). The results show that different approaches analyse the same data in different ways [7]. According to Jocelyn et al. in a paper written in 2016 [14], it is also relevant that, given a dangerous scenario, different people may arrive at different assessments of the risks since their varied backgrounds and knowledge affect how much significance they assign to the potential of injury. A quantitative risk-estimating approach is the most accurate method for determining the consequences associated with risk and the likelihood that these consequences will materialise. They recommended using the Logical Analysis of Data (LAD) combined with dynamic experience feedback to help detect and update risk in decision-making. LAD is a data mining technique that uses Boolean logic to identify and categorise patterns. LAD means scanning any numerical database to extract information from patterns that are naturally contained in the database [12]. This method was used by Jocelyn et al. in 2016 [14] to calculate the likelihood that harm would occur. The database utilised to achieve this goal contained 23 indicators and 19 fatal and 4 non-fatal belt conveyor-related workplace incidents. The accident model used by the authors was the MELITO paradigm; it consisted of a description of the event moment (M), the equipment involved (E), the accident's location (L), the person(s) involved (I), the task(s) being performed at the time of the accident (T), and the workplace's organisation (O). The patterns showed that equipment, organisation, people, and times were the main sources of risk factors and potential causes of accidents [14].

4.2. Standards and Regulations in the Literature

Many laws, rules, standards, and procedures are in place to ensure that machines are safe for people performing different jobs, such as operation and maintenance [15]. The safety of machinery is essential in Industry 4.0; considering the collaborative robot, which is designed to work in direct contact with humans, functional safety is essential [13].

In the EU regulatory context, the use of robotic systems must comply with the Machinery Directive (2006/42/EC) [16] essential health and safety requirements, either directly by adhering to the requirements outlined in the directive or by using the harmonised standards. According to the Machinery Directive (2006/42/EC), all robotic applications must perform a risk assessment. The 2006 ISO 10218 standard [17], which outlines specifications for the inherent safety design, safety precautions, and information for using industrial robots, was drastically revised to introduce a risk-based approach. Furthermore, a new automatic operation mode termed "Collaborative Operation" was established to enable robots to accomplish planned tasks in partnership with a person while sharing a workspace. The term "collaborative operation" refers to a state of operation in which a properly constructed robot operates in close coordination with a person or people within a clearly defined shared workspace where they can carry out many activities at once [18]. The authors of [19] discussed the regulations' limitations regarding collaborative robots, focusing on the automotive industry. Interviews with 26 knowledgeable stakeholders in Sweden's automotive sector were conducted as part of the study to better understand the perceived regulatory barriers. The data were gathered between January 2019 and March 2020. In addition to ISO 10128 [17], collaborative robots are covered under ISO/TS 15066—Robots and robotic devices [20]. According to the stakeholders, the biggest issue with collaborative automation legislation is that robots operate near people rather than in fenced-off zones, making it more difficult to assess the risks because the robots might act in ways that are viewed as independent.

A summary of the European and international standards mentioned in the literature and their users is given in Table 4.

Table 4. European and international directives and standards.

Normative/Standards	Description	Who Should Use It?
ISO/IEC Guide 51: 2014 [21]	Outlines guidelines and suggestions for standards drafters on the inclusion of safety-related considerations in standards. Refers to any element of environment, property, or human safety, alone or in combination.	Drafters of standards
Machinery Directive 2006/42/EC	This regulation covers the following products: machinery, interchangeable equipment, lifting accessories, safety parts, chains, ropes, webbing, detachable mechanical transmission devices, and partially finished machinery. The Directive's Annex I also outlines important health and safety laws that apply to the creation of machinery.	Machinery designers Manufacturers
ISO 10218 [17]	Part 1 outlines specifications and rules for the inherently safe design, safety precautions, and usage instructions for industrial robots. Part 2 explains the precautions that must be taken while integrating industrial robots and industrial robot systems.	Manufacturers End users of collaborative robots (cobots)
ISO/TS 15066	Supplements the standards and instructions on operating collaborative industrial robots provided in ISO 10218-1 and ISO 10218-2 [17] by defining safety requirements for collaborative industrial robot systems and the workplace.	End users of collaborative robots (cobots)
ISO 10218 [17]	The first part of ISO 10218 [17] lays out specifications for the fundamentally safe design, safety precautions, and usage instructions for industrial robots. The safety criteria for the integration of industrial robots, industrial robot systems, and industrial robot cells are outlined in ISO 10218's second section [17]. Along with providing standards to remove or significantly reduce the risks associated with these hazards, it also outlines the basic dangers and potentially dangerous circumstances connected to these systems.	Robot designers Manufacturers End users of collaborative robots (cobots)
ISO 9000 family [22]	Five quality management system (QMS) standards from the ISO 9000 [22] family enable companies to ensure that they accomplish the expectations of customers and other stakeholders while conforming to legislative and regulatory requirements for a given good or service.	Manufacturers
ISO 12100 [11]	In order to achieve safety in the design of machinery, ISO 12100:2010 [11] outlines fundamental terms, principles, and methodologies. It provides the fundamentals of risk assessment and risk mitigation to aid designers in accomplishing this goal. The design, use, occurrences, accidents, and hazards related to machinery are the foundation for these principles, which are founded on knowledge and experience. During pertinent periods of the machine life cycle, procedures are given for recognising hazards, estimating and evaluating risks, and eliminating or sufficiently reducing risks. Advice is provided regarding the risk assessment and reduction process being documented and verified.	Machinery designers

Table 4. *Cont.*

Normative/Standards	Description	Who Should Use It?
ISO 13849 [23]	Parts of machinery control systems that are involved with providing safety tasks are subject to ISO 13849 (called safety-related parts of a control system) [23]. The guideline consists of two parts. The first part of ISO 13849-1 [23], General Principles for Design, outlines safety criteria and recommendations for integrating safety-related components into control systems (hardware or software). The processes to be followed for validating by analysis or tests the safety functions of a system, the category attained, and the performance level achieved are outlined in ISO 13849-2 Part 2: Validation [23].	Machinery designers
IEC 62061 [24]	The implementation of IEC/EN 61508 [25] for machinery is IEC/EN 62061 [24]. It offers specifications relevant to the system-level design of all types of electrical control systems for equipment safety and for the design of simple subsystems or devices.	Machinery designers
ISO 7010 [26]	ISO 7010 [26] specifies safety signs for emergency evacuation, fire protection, health hazard information, and accident prevention. Each safety sign is shaped and coloured by ISO 3864-1 [27], and the graphical symbols are created by ISO 3864-3 [27]. Therefore, this document suits any context where human safety issues must be considered. However, it does not apply to the signals used to direct traffic on roads, rivers, ships, and air, nor does it generally apply to any industry subject to regulations that may differ concerning any aspects of this document from the ISO 3864 series.	Facilities security managers
CSA Z432 [28]	CSA Z432 Safeguarding of Machinery contains guidance on selecting and using guards and safety devices to safeguard employees from risks connected with using mobile or stationary machinery [28].	Machinery designers Manufacturers Maintenance personnel
ROHS_Quebec [29]	This regulation aims to set standards for items like sanitary facilities; ventilation; hygiene, sanitation, and cleanliness in establishments; area conditions, storage and handling of dangerous substances; tool and machine safety; specific high-risk tasks; and individual protective equipment to ensure the quality of the working environment, protect employees, and guarantee their physical and safety well-being.	Employers
CSA Z434 [30]	CSA Z434 [30] is the adoption of ISO Standard 10218 [17] with Canadian modifications.	Robot designers Manufacturers End users of collaborative robots (cobots)

From the point of view of the stakeholders interviewed by [19], the current regulation is not in line with existing norms, and the safety directives require excessive safety systems that make the solutions tedious and inefficient. Some respondents believe that an undeniable degree of risk should be considered tolerable, but, for this to happen, it is necessary to educate operators on the systems they will use. The authors suggested and implemented a new safety attitude called *deliberative safety*; it enables the changing of safety measures during operation depending on the requirements and intents of both people and robots using the system. The suggested deliberate safety emphasises how important adaptive safety measures are for addressing safety issues and performance. They suggested several Key Performance Indicators (KPI) to evaluate the need for flexibility in an operation (*namely, degrees of freedom, interaction, speed, and concurrency*) and the implementation of proper safety measures (*namely, coordination, monitoring, and complexity*) [19].

The "Safety Aspects-Guidelines for their inclusion in standards" section of ISO/IEC Guide 51: 2014 [21] provides an overview of the key principles of machinery safety. Using the 3-step Method and Protective Measures—Step 1: Inherently Safe Design Measures, Step 2: Safeguarding and Complementary Protective Measures, and Step 3: Information for Use—a safe machine is created based on a risk assessment by reducing or eliminating risks. The authors of [15] applied this approach to COVID-19 infection control. They applied the risk assessment process established in the standard to reduce the spread of COVID-19 in factories. The use of this methodology emphasises not only the actions and the personnel who implement them but also the assessment of their efficacy, financial impact, and applicability [15].

The ISO 12100:2010 [11] is an International Standard to give designers a framework and direction for decisions during the creation of machinery so that they may create products that are secure for the usage they are designed for. The ISO 12100 is the most used European standard in use during the design phase of a machine [31]. ISO 13849 and IEC 62061 [25] are two widely accepted worldwide functional safety standards that incorporate safeguards into machinery. When activated, they inhibit potentially dangerous movements, protecting workers. Although they are both built on similar concepts, these standards differ in key important ways. The authors of [13] examined those variations and any potential repercussions. Different levels of reliability in safety systems may result from subjective safety system specification and design, even when the same machine's hazard zone is considered, depending on which standard is applied. While the outcome was comparable with respect to the specified range of reliability, the variables used to estimate Performance Level (PL) and Safety Integrity Level (SIL), safety requirements attained, distribution of PL and SIL, common causes of failures, and diagnostic coverage were different. Therefore, system designers, technologists, and engineers should be trained to use both standards to decide which option is best for a particular design [13]. Data on the utilisation of regulatory documents from interviews and observations of 17 machinery manufacturers were represented in an exploratory study by [31] on integrating safety during the design and production phases of machinery in Canada. To develop their machinery in accordance with the needs of their customers and the health and safety regulations of the nations where they would be delivered, all manufacturers typically examined between five and six normative and regulatory papers. When creating their machines, the manufacturers they interviewed mentioned more than 30 regulations and standards. While these standards and regulations cover many topics, machine safety is one of them. All employees typically have access to these documents via an intranet. The monitoring of updates was generally performed, although it was not a widespread practice, and not all manufacturers had a systematic method for monitoring standards and regulations. Table 5 shows the most used documents in the companies interviewed by the authors.

Table 5. Most used documents in the companies interviewed by [31].

Document	Topic	Number of Manufacturers
Internal document	Internal design guidelines	14
CSA Z432 [28]	General safety of machinery	13
ISO 12 100 [11]	General safety of machinery	12
ROHS [29]	OHS regulation	10
ISO 13849 [23]	Safety of control system	9
CSA Z434 [30]	Robot safety	6

The majority of manufacturers followed the general safety of equipment standards CSA Z432 (Safeguarding of machinery) and ISO 12100 (Safety of machinery—General principles for design—Risk assessment and risk mitigation) [11]. One thing to remember is that twelve of the seventeen manufacturers adopted the ISO 12100 standard, even though only eight exported their goods to other countries. Ten manufacturers referred to the Regulation Related to Occupational Health and Safety (ROHS) in Quebec [29]. This might be explained due to the document's more generic nature when compared to more particular and detailed national and international standards about machinery safety. Nine manufacturers adopted the international standard ISO 13849 (Safety of machinery—Safety-related parts of control systems) [23], while six manufacturers used the Canadian standard CSA Z434 (Industrial robots and robot systems) [30]. Internal design guidelines were used by seventeen manufacturers, including regulations that went beyond the limits of electrical codes, modifications to regulations governing the geometry of components, and regulations governing the size of guards to improve operator visibility. According to most respondents, design teams typically had one person responsible for learning about and recording these references, aggregating the various revisions, and telling other team members about them. Respondents also stated that it was occasionally challenging to adhere to standards since the actions they advise can be impractical or prohibitively expensive [31].

Two studies were conducted in Russian panorama: the first one focused on Federal Law n.184-FZ of 27 December 2002 "On technical regulation" and the Customs Union technical regulation (CU TR) "On safety of Machinery and Equipment" on the design and manufacture of power engineering machine industry products. The design document "Safety Case" (SC) was elaborated on based on the Machinery Directive 2006/42/EC to harmonise the Russian standards with European Union standards. Aronson et al. [32] developed a model called "Elaboration of Requirements on Safety Cases for Turbines" [32]. The second one was based on the regulations "On the safety of machinery and equipment", and integrated management system architecture was suggested by [33]. The proposed technique for assessing the stages of process improvement based on the ISO 9000 family of standards [22] can be used to figure out the best path for an organisation's process development [31,32]. The study conducted by Saito et al. [18] details a case of the international harmonisation of Japanese machinery safety law and issues with applying ISO safety standards to Japanese workplaces. To understand the situation, a questionnaire survey was conducted in 2011. The findings suggested that international standards may not have been fully referenced or examined [18].

In the Polish scenario, Macek conducted a study on safety problems related to the relocation of machines and devices in Poland. Devices can be categorised into two groups:

1. New devices introduced to the European market for the first time;
2. Old devices already used previously.

The Machinery Directive contains requirements of the first category; the Tool Directive contains those for the second category. Production relocation should start with an economic analysis and concept for delocalisation, followed by delocalisation planning, and, lastly, the transfer. Moving machinery and other equipment is a difficult task that calls for extreme caution and compliance with safety regulations, such as those set forth in the Road Transport Act of 2001, which governs the standards for drivers' entrance to employment. The Polish standard PN-EN ISO 7010/2012 [34] adopts the European Standard ISO 7010:2011 (2011), which specifies colours and warning signals. According to the author, if the parameters, use, or kind of modified machinery considerably changes after being put into service and the level of risk is increased, it should be classified as new and the Machinery Directive should be followed [35].

4.3. Lockout Problems in the Literature

The most popular approach for safety isolating a machine's power source is using lockout/tagout protocols, which also increase safety during routine and emergency maintenance by limiting harmful energies. To carry out repairs safely, all of a machine's energy supply sources must be insulated, according to the essential safety and health protection requirement 1.6.3 of the Machinery Directive 2006/42/EC. The procedures, methods, and techniques used in lockout prevent workers from harm caused by the unintentional release of hazardous energy. The procedure, according to international standard ISO

14118:2000 [36], entails the following four steps: (a) isolating (disconnecting, separating) the machine (or defined parts of the machine) from all power sources; (b) locking (or otherwise securing), if necessary (for example, in large machines or installations), all the isolating units in the "isolated" position; (c) dissipating or restraining any stored energy; (d) ensuring that the actions made in accordance with (a), (b), and (c) above have had the desired effect. The procedure has been schematised in Figure 10.

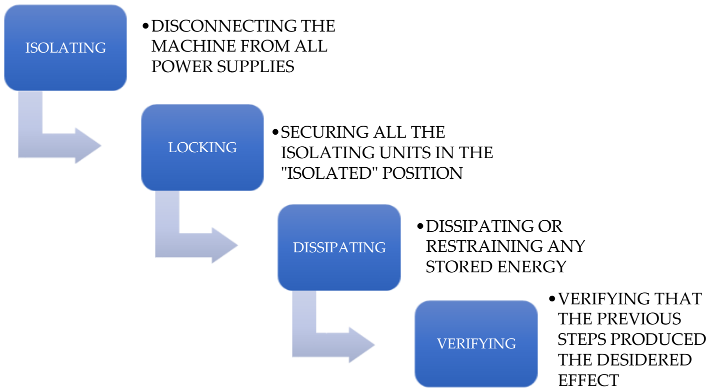

Figure 10. Procedure to safely isolate a machine, ISO 14118:2000 [36].

Failure to implement lockout measures to manage hazardous energies is one of the leading causes of serious and fatal injuries caused by machinery. The high number of accidents shows that organisations have difficulty applying the lockout procedures. Based on a review of 106 accident reports involving machinery in the manufacturing and processing industry, in Quebec, 54% of accidents were caused by wrong lockout procedures [1]. Bulzacchelli et al. [37] carried out research analysing 624 lockout/tagout accidents in the manufacturing industry in the USA. The findings are represented in Figure 11. They observed that in 58.8% of incidents, a lockout was not conducted at all; in a small percentage of incidents, lockout procedures failed due to human error (5.2); and a smaller percentage of incidents occurred despite the energy control being in use (1.2) [37]. This modest percentage implies that lockout/tagout methods do, in fact, reduce mortality when utilised correctly.

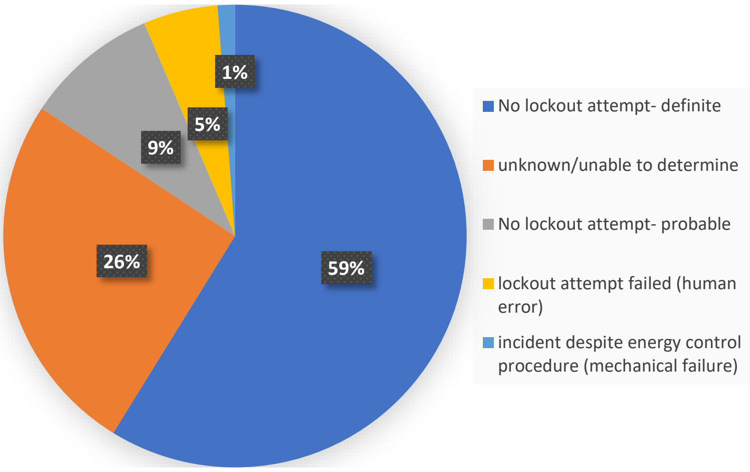

Figure 11. Incidents related to energy adapted from Bulzacchelli et al. [37].

According to the authors, the majority of workers killed in lockout/tagout-related incidents were stuck in or between pieces of equipment (52.1%) and numerous people were electrocuted (26.4%) or struck by or against an object (10.7%), as shown in Figure 12.

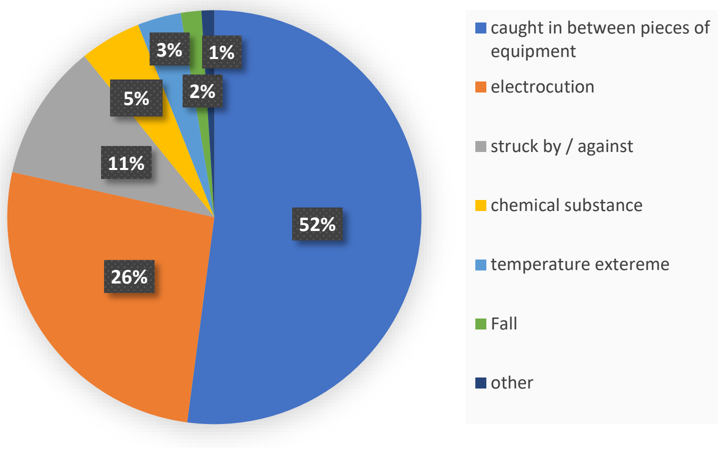

Figure 12. Cause of death in lockout/tagout-related incidents (%) adapted from Bulzacchelli et al. [37].

To understand how organisations implement lockout programmes, Karimi et al. [38] conducted a qualitative research study published in 2018. The study team created, tested, and utilised a questionnaire as a tool for collecting interview data and incorporating data from site visits and document reviews. A heterogeneous sample formed by 13 companies in Quebec was analysed. The companies chosen were in the following industries: food and agriculture, printing, plastic product manufacture, pulp and paper, metal fabrication, chemical, and health. The following observations were made:

1. *Incomplete lockout programmes: in ten companies, several elements were absent or lacking*.
2. *Missing steps in general lockout procedures*: six firms encountered near-miss situations.
3. *Not reading the placards*: ten organisations claimed that employees sporadically read the placards when performing lockout procedures.
4. *Using alternative methods without risk assessment*: only three companies validated alternate lockout procedures for a specific activity using some type of risk analysis tool.
5. *Poor training*: in eight organisations, the training had no practical part, and, in nine organisations, the lockout programme was not part of the training.
6. *Absence of supervision and coordination of subcontractors*: only four programs indicated evaluations of subcontractors' competencies and in eight companies there was an absence of synchronisation of the roles and responsibilities.
7. *Lack of audit tools and documentation of audit results:* even if more than half of the organisations (9/13) claimed that they regularly conducted audits of their lockout programmes, lockout practices, and/or lockout applications, they discovered that just one organisation had separate checklists (tools) for each of these kinds of audit [37].

Poisson and Chinniah [39] observed the lockout procedures in eight sawmills, and 57 interventions that required lockout procedures were observed. In the eight factories, in contrast to the standards and regulations, which only describe one universal lockout method, five techniques were used. Based on the findings, it can be concluded that both the lockout method and the return to service procedure omitted the verification stage. Lockout cards were available or being created, but employees did not utilise them. Workers may be put in danger when troubleshooting and unjamming are performed without following lockout rules [40].

Karimi et al. [40] developed a self-audit tool to apply lockout to machinery easily. The two steps of the self-audit tool for the lockout application were the pre-audit and the audit. These two phases of the tool were the prerequisites and requirements for using lockout procedures. They were composed of a collection of checklist statements. The self-audit tool created was tested for content validity to ensure that it fully complied with all Canadian and American standards. To do this, a panel of six experts in hazardous energy control was asked to evaluate the suitability and validity of the checklist statements in the tool. After gathering all the feedback, six organisations tested the self-audit tool to obtain feedback from a more practical perspective. All the chosen organisations had some experience with internal audits of lockout applications; general information about the company is shown in Table 6. The authors updated their work according to the companies' requests. The participating companies generally regarded the self-audit as informative and simple [40].

Table 6. General information about the companies selected for the Karimi et al. (2019) [40] study.

Company	Sector	Size (Number of Employees)	Approximate Number of Machines/Equipment
1	Chemical	<100	125
2	Manufacturing	<500	800
3	Printing	<500	100
4	Municipal	≥500	5000
5	Pulp and paper	<500	4000
6	Aerospace	≥500	1300

From the analysis of Poisson and Chinniah [39], the main factors for the correct application of lockout of machinery in sawmills were as follows:

- Clear management leadership regarding lockouts.
- Workers following the bulk of lockout protocols and being empowered to do so.
- Lockout hardware located near the machinery and easily accessible.
- Easily accessible devices for isolating sound that require little effort to turn off.
- Easy-to-follow procedures, saving time and making ignoring them less tempting. The procedures took an average of 3 min.
- Improvements in lockout procedures through worker feedback.
- Employee sense of ownership fostered via participation in the creation of procedures.
- Sufficient training on lockout procedures.
- Intolerance of infractions of lockout procedures, with sanctions implemented progressively.

Among the main difficulties was the need to improve lockout programmes regarding general lockout and return-to-service procedures [39]. In accordance with [39], [38] found some good practices, among those "improving safety culture through training of employees and progressive incentive and disciplinary measures" [38].

Training must be provided to new or inexperienced employees who must operate or maintain machines. According to [1], correct training on operators' production disturbances and mechanics lockout procedures should be covered with practical training. Training workers on specific lockout procedures is also important. The authors identified a lack of training and the absence of lockout procedures during maintenance as the main causes of accidents [1].

The researchers of the study published by Burlet-Vienney et al. in 2021 [41] reported on energy control procedures on building sites. As can be seen in Figure 13, the study concentrated on four professions: electricians, pipefitters, refrigeration mechanics, and construction millwrights. Ten individuals participated in a semi-structured interview and answered a questionnaire for each of the four trades the study focused on. All participants understood the purpose of the lockout application, although only a small portion of them (18%) were aware of the current energy control regulation. Even though 89% of participants reported having taken at least one training course on lockout and energy control over their careers, 10% of participants insisted that they had not. Participants reported enrolling in training programmes as part of a plan to obtain access to an industrial location in two-thirds of the cases. In 8% of the cases, the business made the arrangements for the employees' training; in other instances, the training was a cooperative effort or the participant chose to participate. The participants appeared to have mostly learnt about the theoretical elements of a lockout from their experiences on industrial sites, according to the data gathered about the training [41].

Training enables a worker to obtain the information and expertise required to manage the ongoing hazards associated with a certain job environment. In addition, it might encourage motivation while stimulating workers' interest in accident prevention. With the right training, a worker can close the gap between their current abilities and those necessary to complete tasks safely and comprehend the risks to which they are exposed. Unfortunately, proper safety training is not a common practice from the point of view of workers; they consider that they do not receive enough training regarding machine safety, especially regarding lockout/tagout procedures [42].

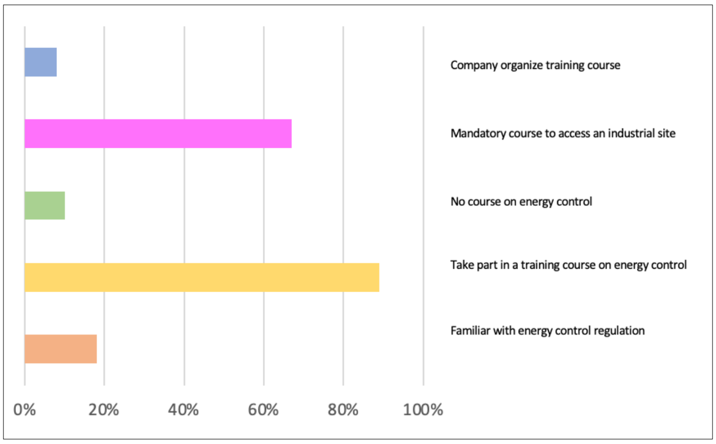

Figure 13. % from the sudy of Burlet-Vienney et al. in 2021 [41].

Training should be greatly increased; it is a decisive component of each manufacturing process. In addition, training employees is crucial for both new and transferred roles [35].

4.4. Surveys in the Literature

Eleven papers that conducted observations and/or surveys were identified in the literature analysis. The principle aim of the survey works present in the literature was to investigate energy control practices or collect opinions about different risk identification or risk assessment tools.

Poisson and Chinniah [39] conducted qualitative research based on observing 57 lockout procedures. The goal was to examine both intentional and accidental interventions and, to do so, the researchers spent two days in sawmills. From the observations, different lockout methods were applied in the eight industries involved in the study and significant steps in the lockout protocols were bypassed. Some interventions were performed without following lockout protocols, putting personnel at risk.

One of the main factors contributing to serious and fatal injuries from machinery is the failure to apply lockout procedures for the management of hazardous energies. The high number of accidents shows that organisations have difficulties applying lockout procedures. To comprehend how businesses implement lockout programmes, Karimi et al. [38] conducted qualitative research. The study team created, tested, and employed a questionnaire for data collection through interviews, incorporating data from direct observations and document reviews. It was discovered that there were incomplete lockout programs, missing steps in general lockout procedures, failures to read placards, uses of alternative methods without risk assessment, inadequate training for alternative methods, a lack of supervision and coordination of subcontractors, and a lack of audit tools and documentation of audit findings. Chiasson et al. [7] conducted a study comparing eight different methods to determine the risk factors associated with musculoskeletal problems. Three risk categories were used to compare the outcomes (low, moderate, high). Video recordings were used to collect data, and measurements were made at 224 workstations involving 567 tasks. The study's employee participants were also given a questionnaire to collect opinions. The results show that different approaches analyse the same data differently [7].

Saito et al. [18] distributed questionnaires to domestic robot users and manufacturers. This questionnaire aimed to understand the current use of industrial robots in Japanese worksites. The questionnaire comprised 24 items on opinions on the regulations and ISO standards. The findings suggested that international standards may not have been fully referenced or examined [18]. According to [43], small businesses are more likely than large ones to experience fatal or serious accidents, and they also experience more lost workdays because of injuries. However, the short-term financial advantages of prevention are not immediately apparent. Farina et al.'s [43] project consisted of four phases:

1. A self-assessment questionnaire for the companies to complete and an invitation to participate in the project.
2. Visits to the companies conducted by technicians without juridical power.
3. Free training and meetings to give information on current regulations and economic incentives available in Italy.
4. An examination of a representative group of the chosen companies, during which the inspectors compiled the same checklist used in the initial visits.

The results revealed a large improvement (more than 20%) in the environment but no meaningful increase for the machines [43]. Energy management on construction sites is crucial and was investigated by researchers [41] focusing on four professions—electricians, pipefitters, refrigeration mechanics, and construction millwrights. The questionnaire and semi-structured interviews conducted with ten or so participants for each of the four trades reported that lockout procedures in construction sites were in fact needed and being used, and highlight the differences between actual practices and legislative requirements that do not discern between different types of construction sites [41].

Two exploratory studies were carried out in the province of Quebec. One of these, detailed in [31], was based on interviews and observations conducted at 17 machinery manufacturers. They investigated the application of norms, risk assessment and reduction techniques, the evasion of safety precautions, the design of the safety-related components of control systems, maintenance considerations during the design phase, ergonomics, and industrial hygiene [38]. The other study was conducted by Tremblay et al., in 2018 [42]. The aim was to highlight the problem with machinery in hospitals; to do so, 17 managers and 17 workers were questioned. Information about the machines used, their risks, and documents about machinery risk management procedures were gathered. The findings demonstrate that machine-related hazards are significant in this industry and that machinery safety is frequently lacking. None of the facilities were equipped with lockout/tagout procedures, methodologies for evaluating machine risk, or a dedicated document describing safety rules for handling machine hazards [42]. To better understand the execution of the reduced speed and energy operating conditions used for maintenance and other interventions in Quebec and determine the factors influencing the choice of reduced speed and energy values in Quebec, Chinniah et al. conducted a study in 2017 [44].

Chinniah et al. [12] investigated the flaws in six risk estimation tools applied to four production activity scenarios. After the use of a specific tool and the result calculation by the researchers, experts were asked to express their degree of agreement with the risk level obtained using a 5-point Likert scale, justifying their answers. More than 28% disagreed with the risk level obtained [12]. The second part of the study was carried out by Chinniah et al. [12], in it five potential construction flaws of the risk estimation parameter were analysed. Participants in the study selected the right level for each of the two key risk estimation parameters—the severity of harm and the probability of harm—and were then asked to rate the decision's difficulty on a scale of 1 to 5.

In most cases, participants indicated high level of difficulties when applying a parameter to the appropriate defect. The findings indicated that the impact of the parameter's construction flaws was not uniform. For example, the probability of harm parameters appeared to be less solid than the severity of harm parameters [10].

Table 7 summarises the questionnaires and structured interviews used in the literature; for each, the following are analysed: purpose, respondents, sample of respondents, structure of the questionnaire/interviews, and results that the authors extrapolated from the data.

Table 7. Overview of questionnaire/structured interviews in the literature.

Authors	Aim	Responders	Sample	Structure	Results
Chiasson et al., 2012 [7]	Collect opinions on different methods to determine risk factors.	Workstation employees	516 workers	Not available	Different approaches analyse the same data in different ways.
Saito et al., 2015 [18]	Understand the use of industrial robots in Japanese workplaces.	Robot manufacturers and users	36 robot manufacturers 14 robot users	24 items (opinions on the regulations and ISO standards)	The implementation of collaborative robots in Japan is already occurring. Risk assessments are carried out, but data on accidents and incidents are not collected.
Farina et al., 2015 [43]	Self-assessment for companies.	Small companies	103 companies	Not available	Meet the selection criteria of the study to conduct site visits.
Chinniah et al., 2017 [44]	Identify values for safe reduced speed, understand how and why it is used in the company	1 manufacturing industry 1 pulp and paper sector 3 printing companies 3 food processing companies 1 horticulture and food processing company	9 companies	Two parts: Part 1: i. General information about the company ii. Contact information iii. Types of interventions requiring the safe operating mode iv. Reasons behind the use of reduced speeds v. Accident history Part 2: i. Actual values of reduced speed and energy used ii. Whether this feature was added or included in design iii. Understanding the reasons behind the choice	Users occasionally modify machines to include reduced speed settings since designers and manufacturers leave them omitted. Almost every company replaced or removed guards and/or disabled protective devices.
Karimi et al., 2018 [38]	Understand the application of lockout procedures and other methods of control of hazardous energies in the selected companies.	2 chemical industries 2 food industry 1 pulp and paper sector 2 plastic industries 1 fabrication sector 1 recycling sector 1 printing sector 1 horticulture and agriculture sector 1 aerospace sector 1 health service	13 companies	Six items: i. The general lockout programmes ii. Application of lockout iii. Other methods of control of hazardous energies iv. Sub-contractor management v. Training vi. Audit/inspections	○ Incomplete lockout programmes ○ Missing steps in general lockout procedures ○ Not reading placards ○ Using alternative methods without risk assessment ○ Poor training on alternative methods ○ Absence of supervision and coordination of subcontractors ○ Lack of audit tools and documentation of audit results

Table 7. *Cont.*

Authors	Aim	Responders	Sample	Structure	Results
Tremblay and Gauthier, 2018 [42]	Obtain non-medical managers' and personnel's perspectives on managing machinery risk.	Hospitals	17 managers 17 workers	Structured around five risk management practices: i. Machine risk assessment ii. Safeguarding of machinery iii. Lockout/tagout iv. Machine and equipment inspection v. Training	Machine-related dangers are a problem in the hospital sector; yet, machinery protection is frequently inadequate. None of the facilities had any protocols for evaluating machine risk, a lockout/tagout programme, or a specific document outlining safety guidelines for dealing with machine threats.
Chinniah et al., 2018 [12]	Test potential flaws in six risk estimation tools.	Maintenance personnel or safety practitioners in businesses, industry associations occupational health and safety advisors, and engineers with expertise in machinery safety	25 participants	Not available	Divergent outcomes can be amplified by architecture that places more emphasis on one parameter, which can also make the tool less capable of correctly classifying instances. In addition, it is challenging to discern between scenarios when architecture's unequal risk level distribution is present, making users unhappy with the outcomes.
Gauthier et al., 2018 [13]	Test the impact of flaws disturbing the parameters used in risk estimation tools.	Maintenance personnel or safety practitioners in businesses, industry associations, occupational health and safety advisors, and engineers with expertise in machinery safety	25 participants	Not available	In most cases, participants were able to link perceived difficulties with applying a parameter to the appropriate defect. The findings indicated that the impact of a parameter's construction errors was not uniform. The probability of harm parameters appeared to be less solid than the severity of harm parameters.
Burlet-Vienney et al., 2021 [41]	Recognise how energy is controlled in the construction industry.	Electricians, pipefitters, refrigeration mechanics, and construction millwrights	38 participants	Four sections: i. Identification of participants ii. Participants' energy control practices iii. Open-ended description of at least two typical work experiences on a construction site iv. Discussion about factor (such as type of construction site, type of work required) influence on energy control	The primary concern in the construction industry is energy control, which mostly depends on the type of construction site.

5. Conclusions

This study aimed to carry out a literature analysis to examine the current state of the art for the safety of machinery. In line with the objective of the analysis, 29 studies published from 2008 to 2024 were examined. The papers were examined through bibliometric analysis of the year of publication, country, citation statistics, and study of the keywords. These studies were classified into accident analysis papers, papers focused on the normative, papers that addressed risk assessment tools, and papers that conducted quantitative research. In addition, a more in-depth analysis of the articles associated with the keywords with the highest number of occurrences was carried out. Lastly, studies with quantitative analyses were analysed in order to identify new possible aspects that it is necessary to investigate.

As can be seen from the studies presented in this review, the current legislation has some limitations, the integration of the European standards with legislation in other countries is not straightforward, and some legislation has not been fully referenced or examined [18,32,33]. The articles also show that training is crucial and enables workers to gain the information and expertise required to manage the ongoing hazards associated with a certain job environment. Furthermore, it might encourage motivation while stimulating workers' interest in accident prevention [41]. Unfortunately, proper safety training is not a common practice; workers consider that they do not receive enough training regarding machine safety, especially regarding lockout/tagout procedures [42]. Training can be seen as one of the causes of non-compliance with the safety procedures that workers should perform to ensure their safety and that of their colleagues. From the analysis of the papers about lockout procedures, it appears clear that in most of the cases, when an accident happened, the lockout procedure was not carried out at all or the accident was caused by the wrong application of the procedure [1,37,38].

As highlighted by Scorgie et al. (2024) [45], optimising worker training programmes through the use of innovative methodologies such as virtual reality could contribute to improving safety, especially in the construction and firefighting sectors, which are the most investigated. The authors found inadequate training to be one of the primary causes of non-compliance with protective procedures. The results of the conducted meta-analyses further demonstrated a greater effectiveness of virtual reality compared to traditional methods in acquiring and retaining safety-related knowledge over time. These findings suggest that updating training through new immersive technologies may optimise worker training, significantly increasing workplace safety levels.

Based on the results of this review, future research activities may include an in-depth analysis of the current training status of workers in industries through quantitative analyses that investigate the correlation between training and workers' awareness of the aspects of security; studies could also be carried out on how to make the training of workers on lockout procedures more effective and how it is possible through the new technologies on the market to assist workers during these operations and verify the correct execution.

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