Journal of Safety Science and Resilience 7 (2026) 100272

Contents lists available at ScienceDirect

Journal of Safety Science and Resilience

journal homepage: www.keaipublishing.com/en/journals/journal-of-safety-science-and-resilience/

A state-of-the-art review of safety leading indicators across diverse industries

Haleh Sadeghi [a], Saeed Reza Mohandes [a], Akilu Yunusa-Kaltungo [b,*], Clara Cheung [a], Patrick Manu [c]

[a] Department of Civil Engineering and Management, School of Engineering, The University of Manchester, Manchester, M13 9PL, United Kingdom
[b] Department of Engineering for Sustainability, School of Engineering, The University of Manchester, Manchester, M13 9PL, United Kingdom
[c] School of Architecture and Environment, University of the West of England, Coldharbour Lane, Bristol, BS16 1QY, United Kingdom

ARTICLE INFO

Keywords:
Safety leading indicators
Occupational safety and health
Safety management
Cross-sectoral analysis
Proactive safety measures
Systematic literature review

ABSTRACT

Numerous studies have explored safety leading indicators (SLIs) and their impact on safety performance across industries. However, inconsistent use of these SLIs hinders the comparison of findings and the drawing of conclusions. Thus, there is a demand for standardised SLIs that can be universally implemented across sectors, aiming to enhance safety performance. To address this, a comprehensive Systematic Literature Review (SLR) was conducted in this paper. The SLR employs the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol for systematic searches, followed by conducting scientometric analysis, content analysis, identification of research gaps, and the proposal of potential future streams. Using an evidence quality assessment method, 67 SLIs were discovered. "Task characteristics" displayed the most relationships with other SLIs, while "Training and education" appeared most frequently. Moreover, it is observed that the existing literature lacks consideration of the utilisation of emerging approaches such as AI-based techniques and digitalisation, thereby limiting improvements in Occupational Safety and Health (OSH). The findings from this SLR provide valuable insights to safety professionals and managers, aiding the development of safety policies and programs by emphasising key SLIs that contribute to safety performance, which, in turn, improves OSH across multiple industries and regions.

1. Introduction

Workplace accidents continue to be a worldwide concern, particularly in high-risk sectors, such as construction, manufacturing, mining, and oil and gas. The International Labour Organization (ILO) estimates that >2.3 million people die each year from work-related accidents and diseases; about 374 million non-fatal occupational injuries happen annually, causing notable economic and social consequences [1]. The Health and Safety Executive (HSE) in the UK recorded 135 workplace deaths in 2022/23, mostly in construction, manufacturing, and agriculture [2]. Similar patterns can be seen worldwide; industries including logistics, chemicals, and healthcare are also experiencing growing safety concerns [3].

In such settings, efficient Occupational Safety and Health (OSH) management depends on methodically expecting, tracking, and enhancing organisational safety performance [4,5]. Regularly measuring safety performance helps companies to spot developing hazards, assist proactive decision-making, and assess the effects of safety projects. High-reliability companies (HROs) maintain operational continuity and safety in complicated, high-risk environments [6]. Even in dangerous systems, they give continual vigilance and education top priorities [7]. Transforming underperforming systems into resilient and adaptive safety cultures requires first identifying and addressing early warning indicators of safety decline. Thus, using timely data to track and identify early signs of rising risk is not only strategic but also essential [8].

Traditionally, safety performance has been assessed by lagging indicators such as Occupational Safety and Health Administration (OSHA) recordable injury rates, DART (Days Away, Restricted, or Transferred) injury rates, and EMR (Experience Modification Rate) [9]. These indicators provide historical information, but their value as predictors of future safety remains uncertain [10]. There is a growing scepticism

Peer review under the responsibility of China Science Publishing & Media Group Ltd.
* Corresponding author.
E-mail address: akilu.kaltungo@manchester.ac.uk (A. Yunusa-Kaltungo).

https://doi.org/10.1016/j.jnlssr.2025.100272
Received 17 January 2025; Received in revised form 8 September 2025; Accepted 12 October 2025
Available online 11 November 2025
2666-4496/© 2025 China Science Publishing & Media Ltd. Publishing Services by Elsevier B.V. on behalf of KeAi Communications Co. Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

among safety professionals regarding the adequacy of lagging indicators, as they may not offer sufficient insights to prevent future accidents effectively. Overemphasis on lagging indicators may unintentionally undermine the importance of safety prevention [11]. In contrast, Safety Leading Indicators (SLIs) are proactive, preventive measures meant to find and handle possible safety concerns before they show up as incidents or injuries [12]. Unlike lagging indicators, which are reactive and based on past incident data, SLIs are forward-looking and meant to indicate conditions or behaviours that might cause negative safety consequences [13,14]. They highlight unsafe trends, system weaknesses, or procedural failures that could worsen if ignored, therefore acting as early warning signals [15]. Importantly, SLIs are not necessarily based on past accident records but rather on continuous monitoring of human factors, organisational processes, and environmental conditions. These indicators could be the number of near-miss reports, the frequency of safety audits, employee involvement in safety training, or the existence of safety protocols during high-risk activities. SLIs promote proactive intervention by emphasising actions and circumstances preceding events, therefore lowering the probability of accidents. Moreover, they are quite important in creating an adaptive safety culture focused on learning, helping organisations change their practices in reaction to developing hazards and operational changes by producing real-time feedback, therefore supporting ongoing improvement [16]. SLIs help not only to lower risk but also to develop organisational resilience in complicated and dynamic work settings by means of methodical monitoring and assessment.

In contrast, SLIs are proactive measures that can predict future safety performance [12]. They are not necessarily based on historical data. SLIs are tied to actions taken to prevent accidents and provide early indications of potential adverse events. They drive preventive actions and contribute to continuous learning and the development of an adaptive safety system [16].

Given this context, two main approaches dominate the analysis of safety factors: sector-specific analysis and cross-sector standardization. Sector-specific analysis tailors SLIs to the specific conditions of each industry, which restricts the broader applicability of the findings and hinders cross-industry comparisons. On the other hand, standardization aims to develop a universal set of SLIs that can be applied across multiple industries, thereby facilitating benchmarking and the sharing of best practices. Several researchers have investigated the impact of SLIs on the safety performance of industrial workplaces using sector-specific analysis, including in sectors such as mining [17], construction [18–20], nuclear [21], and health [22–24], amongst many others. Likewise, quite a few literature review-based studies have been conducted to identify the related indicators that impact the safety of projects in standalone industries [9,20,25]. Despite the efforts undertaken in this area, there has been a dearth of Systematic Literature Review (SLR) papers that examine these indicators across multiple industries, providing a solid and comprehensive picture for both researchers and practitioners. In this study, we adopted the standardisation approach to develop a cohesive and unified understanding of SLIs that can be applied across multiple industries. This approach facilitates more effective benchmarking of safety performance and the identification of best practices that are transferable across sectors. Although the literature on sector-specific SLIs is extensive, it often results in fragmented insights that are difficult to generalise. By systematically analysing SLIs across various industries, our study aims to address this gap and provide a comprehensive overview that benefits a broader range of stakeholders. Standardised SLIs can establish a common language and criteria for safety management, making it easier for companies to adopt and implement effective safety practices regardless of their industry. Ultimately, this can lead to improved safety outcomes on a larger scale. While OSH encompasses both physical safety and health dimensions, this review focuses specifically on SLIs related to the proactive management of physical safety in the workplace. This scope is guided by the observed predominance of safety-focused SLIs in existing literature, as well as their more established link to measurable performance outcomes such as injury rates, near misses, or unsafe behaviours. In doing so, the review addresses an urgent need to consolidate the fragmented body of research around SLIs and their application across industries.

In summary, this SLR paper aims to achieve the following objectives (O):

O1: To analyse existing literature on SLIs through bibliometric, scientometric, and quality assessment techniques in order to evaluate the strength of evidence and identify recurring trends across industries.
O2: To synthesise the key SLIs used across various industries, assess their measurement methods and interactions, and identify research gaps and future directions through detailed content analysis.

Baed on the formulated objectives, the following Research Questions (RQ) — which is related to the materials published on the SLIs' impact on safety performance within multiple and diverse industries that are domiciled in different regions— are furnished:

RQ1: What are the key trends, recurring patterns, and overall strength of evidence in the existing literature on SLIs across industries?
RQ2: Which SLIs are commonly used across industries, how are they measured, and what gaps exist in current research that could inform future studies?

The research questions outlined above reveal critical gaps in our understanding of SLIs. Addressing these gaps is vital for developing a comprehensive understanding of the field, identifying future research directions, and improving methodological approaches. Without this knowledge, organisations may misdirect resources toward ineffective safety measures, resulting in suboptimal safety outcomes. Moreover, the lack of a unified list of SLIs hinders the ability of safety managers across industries to share best practices and drive continuous improvement. A deep understanding of SLIs is essential for identifying specific areas where safety performance can be enhanced, setting meaningful goals, and implementing targeted interventions to improve overall safety performance.

To tackle the research questions mentioned above, the following objectives are furnished:

Safety professionals and decision-makers are provided with a comprehensive and well-structured overview of existing knowledge on SLIs through this SLR paper. It facilitates the development of a deep understanding of the diverse indicators that have been examined, encompassing their definitions, measurement methods, relationships, and potential influence on safety performance. With this knowledge, professionals are empowered to make informed choices regarding selecting and implementing SLIs in their respective organisations, irrespective of sector or region of operation.

2. Methodology

To conduct a comprehensive SLR, several phases were followed in this state-of-the-art review paper. As shown in Fig. 1, Phase I is concerned with the systematic search for the identification of relevant documents in the corpus of literature based on different academic and grey literature. Phases II and III are respectively related to the quality assessment and scientometric analysis, while Phase IV focuses on content analysis. The gaps existing in the body of relevant literature and the corresponding future works are elaborated on in Phase V. Each of the aforesaid phases is expounded in the following sub-sections.

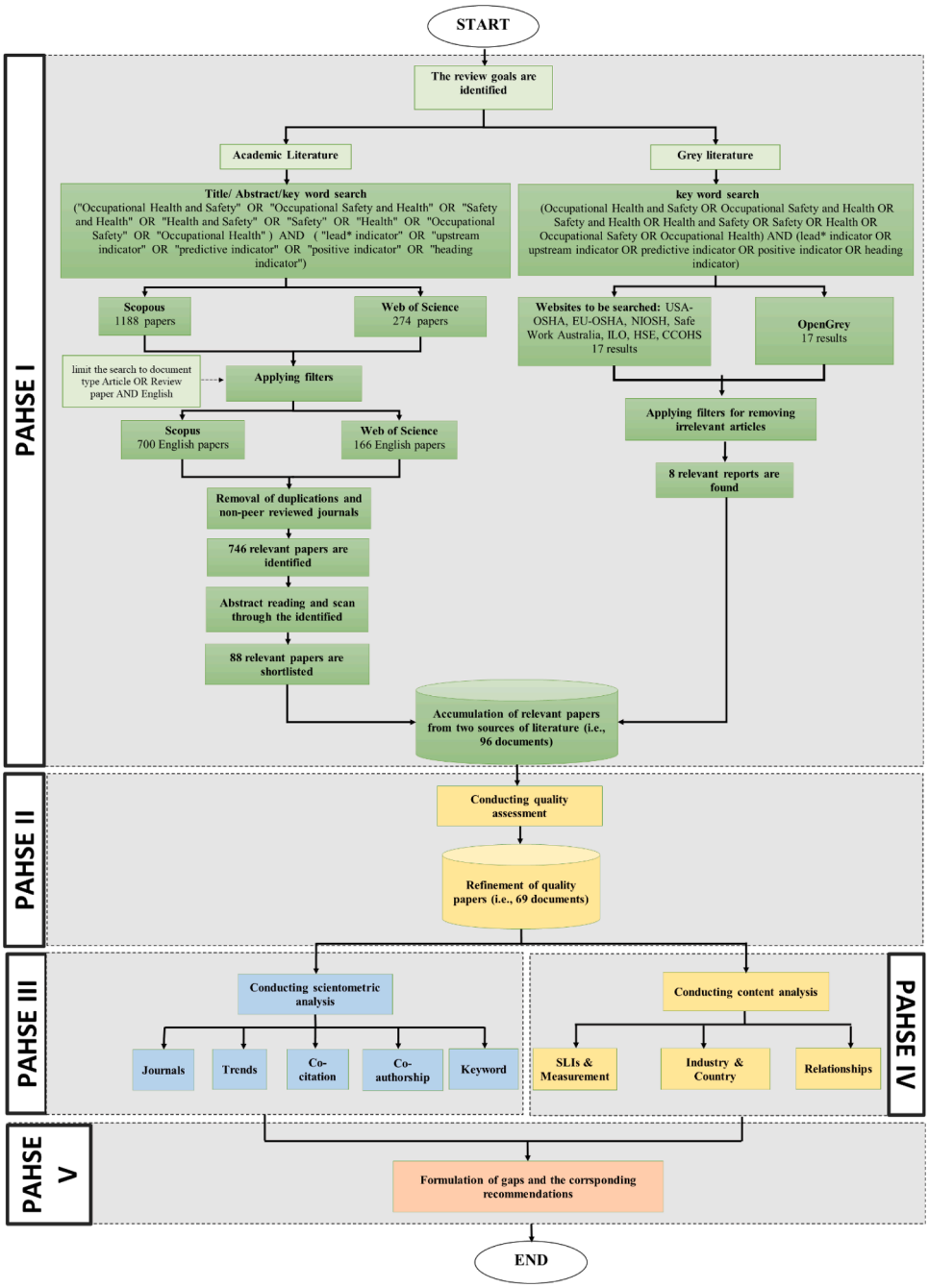


Fig. 1. SLR flowchart.

2.1. Phase I: systematic search

The approach used in this study for undertaking a systematic review is based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), which was developed by Sharma and Oremus [26,27]; these frameworks informed the planning, identification, screening, eligibility assessment, and final inclusion of studies. The detailed PRISMA protocol used in this study is summarised below. We conducted a systematic search of both academic and grey literature. Scopus and Web of Science were chosen for their extensive, cross-disciplinary coverage. For grey literature, we used the OpenGrey database and repositories from major OSH regulators, such as OSHA (USA/EU), SafeWork Australia, and HSE (UK). A comprehensive set of keywords was utilised for the search (see Fig. 1). The search strategy was designed to be comprehensive yet focused, by including a broad range of occupational safety and health-related terms (e.g., "Occupational Safety and Health", "Safety and Health", "Occupational Safety"), combined with variations of leading indicator terminology, including the "lead* indicator", "upstream indicator", "predictive indicator", "positive indicator", and "heading indicator". Additionally, the wildcard (*) was used to capture different word endings (e.g., "leading", "lead"). Although alternative terms such as "measure", "index", or "metric" were considered, they were excluded from the final search string to avoid the retrieval of non-relevant articles (e.g., trailing indicators or general safety statistics); this choice ensured that the search remained aligned with the proactive and predictive nature of SLIs. The search string was developed based on a preliminary scoping review of the literature and iterative testing of keyword combinations. Specifically, we analysed commonly used descriptors for safety leading indicators in academic literature and institutional reports. Adjectives such as "leading,"

Table 1
The scores and corresponding criteria considered for QA.

Robustness of Evidence	Description
1-Very low	Very weak evidence with minimal methodological detail. Findings are largely anecdotal, opinion-based, or speculative, with no clear explanation of data sources, collection, or analysis methods.
2- Low	Weak evidence relying primarily on expert opinion or informal narratives. Limited methodological transparency; unclear participant/sample characteristics or data collection process. Often lacks peer review or rigorous validation.
3-Medium	Moderate-quality evidence supported by some data (qualitative or quantitative), but with limited methodological transparency. Data may be collected through basic surveys or interviews, and analysed using simple methods (e.g., descriptive statistics, thematic grouping), without triangulation or depth.
4-High	Strong evidence with well-defined methods, clear rationale for sampling/data collection, and appropriate analysis techniques. Studies show an effort to control for bias and support conclusions with sufficient depth. Includes triangulation, inter-coder reliability, or advanced analytical tools.
5-Very high	Very strong evidence based on methodologically rigorous research designs, regardless of paradigm. Includes randomised or theory-based sampling, well-executed analysis (qualitative or quantitative), and thoughtful handling of confounding/contextual factors. Results are replicable and clearly reported.

"predictive," "positive," "upstream," and "heading" were selected due to their recurrence in SLI-specific literature. Broader synonyms, such as "measures," "metrics," or "tasks," were excluded after pilot testing revealed a high proportion of false positives and non-relevant records, including studies on safety instrument calibration, task design, or unrelated performance metrics. Our goal was to prioritise relevance and specificity over volume, which was essential for a manageable and focused systematic review. Notably, the search was completed in late December 2024, which defines the endpoint for the included studies. Notably, the following were the inclusion criteria: studies discussed SLIs or related proactive safety performance measures; studies that were peer-reviewed journal articles or quality grey literature (e.g., institutional reports from OSHA, EU-OSHA, National Institute for Occupational Safety and Health (NIOSH), etc.); studies focused on OSH across any industry; studies that were published in English, while the exclusion criteria included studies that focused solely on lagging indicators or post-accident analysis without linking to SLIs; and non-English articles and duplicate records.

Initially, the search resulted in 1193 articles from Scopus and 438 from Web of Science. After filtering for articles and reviews in English, the numbers were reduced to 729 and 177, respectively. Following the removal of duplicates and non-peer-reviewed journals, 757 articles were retained. The selection was narrowed down to 88 relevant articles through a two-stage screening process. Initially, abstracts were reviewed to check for a focus on SLIs, and articles not meeting this criterion were excluded. Notably, this was done by two researchers, so as to increase the quality of abstract screening for the determination of eligibility. Following this, a full-text review of the remaining articles was conducted to confirm their relevance to the research scope. This process ensured that only the most pertinent studies were included. Additionally, eight relevant reports were found in the grey literature sources.

2.2. Phase II: quality assessment

In Phase II, an evidence-based quality assessment (QA) was conducted to determine the robustness of the identified papers and to pinpoint the relevant SLIs [26,28]. QA is regarded as a fundamental requirement in any systematic review [29–31], and several guidelines and recommended practices for the effective implementation of QA on primary studies have been developed over the past few decades [29,32,33]. Examples include the structured QA frameworks developed by the Kitchenham [32] checklist for software engineering studies, the updated evidence scoring matrix proposed by Kitchenham et al. [33], and cross-disciplinary guidance from Yang et al. [31] and [30]. These informed both the scoring criteria (Table 1) and our decision rules for assessing the strength of evidence presented in the included studies. Notably, QA is essential because it helps reduce bias and, in turn, enhances both internal and external validity [34]. Reducing bias involves generating accurate results by addressing systematic errors. Internal validity focuses on ensuring that the study's design and execution are free from flaws, while external validity concerns the extent to which the findings can be generalised [35].

Each paper was scrutinised based on several criteria, including the methodology used, data collection procedures, depth of analysis, sampling techniques, and the handling of confounding variables (see Table 1). To ensure reliability, two researchers independently evaluated and scored each paper, with the combined scores reflecting the overall quality of the studies. Papers that scored below the medium level (one or two on the assessment scale based on the aggregation of the given scores) were excluded from the SLI identification process. Notably, we adopted a structured QA approach to ensure that the studies included in the content analysis met a minimum standard of methodological rigour; the papers scoring below the medium threshold (1 or 2 on our 5-point scale) were excluded to avoid synthesising insights from very weak evidence. This step was essential to enhance the reliability of our findings while maintaining transparency about the limitations of post hoc evaluation methods. After this rigorous QA process, out of 96 documents identified through both academic and grey literature, 69 documents met the necessary threshold and were selected for further analysis. It should be noted that the implemented QA can serve as a guide to other researchers by assisting researchers in gauging the strength of the evidence presented by studies and selecting studies that best support their conclusions (e.g., arguments, hypotheses/conceptual formulations, results, and conclusions).

2.3. Phase III: scientometric analysis

Once the irrelevant articles were excluded, a scientometric analysis was then conducted. Due to the relevance of scientometric analysis for bias minimisation as well as its relevance to science mapping, it is believed that its inclusion could improve the understanding of the studied field [36]. The VOS viewer platform was used to facilitate this study's scientometric analysis, owing to its ability to objectively produce maps illustrating the body of relevant literature [37]. In doing so, several analyses were undertaken [38], including publication trends, journals' contributions, a co-citation map of the authors, a collaboration map of authors, and a map of the most used keywords.

2.4. Phase IV: content analysis

To extract inclusive information from the identified relevant papers, a detailed content analysis was carried out in this SLR paper, as expounded in detail by Siraj and Fayek [39]. Content analysis is a research method that extracts crucial elements and draws reliable conclusions from written, spoken, or visually communicated messages [40]. Depending on the research project and specific issues at hand, content analysis can be applied qualitatively or quantitatively [41]. It is a valuable technique for gathering and organising information, as well as for examining patterns and trends within documents [42]. Qualitative content analysis involves categorising data into groups, while quantitative content analysis involves assigning numerical values to categorised data, such as frequencies, ratings, or rankings, by simply counting the occurrences of specific topics. The current study utilises a combined approach, employing both qualitative and quantitative

content analysis methods. To do so, each paper was scrutinised for identification of the following information: SLIs along with their definitions, the measurements used to characterise each SLI, the relationships existing among the SLIs, the industry and country where the study was undertaken, and the employed research methods. Notably, this phase involved two researchers who meticulously delved into the identified papers. One researcher extracted the necessary information from each paper, and the second researcher reviewed this information to ensure its reliability and accuracy. It is noteworthy that in this study, SLIs are defined as measurable, proactive, and preventive indicators that precede undesirable safety outcomes and are used to monitor, predict, and improve safety performance—unlike lagging indicators, which reflect past incidents (e.g., injury rates), SLIs offer early warnings and provide an opportunity to intervene before an accident occurs. For an indicator to be included in this review, it was required to have a predictive or preventative orientation—typically associated with leading indicators—be observable and measurable (either quantitatively or qualitatively), and directly linked to OSH management practices. We acknowledge that this includes indicators that may not be purely proactive but are commonly recognised in the literature and industry practice as leading in nature.

2.5. Phase V: research gaps formulation and future works

One of the vital components of an inclusive SLR is the exposure of existing gaps and the related research streams to be considered in future endeavours [43]. The research gaps identified in this review paper emerged from an integrated synthesis of insights derived from the content analysis, bibliometric/scientometric findings, quality assessment outcomes, and relevant grey literature.

3. Results and discussion

In this section, the results and the related discussions obtained from the scientometric and content analysis are reported, as well as the expositions on the gaps and the related recommendations. Moreover, implications derived from the research are provided at the end of this section.

3.1. Results from the scientometric analysis and quality assessment

This subsection addresses RQ1; it first presents the findings of the scientometric analysis, followed by those of the quality assessment. For the sake of brevity, all the analyses and the related interpretations are provided in Appendix A, and only the main findings are reported in the following lines. Also, for the sake of brevity, the findings related to the QA undertaken are illustrated in Appendix B.

The scientometric and quality assessment analyses show that research on SLIs has gone from being scattered and exploratory to being more organised and global. The increase in publications after 2014 is in line with the rise of ideas like “Safety Differently,” which redefine safety as having systems that can adapt and act proactively instead of just avoiding accidents. This change in how we think about knowledge is shown by research trends that put more emphasis on predictive measures than reactive ones and encourage the use of human, organisational, and technological factors to improve safety performance. The keyword co-occurrence analysis shows that there are groups of keywords around main ideas like safety culture, leadership engagement, and training. This shows that the field is very focused on behaviour and systems. However, most of the research has been done in the construction and manufacturing sectors, mostly in Western countries. This makes it hard to generalise to other sectors and cultures. The quality assessment, on the other hand, shows that many studies use methods that are moderately to highly robust. However, only a few studies use longitudinal, mixed-method, or intervention-based designs, which are needed to make causal inference and practical use stronger. These findings show that SLI usage is growing, but not in a consistent way. They also show that there needs to be a next phase of research that is both empirically sound and includes more areas, geographies, and new technologies that have been left out.

Summary of RQ1 Findings: This review identified a clear increase in academic interest in SLIs beginning around 2014, influenced by a conceptual shift toward proactive and resilience-based safety management approaches such as “Safety Differently.” The bibliometric and scientometric analyses revealed recurring research patterns centred on leadership, training, safety culture, and behavioural safety, with construction and manufacturing industries receiving the most scholarly attention. Geographically, the literature is heavily concentrated in North America and Europe. In contrast, industries like utilities and railways remain underrepresented. The quality assessment further revealed that while the majority of studies provide moderate to high levels of evidence, relatively few adopt longitudinal or experimental designs. Overall, the strength of evidence is promising but methodologically uneven, highlighting the need for more rigorous, theory-driven, and sector-diverse research.

3.2. Results from content analysis and formulation of gaps and future works

This subsection addresses RQ2; it first presents the findings of the content analysis, followed by the proposal of gaps and future works.

An in-depth review was conducted to extract vital information from shortlisted articles and reports. The extracted information includes a list of SLIs, examples of measures, the industry/sector that used the indicators, relationships with other indicators, research methods, and the country in which the studies were conducted. A review structure was set up to ensure the consistency and quality of the review.

Fig. 2 illustrates the number of studies conducted in different countries. Specifically, it can be seen that most of the studies in this area were conducted in the USA, with 24 studies. The high level of research contribution in the USA on this topic may be attributed to the high number of occupational fatal injuries reported by the U.S. Bureau of Labor Statistics. For instance, the number of fatal work injuries in the USA was around 5190 in 2021, which represents an 8.9 % increase from 4764 in 2020 [44]. Next, Iran and Canada are the second and third-highest contributors in conducting studies on the concerned topic. Australia ranked fourth, with seven studies conducted in this area. Having said that, only four studies were conducted in the United Kingdom and India. In addition, some European countries, such as Switzerland, the Netherlands and Poland, have the least contribution to this area of research (about one study each). It is notable that although Europe is among the most industrialised regions in the world, there is limited research regarding the identification and assessment of SLIs in different industries in this region. Although the United Kingdom has a relatively low level of contribution in conducting studies in this area (around 5 %), it has the highest level of contribution among the European countries. The number of conducted studies in different industries/sectors is presented in Fig. 3. It can be seen that the studies related to SLIs are mostly conducted in the construction industry, which comprises 37 studies. The high number of studies conducted in this area could be due to industry being one of the most hazardous industries in the world; it is estimated that workers in the construction sector are three to six times more likely to die from occupational accidents than workers in other industries/sectors [45]. The studies conducted in the oil and gas industry make up just below one-third of those in the construction industry, which is about 12 studies. Notably, sectors such as utilities and railways seem under-represented, which is imbued with several reasons [46]. First, these industries are usually run under rigorous legal frameworks and prescriptive compliance policies. Due to past emphasis on reporting and regulatory alignment, these settings often highlight lagging indicators—e.g., incident rates and audit results—which may have deprioritised research into proactive or behavioural metrics. Second, the

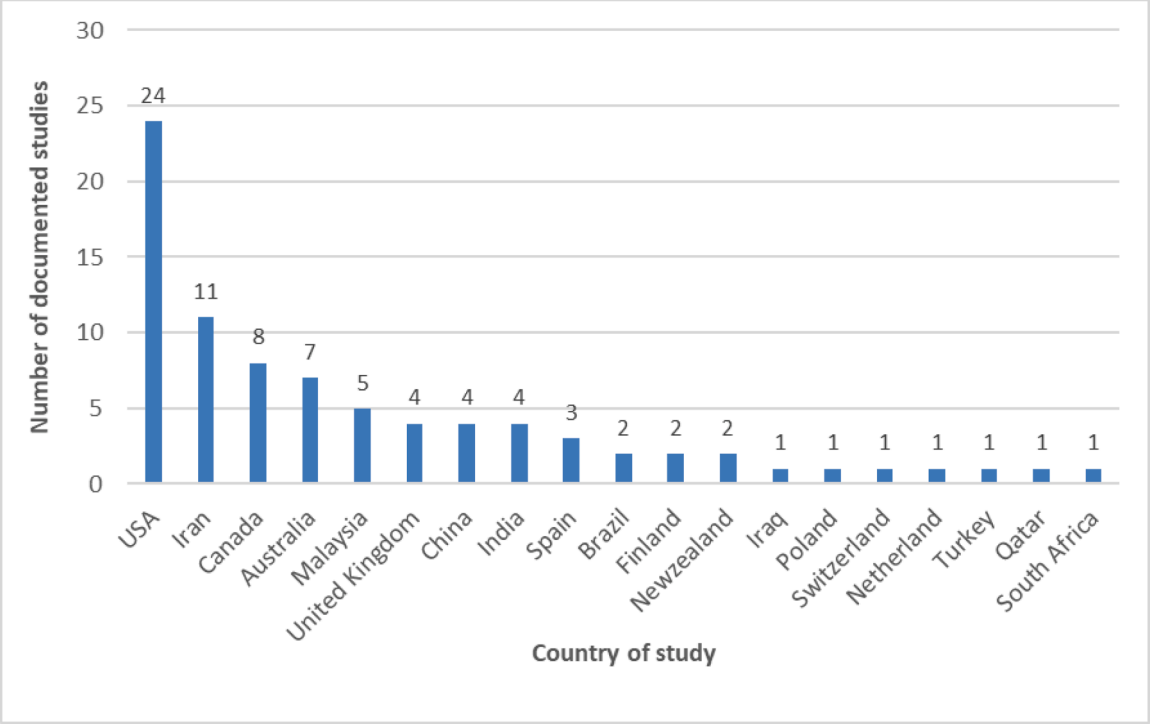


Fig. 2. Number of studies conducted in different countries.

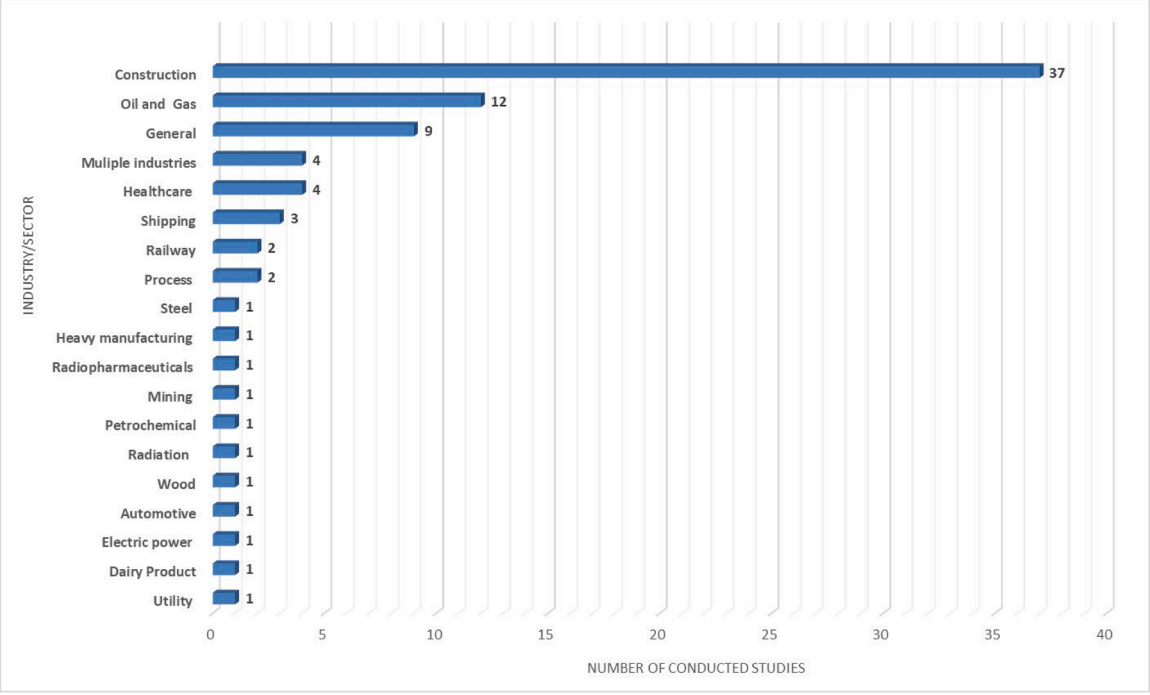


Fig. 3. Number of studies conducted per industry/sector.

assumed stability and control in these sectors—e.g., centralised infrastructure, less subcontracting—may cause one to believe that current safety systems are sufficient, therefore lowering the perceived need for SLI innovation or testing. Third, these industries sometimes manage national security-sensitive operations and vital infrastructure, which restricts access to safety-related information for academic or outside study. This could discourage empirical research or partnerships, usually driving SLI growth. Fourth, industries like utilities may more conservatively implement new safety paradigms than fast-paced sectors like construction or oil & gas, where high-risk, dynamic settings call for constant innovation. This would affect the use and research of SLIs.

Concerning the research methodologies adopted in the relevant literature, it is seen that quantitative-based research was by far the most-employed approach, at 52 % (see Fig. 4). It can also be seen that the utilisation of questionnaire survey (QS) was the fulcrum of the researchers, with around 57 % of the total proportion, whereas focus

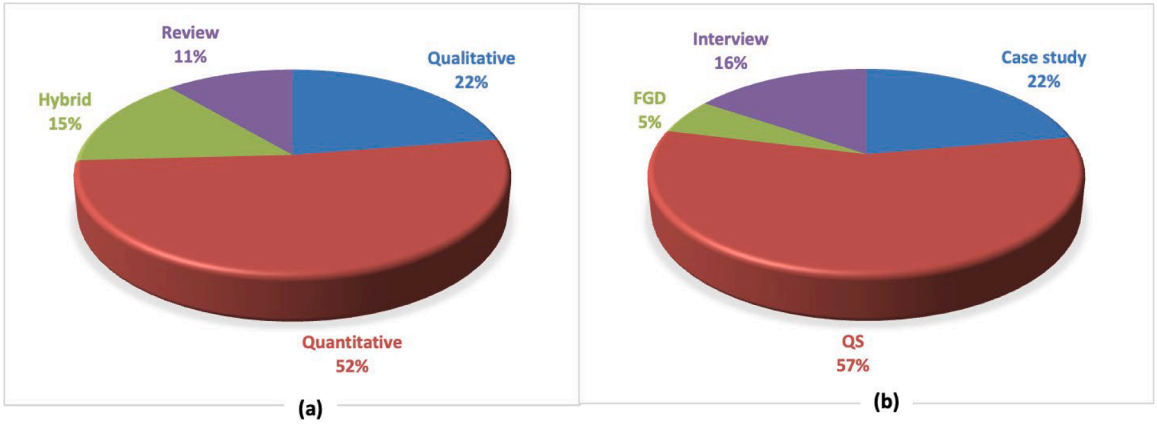


Fig. 4. The breakdown of the methodologies used: (a) the overall research approach employed and (b) the specific research methodology employed.

group discussion (FGD) was the least employed technique (only 5 %). Such inclinations toward the quantitative research approach using QS are imbued with three main reasons. Firstly, quantitative research produces data that is both objective and measurable, making it crucial for SLIs used to predict and prevent future safety incidents. These indicators require precise and quantifiable metrics, ensuring that safety assessments are based on concrete and objective measurements. Secondly, in the realm of SLIs, the analysis often revolves around studying trends, patterns, and correlations among various factors to foresee potential safety risks. The application of statistical analysis tools in quantitative research enables the identification of meaningful relationships and patterns in the data. Safety data is typically collected from a considerable number of individuals or units within an organisation. Quantitative research allows for the efficient analysis of large datasets, a critical aspect when dealing with a broad range of SLIs and multiple data points.

Table 2 shows the SLIs, the respective industries that used them, their corresponding measurements, descriptions, and the related references identified from the literature. After a comprehensive review of the literature, 67 SLIs were identified. The papers that lacked robust evidence were not considered for the identification of relevant SLIs; thus, all the SLIs listed in Table 2 were based on papers that passed the quality assessment. As demonstrated by the SLIs utilised across various industries in this table, the indicators "Management commitment to safety/safety policy" (SLI 1), " Training and education" (SLI 17), "Hazard identification and assessment" (SLI 18), "Near-miss reporting" (SLI 23), "Communication and coordination" (SLI 24), "Safety audits" (SLI 55), and "Safety climate" (SLI 61) are essential across all industries due to their fundamental role in creating robust safety management systems. SLI 1 is critical as it sets safety as a priority within the organisation, allocates necessary resources, and fosters a culture that emphasises safety at all levels. SLI 17 is also vital for providing employees with the knowledge and skills required to perform their duties safely, preventing accidents, and ensuring compliance with safety procedures. Similarly, SLI 18 is a proactive measure that detects potential risks and implements control measures before incidents occur, making it crucial for all work environments, while SLI 23 supports a culture of continuous improvement by encouraging the identification and correction of potential hazards. Having said that, SLI 24 ensures that safety information is effectively shared and that all stakeholders are aligned in their safety efforts, facilitating the seamless implementation of safety measures. SLI 55 provides a systematic approach to evaluating and improving safety management systems, ensuring compliance with regulations and identifying areas for improvement. Finally, SLI 61 measures collective attitudes and perceptions toward safety within an organisation, which is essential for maintaining a positive and proactive safety culture. These SLIs are universally acknowledged for their importance in enhancing workplace safety and ensuring continuous improvement across different industries.

In addition, it is evident that the construction and oil & gas industries employ the highest number of indicators. This can be attributed to the inherently high-risk nature of these sectors, which require a comprehensive and multifaceted approach to safety management. The construction industry faces a dynamic and unpredictable work environment with numerous hazards, including working at heights, heavy machinery operation, and exposure to hazardous materials. These risks necessitate robust safety protocols, extensive training, and continuous monitoring to ensure worker safety and regulatory compliance. Therefore, a wide range of SLIs is essential for addressing the diverse safety challenges present in construction projects. Similarly, the oil & gas industry is characterised by high-risk operations such as drilling, extraction, and processing of flammable and toxic substances. The potential for catastrophic incidents, such as explosions or oil spills, highlights the need for stringent safety measures. Comprehensive SLIs are crucial in this sector to monitor and mitigate risks effectively, ensuring the safety of personnel, the environment, and infrastructure.

In another vein, these 67 SLIs were mapped onto the PLAN-DO—-CHECK-ACT (PDCA) framework according to their meanings in safety management practices [47]. The mapping was performed because the PDCA framework is widely used/known in OSH management practice, and therefore, the mapping facilitates the ease of application of the identified SLIs across different sectors. Notably, while each SLI is assigned to a primary category in the PDCA cycle for analytical clarity, many indicators are cross-cutting in nature and may influence multiple stages of the safety management process; thus, assignments in this study were made based on the predominant phase where the indicator is conceptually initiated or emphasized. Fig. 5 illustrates the distribution of identified SLIs in each of the PDCA groups. It can be seen that 69 % of the indicators were mapped onto the "Do (D)" group, constituting the highest number of SLIs, which is due to the links between most of the identified SLIs and safety management practices such as the identification of risk profiles, organising stakeholders and undertaking activities to implement OSH plans. The "Check (C)" category comprises 15 % of the identified SLIs, while the "Plan (P)" and "Act (A)" categories respectively accounted for 12 % and 4 % of the identified SLIs.

Fig. 6 illustrates the frequency of appearance of SLIs in the body of literature. The dotted red line in this figure shows the average appearance of identified SLIs in the body of literature (threshold). With this in mind, the SLIs, whose frequency of appearance is higher than the threshold, can be considered a highly frequent indicator. This figure shows that "Training and education" is the most frequent SLI in the body of literature, with 36 appearances. Such a high number of appearances could be due to the following reasons: (1) there is a legal requirement for training, and it is mandatory in most workplaces (e.g., toolbox talks would typically be done weekly or before a particularly hazardous task is undertaken); (2) it can easily be measured since it is easy to quantify how many hours of training have been delivered; and (3) it is often

Table 2
Identified SLIs from the body of literature with their definitions based on the PDCA framework.

Plan, Do, Check, Act	SLIs	Industry	Measure	Description	References
Plan	1. **Management commitment to safety/ safety policy**	All	Frequency of management safety walkthroughs; number of safety meetings attended by management	It pertains to situations when management gives a high priority to safe operations in the company, demonstrates care for the safety and welfare of its employees, works to enhance safety in its facilities and address safety issues, and actively participates in safety programs.	[9,18–20,23,24, 48–58]
	2. **Safety consideration in the planning stages of work**	CON; MAN	Number of plans that incorporate safety elements; frequency of safety-focused planning sessions	Safety is taken into account during the planning process, including both pre-works planning and short-term planning.	[20,49,59–62]
	3. **Safety considerations in the design phase**	CON; O&G	Percentage of designs with integrated safety controls; number of hazards mitigated at the design stage	Safety design involves considering occupational safety and health risk factors during the design phase of structures, products, equipment, or any other facilities. This is done to reduce the likelihood and severity of accidents through preventive measures and monitoring of consequences.	[18–20,63,64]
	4. **Safety** rules and procedures	CON; MAN; HC	Number of formal rules enforced; rate of disciplinary actions for violations	Focuses on the existence, accessibility, and enforcement of written safety protocols, including consequences for non-compliance. Does not include training or awareness programs.	[19,22,51,56,61]
	5. **Laboratory diagnostics**	HC	Number of diagnostic tests conducted; turnaround time for lab results	Equipment and reagents are made available to enable effective and swift detection of priority diseases.	[22]
	6. **Return-to-work practices**	CON	Average duration of return-to-work programs; number of workers successfully reintegrated	The management process ensures a safe and efficient return to work for injured workers, aiming to lessen financial burdens on both the employee and employer.	[55,65]
	7. **Emergency preparedness**	MAN; O&G; PRC; CON; EXP	Frequency of emergency drills; response time during simulations; availability of emergency plans	Being proactive in addressing human performance and safety issues, the organisation should anticipate problems and prepare for them in case of actual incidents.	[61,62,64,66–69]
	8. **Task characteristics**	CON; MAN	Worker-reported task stress levels; frequency of high-risk task assignments	Task characteristics refer to the type of task, time, job demands, and equipment-related features, which include job autonomy, job safety, job satisfaction, job stress, machinery and tool safety, time pressure (e.g., deadlines), work intensity (e.g., cognitive demands), workload, pressure, and work pace.	[53,56,65,70]
Do	9. **Involvement of supply chain and workforce**	CON	Number of safety meetings held with supply chain partners; compliance rates among contractors	Subcontractors, suppliers, and self-employed workers are involved in occupational safety and health throughout a project.	[20,25]
	10. **Client-led safety monitoring**	CON; O&G	Client participation in safety meetings; frequency of client site safety audits	The client also participates in occupational safety and health throughout a project.	[8,19,20,25,67,71]
	11. **Designer-led safety monitoring**	CON	Frequency of design team safety reviews; number of design changes made for safety reasons	The entire design team is involved in occupational safety and health throughout a project.	[20]
	12. **Principal contractor-led safety monitoring**	CON; O&G	Number of principal contractor-led safety inspections or briefings	The principal/main contractor is actively involved in occupational safety and health throughout a project.	[20,67,71]
	13. **Supervisor-led safety monitoring**	CON; PCH; MAN; EXP	Frequency of supervisor-led inspections; number of intervention actions taken	Emphasises proactive supervisory engagement in on-site safety verification and real-time correction of unsafe behaviours or conditions.	[12,19,50,56,62, 68,71–73]
	14. **Project management team-led safety monitoring**	CON	Frequency of project management team involvement in safety inspections or reviews	Project management team members are engaged in related safety activities.	[8]
	15. **Management of change**	EXP	Number of change processes reviewed for safety implications; frequency of change audits	The organization can adapt to new or complex problems, maximizing its ability to address issues arising from changes in the control process and updates of drawings without disrupting overall functionality.	[63,68]
	16. **Safety score for contractor selection**	MAN	Percentage of contractors evaluated based on safety records before selection	Safety records and performance should be taken into account as a prequalification when selecting a contractor.	[62]
	17. T**raining and education**	All	Training hours in certified programs; competency test pass rates	Covers structured training aimed at skill development and certification in safety practices, excluding inductions and briefings.	[9,19,20,25,50,52, 54–56,60,61,63,64, 66,67,69,73–82]
	18. **Hazard identification and assessment**	All	Number of hazards identified per month; effectiveness of risk assessments	Procedures are in place to identify, analyze, and evaluate existing risks, aiming to prevent the recurrence of accidents or similar undesirable events.	[9,19,25,52,54,61, 63,67,72,74,79,83, 84]
	19. **Hazard prevention and control**	CON; UT	Percentage of identified hazards mitigated; number of control measures implemented	Implementing the agreed-upon actions to rectify identified hazards.	[9,54,55,83]

(*continued on next page*)

Table 2 (*continued*)

Plan, Do, Check, Act	SLIs	Industry	Measure	Description	References
	20. **Site inductions**	CON	Percentage of workers receiving site induction; quality of induction content	On commencement at a workplace, workers undergo an introductory safety orientation session to provide them with essential safety information and a basic understanding of the worksite's safety requirements and processes.	[65,83,84]
	21. **Toolbox meetings**	CON	Frequency of toolbox meetings held; number of attendees	Regular safety communication events are conducted to exchange safety information between line management and workers, usually on a weekly basis.	[19,60,80,83]
	22. **Pre-task safety meetings**	CON	Number of pre-task meetings conducted per shift; attendance rate	At the start of each work shift, the supervisor and their crew hold a safety communication event to discuss the day's planned tasks, potential safety hazards and controls, and any other relevant safety information.	[8,19,25,73,80, 83–85]
	23. **Near-miss reporting**	All	Number of near-misses reported; ratio of near-misses to incidents	Near-miss incidents, which involve potential hazards or incidents without property damage or personal injury, are reported.	[8,19,72,74,78,80, 81,86–88]
	24. **Communication and coordination**	All	Number of cross-team safety meetings; documented coordination protocols	Refers to structured communication across different roles or departments to ensure safety alignment and response efficiency.	[19,23,24,50,51, 54,56,61,63,64,68, 69,81,89,90]
	25. **Digitalisation embracement for worker Safety**	CON	Use of wearable tech; number of automated safety alerts issued; digital tracking compliance	Activities that enhance worker safety through automation and digitalization are implemented. Automation takes over dangerous tasks, allowing human workers to focus on cognitive tasks. Sensing and alert-based technologies, such as radio frequency identification (RFID), track and monitor worker productivity and safety.	[91]
	26. **Disease detection**	HC	Number of cases detected; diagnostic response times	Health professionals are trained and demonstrate relevant clinical skills for disease detection.	[22]
	27. **Consolidating and securing pathogens**	HC	Percentage of pathogens secured; frequency of control audits	Adequate control of security-sensitive pathogens is maintained.	[22]
	28. **Drug and alcohol tests**	CON	Number of drug and alcohol screenings conducted per month	Workers' bodies are subjected to preliminary or confirming blood alcohol content (BAC) tests and drug tests to identify alcohol and drug presence.	[19,25,60,83,92]
	29. **Electrical safety**	CON; UT	Number of electrical hazard signs installed; number of electrical safety training sessions	Safety precautions are taken to prevent electrocution accidents on the project. For instance, warning signs are posted and maintained where electric circuits and high-voltage power lines exist.	[66,93]
	30. **Fire safety**	CON; UT	Fire drill frequency; fire extinguisher inspections conducted on schedule	Safety precautions are taken to prevent fire accidents on the project.	[66,94]
	31. **Equipment/plant and temporary structures safety**	CON; O&G; PRC	Percentage of equipment inspected; temporary structures checked for compliance	Assurance is provided for the proper condition of safety equipment, temporary structures, alarms, and measurement tools.	[66,69,84]
	32. **Equipment/plant operation and demand on safety systems**	O&G; PCH; PRC	Number of incidents triggered by system overload; frequency of system checks	The evaluation of the physical operation of the plant includes assessing demand and pressure on the instrumented system.	[67,95]
	33. **Housekeeping**	CON; EXP	Number of housekeeping inspections passed; cleanliness audit scores	Housekeeping encompasses various aspects, including site cleanliness, waste removal, and material and equipment storage.	[8,19,60,68,86]
	34. **Inspection and safety-critical equipment/plant maintenance**	CON; MAN; O&G; EXP; DR; PRC; RW	Equipment downtime due to missed maintenance; compliance with maintenance schedules	A technical inspection is essential to maintain the correct performance conditions of the equipment and prevent blowout incidents.	[19,62–64,67–69, 74,76,96]
	35. **Off-the-job safety**	UN	Number of off-the-job incidents reported; participation in safety awareness campaigns	Efforts are made to manage, track, and reduce incidents and injuries occurring outside the workplace.	[63,97]
	36. **Penalties/ infringements**	CON	Number of penalties issued; types and frequency of infringements	Regulators impose monetary and non-financial actions for breaches of statutory requirements, including improvement notices, infringement notices, penalty notices, and prosecutions.	[19,83]
	37. **Non-compliances**	CON	Number of non-compliance events; time taken to close non-compliance issues	Non-compliance includes breaches of statutory requirements or industry standards, compliance codes, significant breaches of contractor procedures, processes, or multiple examples of 'deficiency' evident.	[25,63,75,83]
	38. **PPE (personal protective equipment)**	CON; MAN; O&G; HC; EXP; DR; PRC; RW	PPE issuance rates; frequency of PPE compliance checks	Covers the provisioning and enforcement of PPE use, not the hazards necessitating it (biological, chemical, etc.).	[19,22,60,73,98]
	39. **Contact with biological agents**	EXP	Incidents related to biological exposure; use of PPE in biological handling areas	Situations in which workers are in contact with infectious waste, human and animal body fluids, laboratory materials, and sewage in their work environment are considered.	[56,68]
	40. **Contact with chemicals agents**	UN	Air quality tests; chemical handling training sessions completed	Situations in which workers are exposed to dust and powder, fumes and smoke from molten materials, fine droplets and fumes in the air, and mineral acids	[56,99]

(*continued on next page*)

Table 2 (*continued*)

Plan, Do, Check, Act	SLIs	Industry	Measure	Description	References
				or organic alkalis in the workplace are taken into account.	
	41. **Ergonomic agents**	UN	Ergonomic risk assessments completed; reported musculoskeletal disorders	Ergonomic factors include the ergonomic situation of the workplace, such as painful or tedious tasks, repetitive and monotonous movements, prolonged sitting or standing, and severe movements of the arm and hand during work.	[56,100]
	42. **Contact with physical agents**	UN	Noise and vibration exposure readings; radiation monitoring records	Situations involving contact with noise in the work environment, exposure to vibration devices, and radiation (e.g., ultraviolet, infrared, X-rays) in work are considered.	[56]
	43. **Healthy and safe site condition**	CON	Score from healthy site condition audits; availability of fall protection and safe access	The degree of healthy and safe site conditions provided to employees at the project is assessed. Measures are taken to provide adequate safe access, protect workers at height, prevent falling and slipping, and avoid contact with unprotected equipment and barriers.	[66,101]
	44. **Environmental variability**	MAN	Number of delays or incidents due to weather/environmental conditions	The impact of natural environmental factors (e.g., wind speed, humidity) on normal operations is evaluated.	[53,62]
	45. **Restrictions for positive health**	MAN; O&G	Employee participation in health initiatives; frequency of fitness/ wellness programs	The severity of restrictions on employees' involvement in non-job activities (e.g., weight control initiatives, physical exercise) is measured to achieve positive health outcomes. Regular physical exercise, body weight control, and breaks between work shifts are encouraged to improve employees' health.	[53,67,70]
	46. **Provision of safety resources**	CON	Amount of safety budget allocated; availability of critical safety equipment	The safety committee's effort (e.g., supervisory, owner safety representative, and project leaders) in providing necessary safety resources is considered.	[19,73]
	47. **Workers' compensation claims management**	CON	Time to process compensation claims; number of successful worker reintegrations	The management process ensures timely filing of claims, care for injured workers, and minimizes the financial impact of claims on the organization.	[55,73]
	48. **Co-worker support**	CON	Co-worker support scores from surveys; incident reporting influenced by peers	Co-worker support, which influences employees' perceptions and attitudes in workgroups, is taken into account, going beyond the influence of supervisors.	[12,49,71]
	49. Employee participation	CON; MAN; O&G	Number of workers on safety committees; frequency of participatory improvement workshops	Assesses structured employee engagement in official safety decision-making and governance processes.	[52,54–56,61,63, 78]
	50. **Workforce safety qualification and certification**	CON; PRC; EXP; O&G; ST	Percentage of certified staff; compliance with role-based safety credentials	Evaluates possession of formal qualifications and certifications required for role-specific safety performance.	[20,56,64,68,69, 71,102,103]
	51. **Individual psychological stability**	CON; MAN	Psychological health surveys; absenteeism due to stress	Individual psychological stability is examined, which includes self-efficacy, optimism, hope, and resilience as positive dimensions of an individual's psychological state of development.	[12,56,70]
	52. **Cultural difference**	CON	Language training sessions; feedback from migrant workers	Particularly high-power distance among migrant workers can affect safety communication between them and supervisors/superiors, as they may not ask questions if tasks are unsafe or unclear.	[104]
	53. **Job safety analysis (JSA)**	EXP; CON	Number of JSAs conducted; quality of JSA documentation	Job safety analysis refers to both the analytical process of developing safer job procedures and to the document that is developed as a result of the analysis.	[68,83,102]
	54. **Sample handling and transport**	UN	Number of properly handled and documented sample transports	Covers the safeguards in place to control hazards associated with the handling of samples and their transport. The hazards in these areas are typically managed through procedures to log and handle samples, and physical protection of staff (through PPE).	[56,99]
Check	55. **Safety audits**	All	Number of audits performed; audit findings closed within the target date	Process of ensuring the effectiveness of safety management systems and the presence of effective programme elements for identifying, eliminating, or controlling hazards that could adversely impact a company's physical and human assets.	[8,20,25,67,73,74, 79,83,85,105]
	56. **Safety observations**	CON; O&G	Number of safety observations made; actions taken from observations	Formal inspection of the workplace (or a part) using a documented checklist by the supervisor, or any duly appointed personnel, for the purposes of identifying hazardous conditions that have the potential to cause harm to a person.	[8,19,25,63,73,78, 83,87]

(*continued on next page*)

Table 2 (*continued*)

Plan, Do, Check, Act	SLIs	Industry	Measure	Description	References
	57. **Observed worker safety behaviour compliance**	CON; RW; MIN	Proportion of compliant behaviours observed; frequency of unsafe acts reported	Focuses on field-level observations of individual behaviour and adherence to safe practices during operations.	[17,85,96]
	58. **Workers' authorities and anonymous reporting**	CON; SHP	Number of anonymous reports received; worker awareness of reporting protocols	It refers to the situations when management/ supervisors attempt to avoid blaming workers who report incidents or accidents, there is a policy to empower workers to stop work in case of incidences or near misses, there is a clear procedure for reporting of incidents, accidents, or potential hazards, with well-defined roles and responsibilities and the reporting procedure is anonymous, Workers are given positive incentive to report potential hazards.	[60,89,106]
	59. **Incident investigation and analysis**	CON; O&G	Root cause analyses conducted; corrective actions implemented	The method of gathering and analysing information and incident facts, determining root causes, and identifying safety improvements to prevent future accidents.	[19,55,67]
	60. **Reward mechanism**	CON; PCH; MAN	Number of incentives given for safe behavior; participation in recognition programs	Motivations given to the workforce to comply with safety rules and actively participate in safety improvement activities.	[19,20,25,49–51, 56,62,73,84,85, 105]
	61. **Safety climate**	All	Safety climate index scores from surveys	Employees' perception of the priority an organisation and workgroup placed on safety-related policies, procedures, and practices.	[4,12,18–20,57,58, 75,80,107–115]
	62. **Safety culture**	CON; O&G; SHP; RA	Number of safety culture assessments; improvement actions from assessments	Safety culture embodies the value placed on safety and the extent to which people take personal responsibility for safety in an organisation. Safety culture is often described as the "personality" of an organisation, as it is a shared value of safety.	[18,67,89,116]
	63. **Epidemiological analysis and investigation**	HC	Number of epidemiological reviews completed; trends identified	Analysis of disease surveillance data is conducted to identify disease-specific trends and derive baseline data.	[22]
	64. **Safety perception survey**	UN	Completion rate of safety surveys; thematic analysis outputs	A methodologically grounded instrument designed to evaluate worker perceptions of safety dimensions to inform interventions.	[63]
5. Act	65. **Meta-evaluation of safety leading indicators**	CON	Number of indicators with positive trends; inter-indicator correlation matrix	Synthesis-level evaluation of the effectiveness and directional trends of implemented SLIs to inform programme refinement.	[81]
	66. **Safety programme evaluation and improvement**	CON; UT; O&G; EXP; MIN	Audit frequency; proportion of improvements implemented post-evaluation	Refers to formal, periodic evaluations of safety management systems to assess gaps and implement improvements.	[9,17,54,63,81, 102]
	67. **Post-incident organisational safety learning**	CON; SHP; RA	Number of learning reviews conducted; dissemination of safety lessons	Measures institutional processes of reflecting on and disseminating safety lessons from incidents or near-misses.	[20,63,89,116]

Note: The full form of the abbreviations used in the table are as follows: CON: Construction; MAN: Manufacturing; O&G: Oil and Gas; HC: Healthcare; PRC: Process; EXP: Explosive; PCH: Petrochemical; UT: Utility; DR: Dairy; RW: Railway; UN: Unspecified; ST: Steel; MIN: Mining; SHP: Shipping; RA: Radiopharmaceutical.

correlated with safe work practices and it can help to reduce the frequency of injuries during activities [9,73]. Similarly, the management's unwavering dedication to safety policy (i.e., the "management commitment to safety/ safety policy" indicator) represents a significant SLI for safety performance, establishing the atmosphere and cultivating an overarching safety culture within an organisation [117]. This creates an environment that prioritises safety, with clear expectations communicated to the entire workforce.

Furthermore, effective communication and coordination (i.e., the "Communication and coordination" indicator) hold paramount importance as SLIs for safety performance. They enable seamless collaboration, information sharing, and proactive risk management. Through transparent communication, safety instructions and expectations are effectively conveyed to all stakeholders, thereby minimising the chances of misunderstandings or accidents [118]. Open channels of communication also encourage the timely reporting of hazards, allowing prompt intervention and the implementation of mitigation measures, thus reducing the likelihood of accidents or injuries. Safety climate is also a significant SLI that demands attention for various reasons. A positive safety climate influences the behaviour and decision-making of stakeholders, leading to safer choices and adherence to safety protocols [119]. It also encourages the reporting of hazards and safety concerns without fear of reprisal. A positive safety climate promotes employee engagement, ownership of safety, and a proactive safety culture.

Having said that, "Hazard identification and assessment" and "Co-worker support" are critical SLIs for safety performance. In regard to the former, they enable proactive risk management, regulatory compliance, and informed decision-making [120]. By effectively identifying and assessing hazards, control measures can be implemented to enhance safety throughout the lifecycle of operations. On the other hand, with respect to the latter, when workers feel supported by colleagues, it fosters better communication, collaboration, hazard identification, and mitigation. Co-worker support also improves worker morale, and motivation contributes to a safer work environment [121].

Table 3 shows the existing relationships among the SLIs that are mentioned in the body of literature. Notably, due to the extensive number of SLIs (67 in total), a complete SLI-to-SLI matrix would be too dense for inclusion here; instead, a summarised version highlighting the most interrelated SLIs is provided here, while the complete matrix is provided in the Supplementary file. Notably, the indicator "Task characteristics" (i.e., SLI 8) has the highest number of relationships with the other indicators, which shows its essence in improving the management of OSH in companies. This could be due to the fact that the characteristics of a task (including the type of task, time, complexity/simplicity, job demands, and equipment-related characteristics) mostly determine the OSH risks associated with a particular task as well as the measures

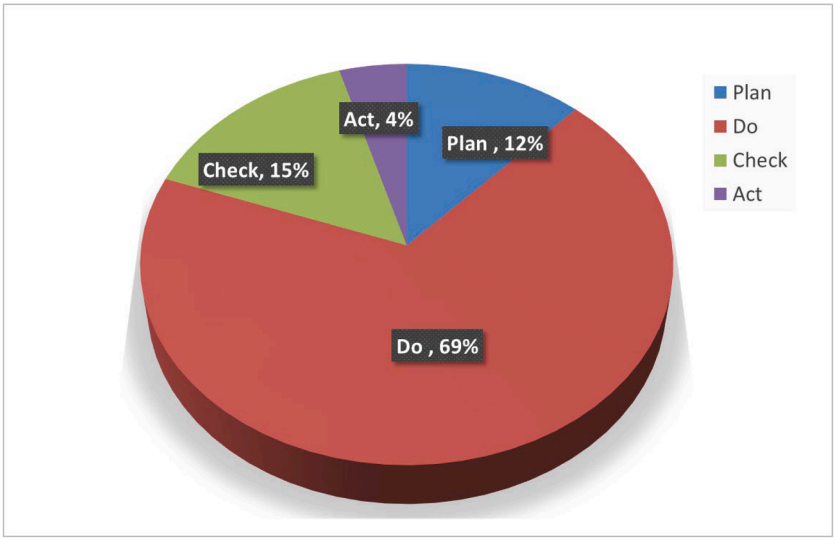


Fig. 5. Distribution of SLIs based on the PDCA framework.

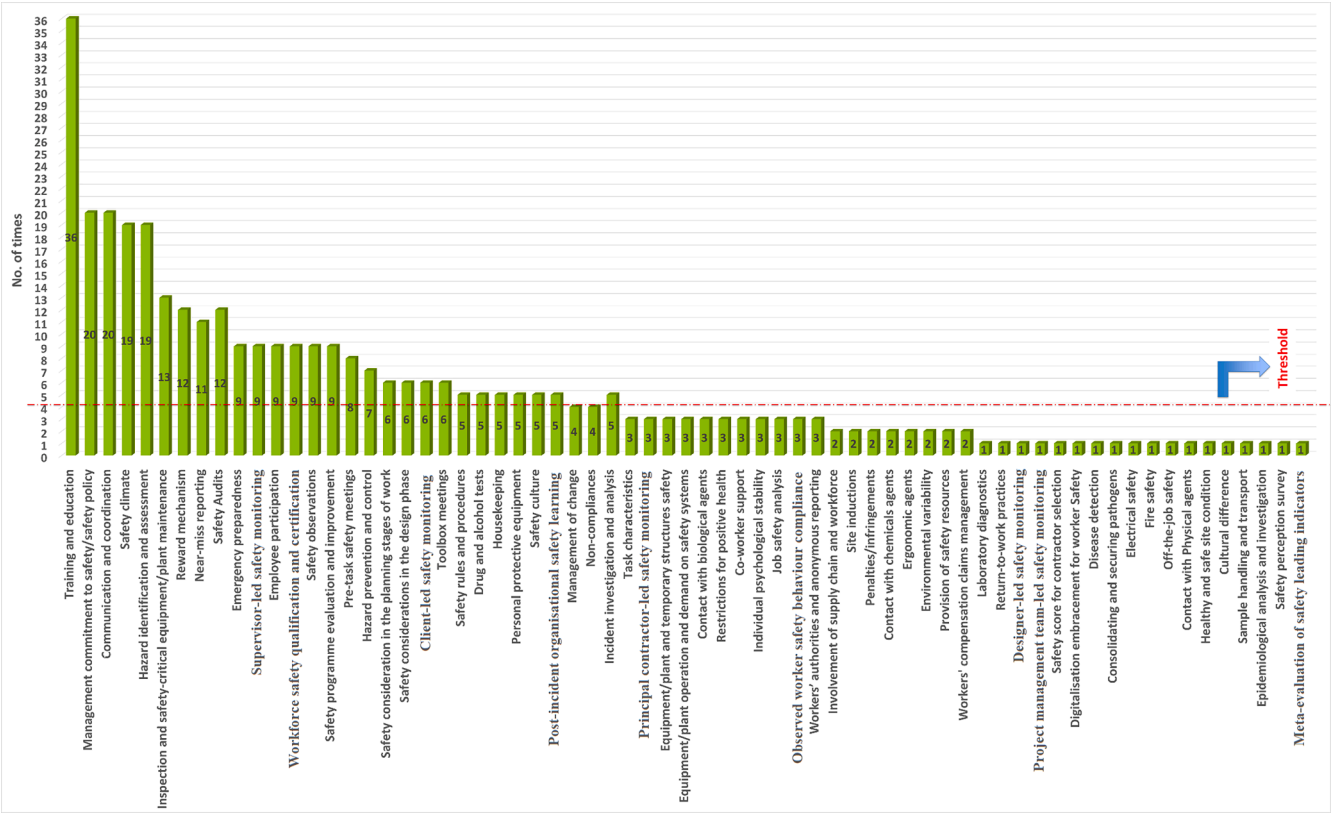


Fig. 6. Frequency of appearance of SLIs in the body of literature.

required to address the risks. For instance, if a task is classified as a low-hazard task (e.g., taping the trim/foot of an interior wall prior to painting), then the need for the corresponding SLIs (e.g., the extent of involvement of a supervisor) may be far less [53]. Furthermore, "Supervisor-led safety monitoring" (i.e., SLI 13) exhibits strong interconnections with other pivotal indicators impacting safety performance. Their leadership, communication, coordination, engagement, expertise, and monitoring activities exert influence over various aspects of safety performance [122]. Through the active involvement of supervisors, organisations can bolster their safety culture, enhance communication channels, foster employee engagement, promote hazard identification and assessment, support training and competence development, facilitate performance monitoring and feedback, and drive incident investigations and corrective actions [123]. For instance, when supervisors partake in establishing safety goals and expectations for a task, it fosters improved communication and collaboration among team members, aiding in the identification and mitigation of potential hazards. Moreover, when supervisors are physically present on-site and actively oversee tasks, they ensure adherence to safe practices and procedures, intervening promptly to prevent unsafe behaviour or conditions.

The content analysis identifies commonly used and cross-sectoral

Table 3
Relationships between identified SLIs.

SLIs	The existence of relationships mentioned in the body of knowledge
SLI 8	SLI 1, SLI 4, SLI 13, SLI 24, SLI 48, SLI 49, SLI 50, SLI 51, SLI 58, SLI 60, SLI 61, SLI 66
SLI 13	SLI 1, SLI7, SLI 48, SLI 50, SLI 51, SLI 51, SLI 58, SLI 66, SLI 60, SLI 61
SLI 48	SLI 1, SLI 13, SLI 17, SLI 24, SLI 49, SLI 51, SLI 61, SLI 60
SLI 17	SLI 1, SLI 7, SLI 13, SLI 24, SLI 58, SLI 60, SLI 48, SLI 60
SLI 1	SLI 13, SLI 60, SLI 61, SLI 17, SLI 24, SLI 49, SLI 58
SLI 60	SLI 1, SLI 8, SLI 13, SLI 17, SLI 24, SLI 48, SLI 58
SLI 31	SLI 7, SLI 7, SLI 24, SLI 34, SLI 50, SLI 55
SLI 51	SLI 13, SLI 62, SLI 4, SLI 8, SLI 50, SLI 61
SLI 58	SLI 1, SLI 17, SLI 48, SLI 49, SLI 60, SLI 13
SLI 61	SLI 13, SLI 37, SLI 48, SLI 51, SLI 56, SLI 62
SLI 7	SLI 17, SLI 24, SLI 34, SLI 50, SLI 55
SLI 12	SLI 10, SLI 13, SLI 18, SLI 50, SLI 60
SLI 22	SLI 21, SLI 37, SLI 56, SLI 57
SLI 24	SLI 1, SLI 7, SLI 48, SLI 60
SLI 49	SLI 1, SLI 17, SLI 51, SLI 58
SLI 55	SLI 21, SLI 22, SLI 28, SLI 37
SLI 56	SLI 20, SLI 21, SLI 37, SLI 61
SLI 66	SLI 13, SLI 17, SLI 24, SLI 58
SLI 4	SLI 8, SLI 48, SLI 50
SLI 21	SLI 22, SLI 37, SLI 55
SLI 40	SLI 39, SLI 41, SLI 42
SLI 42	SLI 39, SLI 40, SLI 41
SLI 37	SLI 21, SLI 55
SLI 39	SLI 40, SLI 42
SLI 41	SLI 40, SLI 42
SLI 62	SLI 51, SLI 61
SLI 10	SLI 12
SLI 20	SLI 28

SLIs, offering practitioners a reference point for benchmarking their own indicator sets and improving the structure of safety monitoring systems.

After a thorough review of the relevant literature, several research gaps have been identified that require attention in future studies (i.e., for the gist of challenges and future streams, see Table 4):

- Although the scope of this review centred on SLIs related to physical safety, the findings indicate a notable gap in the development and application of health-related leading indicators. Metrics for psychosocial risk, chronic exposure, and mental well-being remain underrepresented. This imbalance highlights the need for integrative approaches that reflect the full scope of OSH in both research and practice.
- Most of the studies examined used cross-sectional or retrospective designs, which hampers the knowledge of how SLIs affect safety performance over time. To monitor the evolution of SLIs and evaluate their ongoing efficacy across various project or operational phases, longitudinal studies are required. Both the content analysis and QA phases revealed this gap clearly; studies with lower temporal robustness highlighted it.
- Although many studies have concentrated on particular sectors—e.g., construction, manufacturing—there is a striking lack of comparative research examining SLIs across several industries and geographic areas. Our bibliometric mapping also showed notable clustering within separate disciplinary areas. Future research should seek to find the contextual dependencies and generalisability of SLIs across several organisational environments.
- Many studies have evaluated SLIs using self-reported data, which, as shown in our QA, calls into question possible bias and validity. To record SLIs with more accuracy and repeatability, more objective, standardised tools—such as behavioural observation protocols, digital monitoring systems, and triangulated assessments—must be developed and validated. Most studies are from North America and Western Europe, which causes a research imbalance. More empirical research is needed from under-represented areas to assess the efficacy and adaptability of SLIs in various socio-cultural settings, given the cultural impact on safety behaviour and system implementation.

Table 4
Key challenges and the corresponding future research directions.

Key challenges in the existing literature	Future research directions
Neglect of health-related leading indicators	Develop and test SLIs for psychosocial risks, occupational stress, and chronic health conditions
Predominant use of cross-sectional designs	Conduct longitudinal studies to assess SLIs over time and phases
Industry-specific silos in research (e.g., construction-heavy focus)	Perform comparative, cross-sectoral studies to assess the transferability of SLIs
Heavy reliance on self-reported data	Adopt objective data capture methods (e.g., wearables, digital tools, triangulated observations)
Limited use of digital technologies for SLI monitoring	Explore real-time, tech-enabled SLI frameworks using IoT, AI, and immersive tools
Lack of studies on implementation and organisational integration	Investigate practical barriers to SLI integration into management systems and stakeholder resistance
Neglect of intermediate outcomes like safety culture/climate	Study how SLIs influence relational outcomes and behavioural compliance
Lack of predictive modelling or advanced analytics	Use ML/AI to build predictive models of SLIs for proactive decision-making
Absence of prioritisation or ranking of SLIs	Conduct expert-based Delphi studies or meta-analyses to identify high-impact SLIs

- Our study found little integration of digital tools—e.g., IoT, wearables, immersive platforms—into SLI frameworks despite their growing importance. Future research should investigate how such technologies might assist in real-time gathering, forecasting, and feedback of SLI-related data, especially in high-risk sectors.
- Though few studies have discussed the practicalities of implementation—such as integration into safety management systems, stakeholder opposition, or organisational change obstacles—many studies have found or suggested SLIs. Our qualitative synthesis revealed this implementation gap, which highlights the need for future studies concentrating on practical application and change management.
- Most studies have concentrated on traditional lagging results, such as incident rates. On the other hand, SLIs can affect intermediate or relational results, including safety culture, safety climate, and behavioural compliance. Often taken for granted, these links are seldom directly tested; future research should investigate this larger range of effects. Furthermore, interrelationships among SLIs themselves are underexplored, even if certain research suggests interactive or compounding consequences.
- Although SLIs are naturally predictive, only a handful of studies use sophisticated analytics like machine learning (ML) algorithms to forecast safety results or model their influence. Future studies should look at how industry-specific SLI prediction models enable proactive safety management supported by ML.
- While a frequency analysis was carried out in this SLR paper, the results should not be regarded as a definitive ranking of the most significant SLIs. Future research could aim to create a more comprehensive ranking based on some measure of the importance of the SLIs or based on some measure of the impact of the SLIs on safety outcomes. This could, for instance, be undertaken by consulting industry experts (e.g., via a Delphi study) to establish the relative importance of the SLIs [124]. Additionally, a meta-analysis could be conducted to assess the effectiveness of SLIs across various sectors, providing clearer insights into which indicators have the most substantial impact on safety outcomes [43].

Summary of RQ2 Findings: Across sectors, 67 unique SLIs were found. Often used measures were management dedication, Near-miss reporting, Safety audits, Toolbox meetings, and Training and education. Both statistical (e.g., frequency counts, scores) and qualitative techniques (e.g., surveys, interviews) were used to gauge these SLIs;

however, there were discrepancies in standardisation of measurement, cross-sector comparison, application of advanced analytics, and validation of SLIs in developing sectors such as utilities and railroads. Additionally, the identified gaps and proposed future directions provide a targeted research agenda that addresses methodological shortcomings, expands sectoral representation, and supports innovation in SLI development and implementation.

3.3. Implication

Based on the findings derived from this SLR paper, several theoretical and managerial implications are noted. Concerning the theoretical implications, the identification of SLIs impacting safety performance contributes to the development and refinement of safety management theories. By understanding which indicators are most strongly associated with improved safety performance, as well as their interrelationships, researchers can develop more nuanced and comprehensive models of safety management. Furthermore, the attained findings help researchers assess the robustness and generalisability of theories, supporting their further development and refinement, since they could validate and refine the existing theories and models related to safety management.

Several practical implications are provided for the concerned professionals. First, the SLI-related analyses help managers and OSH officers select appropriate indicators to monitor and manage safety performance. It provides an overview of indicators that have been found to be effective in influencing safety outcomes. Managers can use this information to prioritise and focus on the indicators that have the greatest impact on safety performance in their specific contexts. Additionally, the findings obtained in this paper inform the development of safety policies and programs by highlighting the key factors and SLIs that contribute to safety performance. Managers can align their safety policies with the identified indicators and incorporate strategies to enhance those indicators within their domains. This ensures that safety programs are evidence-based and tailored to address the specific needs of the organisation and its stakeholders. In addition, the allocation of resources and investment is another insight catered for by the respective safety professionals and managers. By understanding the SLIs and their impact, managers could allocate appropriate resources, such as funding, time, and personnel, to support the implementation of strategies that enhance those indicators. This targeted resource allocation maximises the effectiveness of safety initiatives and improves overall safety performance. Moreover, the concerned managers and stakeholders can use the provided insights to enhance their own leadership behaviours and encourage supervisors to actively engage in safety initiatives. They can provide training and support to supervisors to improve their capabilities in shaping safety culture, communication, coordination, and employee engagement. Strong leadership and effective supervision contribute to a positive safety climate and promote safe behaviours within teams. On top of all that, this SLR paper allows safety professionals and decision-makers to benchmark their organisation's practices against those reported in the literature. It enables them to compare their current selection and use of SLIs with established practices and recommendations, which in turn facilitates a critical evaluation of existing practices and provides opportunities for improvement and optimisation.

4. Conclusion

This SLR paper provides a comprehensive synthesis of studies that examine how SLIs influence safety performance across various industries. To achieve this, a multi-phase review framework was adopted, incorporating bibliometric analysis using the PRISMA protocol, scientometric mapping, and in-depth content analysis.

Several key insights emerged from the bibliometric and scientometric analyses. Collaboration patterns revealed strong academic ties among researchers in the UK, Spain, the Netherlands, and Denmark. Keyword clustering identified dominant themes such as "leading indicators," "safety management," "occupational accidents," and "accident prevention." Research activity intensified after 2014, peaking in 2019. The United States led in publication output, followed by Iran and Australia. The construction industry accounted for the highest representation, followed by oil and gas and healthcare.

The content analysis and quality assessment processes led to the identification of 67 distinct SLIs that influence safety performance across multiple sectors. Most indicators were associated with the "Do" stage of the PDCA cycle, reflecting an emphasis on actionable safety management practices. Quantitative, survey-based approaches dominated the methodological landscape. "Task characteristics" emerged as the most interconnected indicator, while "Training and education" appeared most frequently. Several indicators—such as SLI 1, 17, 18, 23, 24, 55, and 61—were consistently applicable across all sectors, indicating their foundational importance. Construction and oil and gas sectors presented the widest range of SLIs, reflecting their inherently high-risk environments.

While the findings present a robust mapping of SLIs, they must be interpreted with certain limitations in mind. For instance, emerging paradigms such as AI-driven analytics, digital tools, and predictive modelling remain underrepresented in current research. Methodologically, the prevalence of cross-sectional and retrospective designs restricts insight into the longitudinal effects of SLIs, and reliance on self-reported data raises concerns around potential bias. Sectoral and regional imbalances, particularly the underrepresentation of service sectors and non-Western contexts, further limit the generalisability of the findings.

Moreover, this review is subject to inherent constraints typical of systematic reviews. Although a rigorous protocol was applied, the scope was limited to English-language publications, potentially excluding relevant studies in other languages. The keyword strategy—though iteratively refined—may not have captured all terminological nuances, and elements of the content analysis and thematic classification involved interpretive judgment. These considerations do not detract from the contribution of the study, but they highlight areas for further exploration.

Future research should aim to refine SLI frameworks by incorporating longitudinal and mixed-method designs, expanding the geographical and sectoral diversity of case studies, and integrating digital and AI-based tools to enhance proactive safety management practices. Addressing these gaps will strengthen the empirical foundation for SLIs and advance their practical relevance in OSH systems.

Ethics statement

Not applicable because this work does not involve the use of animal or human subjects.

CRediT authorship contribution statement

Haleh Sadeghi: Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **Saeed Reza Mohandes:** Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **Akilu Yunusa-Kaltungo:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Clara Cheung:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Patrick Manu:** Writing – review & editing, Visualization, Validation, Supervision, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

This research is financially supported by the University of Manchester under the grant titled "Occupational Safety and Health – Understanding Decision Making and Role of Evidence (Grant Number: R127615)".

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jnlssr.2025.100272.

Appendix A

In this appendix, the results of scientometric analysis are provided.

The distribution of the identified research articles per year is depicted in Fig. A1. It can be seen that the number of articles increased considerably after 2014 and reached its peak in 2019, with 17 articles. The increase in article count following 2014 paralleled a conceptual change in how OSH was grasped and applied. Particularly, the release of "Safety Differently" signalled a turning point in safety thinking [125]. This approach challenged conventional compliance-driven models and supported a more adaptive, human-centred safety philosophy, emphasising the ability of workers to negotiate complexity, encouraging learning from variability and success, and sees safety not only as the absence of accidents but also as the presence of system resilience. Leading indicators, systems thinking, and proactive strategies to enhance safety performance were all revived in interest as a result of this reconceptualisation.

Table A1 illustrates the sources of publications on the concerned topic. As one may notice, the *Safety Science* journal constitutes the highest number of documents and citations, followed by the *Journal of Safety Research*, with 20 and 7 documents, respectively. The dominance of the outputs from these two journals is mainly due to their prestige, and technicality of sectoral diversity. The co-citation map of the leading authors is depicted in Fig. A2. In co-citation maps, colours highlight different clusters of authors who are frequently cited together. This analysis provides insights into which authors are most commonly co-cited. For example, as can be observed from the green region of the map, Hallowell, Lingard, and Hinze were co-cited more in the body of relevant literature than the other researchers within the same cluster. Fig. A3 illustrates the collaboration that exists among the scholars carrying out research in the respective field of study. For instance, it can be seen that the strongest collaboration link exists for the UK since there is a high level of collaboration among the researchers in the UK, Spain, Netherlands, and Denmark. Additionally, Australian researchers have collaborated well with their Chinese peers, as shown in blue colour. Furthermore, the highest number of keywords that appeared in the literature is illustrated in Fig. A4. In a co-occurrence keyword analysis, colors indicate different clusters of keywords that frequently appear together. Each color represents a specific thematic area or topic within the research field. This grouping helps reveal the interconnections between various research themes and highlights the most prominent topics. The clusters identify key areas of focus and emerging trends in the literature. As one may notice, the higher the appearance, the bigger the circle. For instance, "leading indicators", "occupational accidents", "safety management" and "accident prevention" are the most commonly used keywords in the body of relevant knowledge. In addition, four different themes can be formed, including "Green colour: Workplace Safety and Health", "Yellow colour: Construction Safety and Accident Prevention", "Red colour: Workplace Diversity and Safety Culture", and "Blue colour: Workplace Safety and Organisational Culture".

These findings provide a research-driven mapping of publication trends, key contributors, and thematic clusters, which can guide future scholars in identifying influential works, emerging areas of focus, and potential collaborators in the SLI domain.

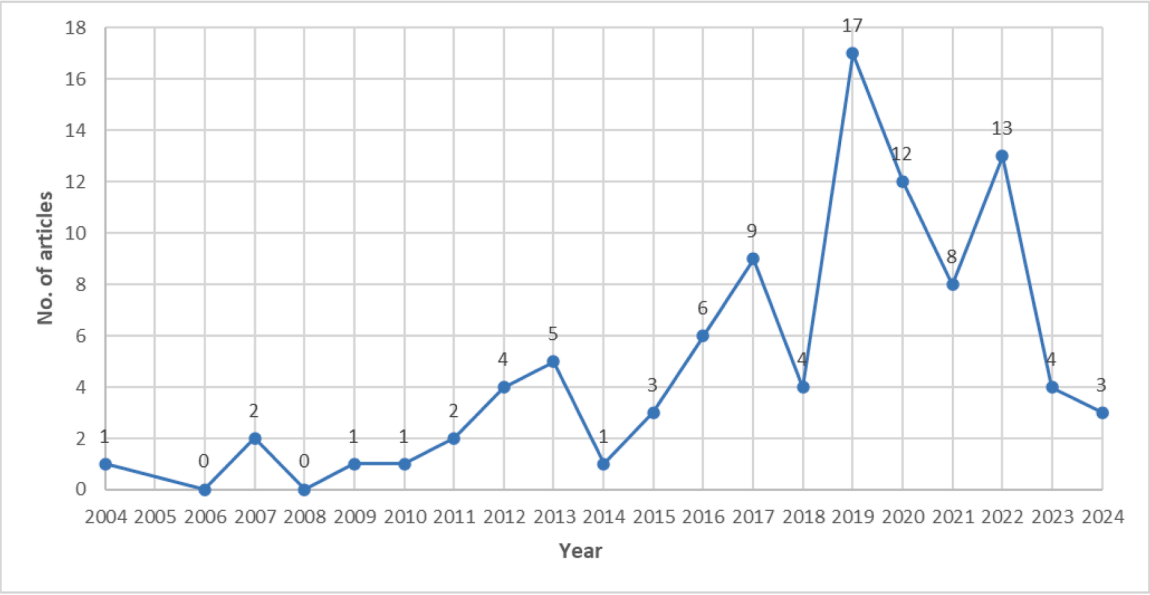


Fig. A1. Distribution of articles per year.

Table A1
Sources of the refined documents for this state-of-the-art review.

Id	Source	Documents	Citations
1	*Safety Science*	20	952
2	*Journal of Safety Research*	7	364
3	*Journal of Construction Engineering and Management*	5	226
4	*Journal of Management in Engineering*	3	119
5	*Engineering, Construction and Architectural Management*	2	54
6	*Process Safety Progress*	1	32
7	*Safety*	2	28
8	*International Journal of Occupational Safety and Ergonomics*	3	27
9	*International Journal of Manpower*	1	26
10	*IEEE Transactions on Systems, Man, And Cybernetics Part A: Systems and Humans*	1	25
11	*Computers and Chemical Engineering*	1	24
12	*Construction Management and Economics*	1	24
13	*Practice Periodical on Structural Design and Construction*	1	21
14	*BMC Health Services Research*	1	18
15	*Progress in Nuclear Energy*	1	18
16	*Work*	2	14
17	*Journal of Loss Prevention in the Process Industries*	2	13
18	*Transportation Research Part C: Emerging Technologies*	1	13
19	*International Journal of Lean Six Sigma*	1	12
20	*American Journal of Industrial Medicine*	2	11
21	*International Journal of Building Pathology And Adaptation*	1	11
22	*Journal of Critical Reviews*	1	10
23	*Stress and Health*	1	9
24	*New Solutions*	1	8
25	*Revista de la Construcción*	1	7
26	*Workplace Health And Safety*	1	7
27	*Process Safety and Environmental Protection*	1	6
28	*Chemical Engineering Transactions*	1	4
29	*Journal of Rail Transport Planning And Management*	1	4
30	*International Journal of Environmental Research and Public Health*	1	3
31	*Journal of UOEH*	1	3
32	*Advances in Science, Technology and Engineering Systems*	1	2
33	*Ergonomics*	1	2
34	*Journal of Occupational and Environmental Medicine*	1	2
35	*Applied Sciences (Switzerland)*	1	1
36	*Health Security*	1	1
37	*Safety and Health at Work*	2	1

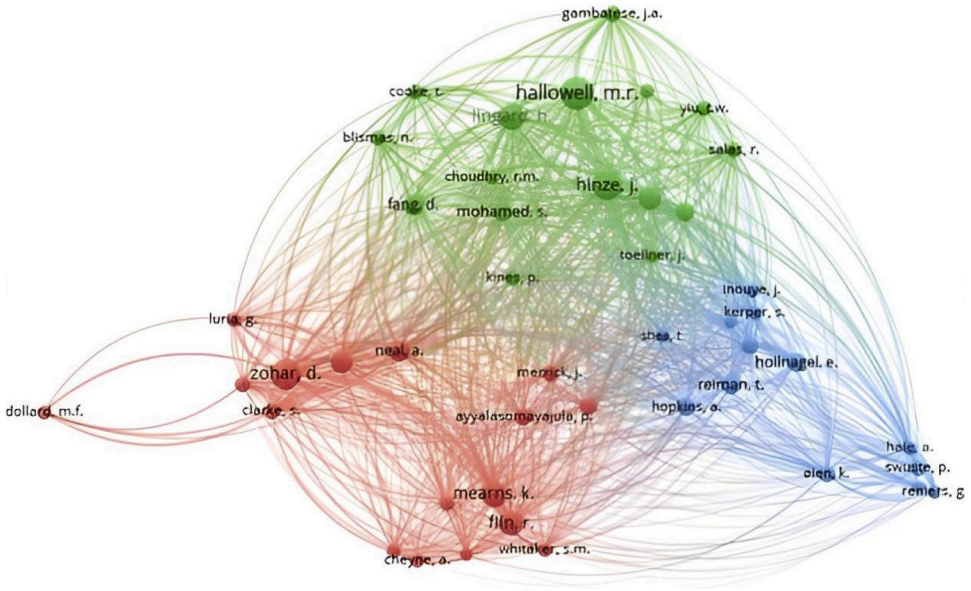


Fig. A2. Co. Citation map of authors.

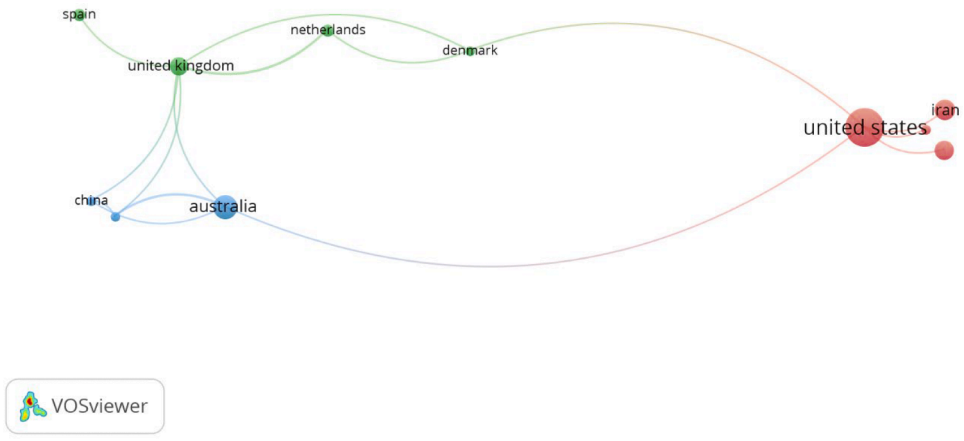


Fig. A3. Co-authorship of countries.

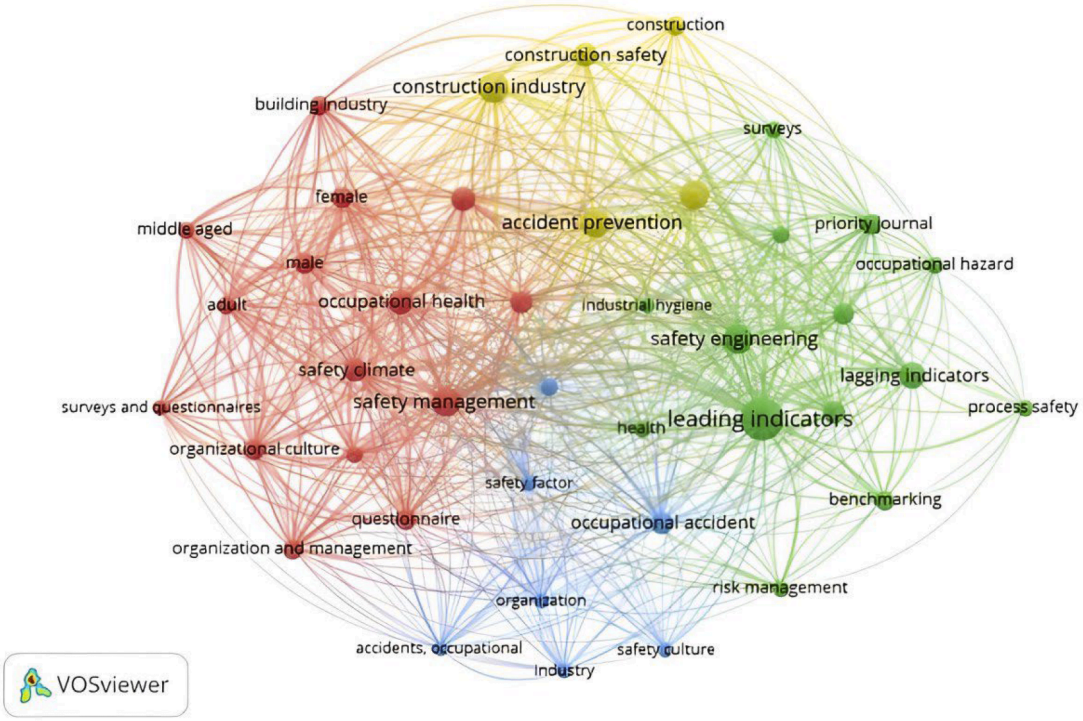


Fig. A4. Co-occurrences of keywords.

Appendix B

In this appendix, the results obtained from QA are provided.

The robustness of the evidence of the identified papers using the employed QA is tabulated in Table B1. According to the insights from Fig. B1, where approximately 32 papers were awarded a score of 3, it becomes apparent that merely two received a rating of 1. Expanding on this, Fig. B1 also reveals that nearly 80 % of the papers attained scores equal to or surpassing 3. This persuasive data substantiates the credibility of the SLIs introduced within this study, underscoring a significant trend within the research community. It signifies that a considerable portion of research within this field may be considered robust, as the majority of papers achieved scores equal to or exceeding 3. The QA highlights the methodological variability across studies and underscores the need for more rigorous, evidence-based research designs, offering valuable guidance for both academic researchers and practitioners seeking reliable findings to inform policy or practice.

Table B1
The scores assigned to the papers for QS.

No.	Reference	Score	Refined/Not Refined	No.	Reference	Score	Refined/Not Refined	No.	Reference	Score	Refined/Not Refined
1	[83]	4	Refined	34	[79]	5	Refined	67	[103]	5	Refined
2	[85]	4	Refined	35	[23]	5	Refined	68	[105]	3	Refined
3	[104]	3	Refined	36	[113]	5	Refined	69	[88]	3	Refined
4	[55]	5	Refined	37	[80]	4	Refined	70	[62]	3	Refined
5	[9]	Review	Not Applicable	38	[107]	3	Refined	71	[126]	2	Not Refined
6	[127]	2	Not Refined	39	[108]	4	Refined	72	[87]	3	Refined
7	[111]	4	Refined	40	[109]	4	Refined	73	[64]	3	Refined
8	[74]	3	Refined	41	[92]	3	Refined	74	[89]	5	Refined
9	[66]	3	Refined	42	[4]	3	Refined	75	[106]	5	Refined
10	[128]	1	Not Refined	43	[54]	2	Not Refined	76	[114]	5	Refined
11	[12]	5	Refined	44	[73]	Review	Not Applicable	77	[98]	5	Refined
12	[69]	4	Refined	45	[86]	Review	Not Applicable	78	[115]	3	Refined
13	[100]	3	Refined	46	[91]	4	Refined	79	[63] *	3	Refined
14	[99]	3	Refined	47	[67]	2	Not Refined	80	[129] *	2	Not Refined
15	[112]	3	Refined	48	[110]	Review	Not Applicable	81	[130] *	2	Not Refined
16	[20]	Review	Not Applicable	49	[24]	2	Not Refined	82	[68] *	3	Refined
17	[22]	3	Refined	50	[95]	5	Refined	83	[21] *	2	Not Refined
18	[76]	3	Refined	51	[57]	5	Refined	84	[131] *	2	Not Refined
19	[96]	3	Refined	52	[58]	4	Refined	85	[132] *	2	Not Refined
20	[56]	4	Refined	53	[72]	4	Refined	86	[81] *	3	Refined
21	[133]	2	Not Refined	54	[60]	4	Refined	87	[134]	3	Refined
22	[84]	3	Refined	55	[75]	4	Refined	88	[135]	4	Refined
23	[77]	4	Refined	56	[48]	5	Refined	89	[134]	3	Refined
24	[52]	5	Refined	57	[49]	3	Refined	90	[135]	4	Refined
25	[136]	2	Not Refined	58	[50]	5	Refined	91	[65]	Review	Not Applicable
26	[59]	4	Refined	59	[51]	5	Refined	92	[90]	3	Refined
27	[25]	Review	Not Applicable	60	[17]	3	Refined	93	[94]	Review	Not Applicable
28	[53]	4	Refined	61	[70]	4	Refined	94	[93]	Review	Not Applicable
29	[137]	1	Not Refined	62	[71]	3	Refined	95	[97]	4	Refined
30	[61]	4	Refined	63	[82]	3	Refined	96	[101]	3	Refined
31	[19]	Review	Not Applicable	64	[116]	4	Refined				
32	[18]	Review	Not Applicable	65	[138]	2	Not Refined				
33	[78]	Review	Not Applicable	66	[8]	3	Refined				

Note.
* denotes that the source is grey literature.

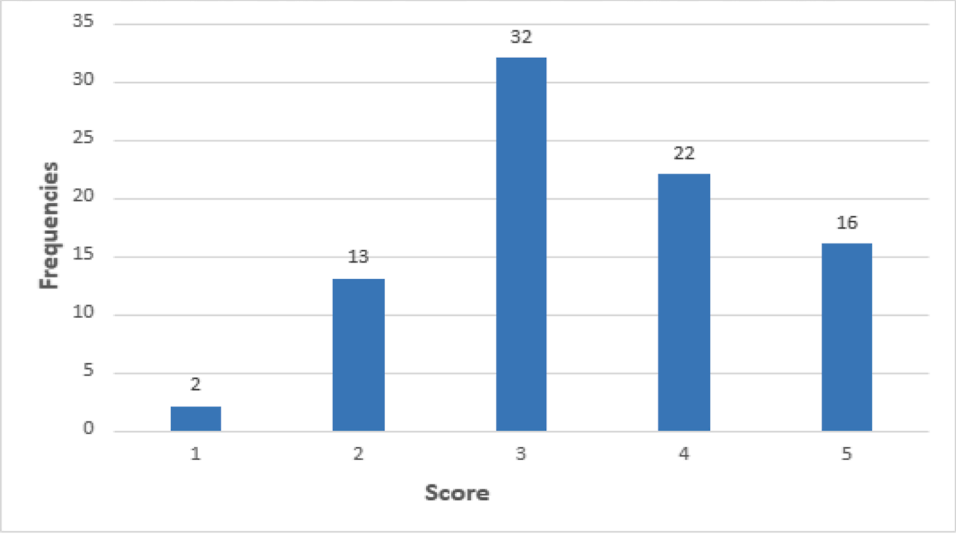


Fig. B1. Breakdown of QA analysis based on the distribution of paper scores.

References

[1] I.L. Organization, Safety and health at the heart of the future of work: building on 100 years of experience, (2019).
[2] U.K. HSE, Work-related fatal injuries in Great Britain, (2023).
[3] D. Michaels, G.R. Wagner, OSHA injury data: an opportunity for improving work injury prevention, Am. J. Public Health. (2025) e1–e8.
[4] B. Pandit, A. Albert, Y. Patil, A.J. Al-Bayati, Impact of safety climate on hazard recognition and safety risk perception, Saf. Sci. 113 (2019) 44–53.
[5] A. Babalola, P. Manu, C. Cheung, A. Yunusa-Kaltungo, P. Bartolo, A systematic review of the application of immersive technologies for safety and health management in the construction sector, J. Safety Res. 85 (2023) 66–85.
[6] A. Yunusa-Kaltungo, A. Labib, A hybrid of industrial maintenance decision making grids, Prod. Plan. Control. 32 (2021) 397–414.
[7] A. Singh, S.C. Misra, V. Kumar, U. Kumar, Identification and ordering of safety performance indicators using fuzzy TOPSIS: a case study in Indian construction company, Int. J. Qual. Reliab. Manag. 39 (2022) 77–114.
[8] M.R. Hallowell, J.W. Hinze, K.C. Baud, A. Wehle, Proactive construction safety control: measuring, monitoring, and responding to safety leading indicators, J. Constr. Eng. Manag. 139 (2013) 4013010.
[9] M.X.M. Ali, K. Arifin, A. Abas, M.A. Ahmad, M. Khairil, M.B. Cyio, M.A. Samad, I. Lampe, M. Mahfudz, M.N. Ali, Systematic literature review on indicators use in safety management practices among utility industries, Int. J. Environ. Res. Public Health. 19 (2022) 6198.
[10] M. Gil, P. Kozioł, K. Wróbel, J. Montewka, Know your safety indicator–A determination of merchant vessels Bow Crossing Range based on big data analytics, Reliab. Eng. Syst. Saf. 220 (2022) 108311.
[11] U. Govender, G. Van Eck, B. Genc, An integrated 4Cs safety framework for the diamond industry of Southern Africa, Resour. Policy. 77 (2022) 102774.
[12] C.M. Cheung, R.P. Zhang, R. Wang, S.-C. Hsu, P. Manu, Group-level safety climate in the construction industry: influence of organizational, group, and individual factors, J. Manag. Eng. 38 (2022) 4021080.
[13] D. Podgórski, Measuring operational performance of OSH management system–A demonstration of AHP-based selection of leading key performance indicators, Saf. Sci. 73 (2015) 146–166.
[14] I. Mohammadfam, M. Kamalinia, M. Momeni, R. Golmohammadi, Y. Hamidi, A. Soltanian, Evaluation of the quality of occupational health and safety management systems based on key performance indicators in certified organizations, Saf. Health Work. 8 (2017) 156–161.
[15] S.L.C. da Silva, F.G. Amaral, Critical factors of success and barriers to the implementation of occupational health and safety management systems: a systematic review of literature, Saf. Sci. 117 (2019) 123–132.
[16] R.A. Quaigrain, M.H. Issa, Comparative analysis of leading and lagging indicators of construction disability management performance: an exploratory study, Int. J. Constr. Manag. 23 (2023) 1205–1213.
[17] E.J. Haas, P. Yorio, Exploring the state of health and safety management system performance measurement in mining organizations, Saf. Sci. 83 (2016) 48–58.
[18] F.J. Forteza, J.M. Carretero-Gómez, A. Sesé, Safety in the construction industry: accidents and precursors, Rev. La Construcción. 19 (2020) 271–281.
[19] A.Y. Shaikh, R. Osei-Kyei, M. Hardie, A critical analysis of safety performance indicators in construction, Int. J. Build. Pathol. Adapt. (2020).
[20] J. Xu, C. Cheung, P. Manu, O. Ejohwomu, Safety leading indicators in construction: a systematic review, Saf. Sci. 139 (2021) 105250.
[21] W.S. Atkins, Development of suitable safety performance indicators for level 4 bio-containment facilities: phase 2, Heal. Saf. Exec. (2011).
[22] N. Kharaishvili, J.W. Blake, D.H. Gorsline, L.R. Brooks, Global health Security capacity and capability measurement framework within the Biological Threat Reduction Program, Heal. Secur. 19 (2021) 163–172.
[23] J. Almost, L.C. Tett, E. VanDenKerkhof, G. Paré, P. Strahlendorf, J. Noonan, T. Hayes, J. Holden, V.S. e Silva, A. Rochon, Leading indicators in occupational health and Safety management systems in healthcare: a quasi-experimental longitudinal study, J. Occup. Environ. Med. 61 (2019) e486–e496.
[24] J.M. Almost, E.G. VanDenKerkhof, P. Strahlendorf, L. Caicco Tett, J. Noonan, T. Hayes, R. Adam, J. Holden, T. Kent-Hillis, M. McDonald, A study of leading indicators for occupational health and safety management systems in healthcare, BMC Health Serv. Res. 18 (2018) 1–7.
[25] M.R. Hallowell, S. Bhandari, W. Alruqi, Methods of safety prediction: analysis and integration of risk assessment, leading indicators, precursor analysis, and safety climate, Constr. Manag. Econ. 38 (2020) 308–321.
[26] D. Tranfield, D. Denyer, P. Smart, Towards a methodology for developing evidence-informed management knowledge by means of systematic review, Br. J. Manag. 14 (2003) 207–222.
[27] D. Moher, A. Liberati, J. Tetzlaff, D.G. Altman, Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement, Bmj 339 (2009).
[28] P.W. Chan, O. Ejohwomu, How Does Project Management Relate to Productivity?: A Systematic Review of Published Evidence, Association for Project Management, 2018.
[29] H. Sadeghi, C.M. Cheung, A. Yunusa-Kaltungo, P. Manu, A systematic review of occupational safety and health in modular integrated construction, Saf. Sci. 189 (2025) 106897.
[30] R. Nieuwlaat, N. Wilczynski, T. Navarro, N. Hobson, R. Jeffery, A. Keepanasseril, T. Agoritsas, N. Mistry, A. Iorio, S. Jack, Interventions for enhancing medication adherence, Cochrane Database Syst. Rev. (2014).
[31] L. Yang, H. Zhang, H. Shen, X. Huang, X. Zhou, G. Rong, D. Shao, Quality assessment in systematic literature reviews: a software engineering perspective, Inf. Softw. Technol 130 (2021) 106397.
[32] B. Kitchenham, Procedures for performing systematic reviews, Keele, UK, Keele Univ 33 (2004) 1–26.
[33] B.A. Kitchenham, D. Budgen, P. Brereton, Evidence-based Software Engineering and Systematic Reviews, CRC press, 2015.
[34] A. Jedlitschka, D. Pfahl, Reporting guidelines for controlled experiments in software engineering, 2005 Int. Symp. Empir. Softw. Eng. 2005 (2005) 10–pp.
[35] S. Keele, Guidelines for performing systematic literature reviews in software engineering, technical report, ver. 2.3 ebse technical report. ebse, 2007.
[36] M. Sohail, H.N. Afrouzi, K. Mehranzamir, J. Ahmed, M.B.M. Siddique, M. Tabassum, A comprehensive scientometric analysis on hybrid renewable energy systems in developing regions of the world, Results Eng 16 (2022) 100481.
[37] R. Kumar, S. Saxena, V. Kumar, V. Prabha, R. Kumar, A. Kukreti, Service innovation research: a bibliometric analysis using VOSviewer, Compet. Rev. An Int. Bus. J. 34 (2024) 736–760.
[38] F. Yarmohammadi, A.Wallace Hayes, G. Karimi, Molecular mechanisms involved in doxorubicin-induced cardiotoxicity: a bibliometrics analysis by VOSviewer, Naunyn. Schmiedebergs. Arch. Pharmacol. 397 (2024) 1971–1984.
[39] N.B. Siraj, A.R. Fayek, Risk identification and common risks in construction: literature review and content analysis, J. Constr. Eng. Manag. 145 (2019) 3119004.
[40] S. Kumar, W.M. Lim, U. Sivarajah, J. Kaur, Artificial intelligence and blockchain integration in business: trends from a bibliometric-content analysis, Inf. Syst. Front. 25 (2023) 871–896.
[41] P. Sabetsarvestani, F. Mohammadi, B. Tehranineshat, M. Bijani, Z. Fereidouni, Barriers to efficient management of in-home care: a qualitative content analysis, Nurs. Open. 9 (2022) 1200–1209.
[42] H. Kim, K.K.F. So, Two decades of customer experience research in hospitality and tourism: a bibliometric analysis and thematic content analysis, Int. J. Hosp. Manag. 100 (2022) 103082.
[43] C. Salihu, M. Hussein, S.R. Mohandes, T. Zayed, Towards a comprehensive review of the deterioration factors and modeling for sewer pipelines: a hybrid of bibliometric, scientometric, and meta-analysis approach, J. Clean. Prod. 351 (2022) 131460.
[44] The U.S. Bureau of Labor Statistics, NATIONAL CENSUS OF FATAL OCCUPATIONAL INJURIES IN 2021, 2021. https://www.bls.gov/news.release/pdf/cfoi.pdf.
[45] International Labour Organisation, Construction: a hazardous work, (2015). https://www.ilo.org/safework/areasofwork/hazardous-work/WCMS_356576/lang–en/index.htm.
[46] A. Hale, D. Borys, Working to rule, or working safely? Part 1: a state of the art review, Saf. Sci. 55 (2013) 207–221.
[47] Health and Safety Executive, Managing for health and safety (HSG65), 2013. https://www.hse.gov.uk/pubns/priced/hsg65.pdf.
[48] Y. Chen, B. McCabe, D. Hyatt, Impact of individual resilience and safety climate on safety performance and psychological stress of construction workers: a case study of the Ontario construction industry, J. Safety Res. 61 (2017) 167–176.
[49] B.H.W. Guo, T.W. Yiu, V.A. González, Y.M. Goh, Using a pressure-state-practice model to develop safety leading indicators for construction projects, J. Constr. Eng. Manag. 143 (2017) 4016092.
[50] M.J. Jafari, D. Eskandari, F. Valipour, Y. Mehrabi, H. Charkhand, M. Mirghotbi, Development and validation of a new safety climate scale for petrochemical industries, Work 58 (2017) 309–317.
[51] T. Shea, H. De Cieri, R. Donohue, B. Cooper, C. Sheehan, Leading indicators of occupational health and safety: an employee and workplace level validation study, Saf. Sci. 85 (2016) 293–304.
[52] A.M. Dale, R. Colvin, M. Barrera, J.R. Strickland, B.A. Evanoff, The association between subcontractor safety management programs and worker perceived safety climate in commercial construction projects, J. Safety Res. 74 (2020) 279–288.
[53] S.S. Mousavi, R. Khani Jazani, E.A. Cudney, P. Trucco, Quantifying the relationship between lean maturity and occupational health and safety: antecedents and leading indicators, Int. J. Lean Six Sigma. 11 (2020) 150–170.
[54] K.-H. Liu, J. Tessler, L.A. Murphy, C.-C. Chang, J.T. Dennerlein, The gap between tools and best practice: an analysis of safety prequalification surveys in the construction industry, NEW Solut. A J. Environ. Occup. Heal. Policy. 28 (2019) 683–703.
[55] L.L. Moore, S.J. Wurzelbacher, I.-C. Chen, M.P. Lampl, S.J. Naber, Reliability and validity of an employer-completed safety hazard and management assessment questionnaire, J. Safety Res. 81 (2022) 283–296.
[56] D. Eskandari, M.J. Gharabagh, A. Barkhordari, N. Gharari, D. Panahi, A. Gholami, G. Teimori-Boghsani, Development of a scale for assessing the organization's safety performance based fuzzy ANP, J. Loss Prev. Process Ind. 69 (2021) 104342.
[57] H. Kasim, C.R.C. Hassan, M.D. Hamid, S.D. Emami, M. Danaee, Determination of factors affecting safety practices in Malaysian radiation facilities, Saf. Sci. 104 (2018) 70–80.
[58] A.P.C. Chan, F.K.W. Wong, C.K.H. Hon, S. Lyu, A.A. Javed, Investigating ethnic minorities' perceptions of safety climate in the construction industry, J. Safety Res. 63 (2017) 9–19.
[59] M. del Carmen Pardo-Ferreira, J.C. Rubio-Romero, A. Gibb, S. Calero-Castro, Using functional resonance analysis method to understand construction activities for concrete structures, Saf. Sci. 128 (2020) 104771.
[60] N.S. Akroush, I.H. El-Adaway, Utilizing construction leading safety indicators: case study of Tennessee, J. Manag. Eng. 33 (2017) 6017002.
[61] M. Falahati, A. Karimi, I. Mohammadfam, A. Mazloumi, A. Reza Khanteymoori, M. Yaseri, Multi-dimensional model for determining the leading performance indicators of safety management systems, Work 67 (2020) 959–969.

[62] T. Reiman, E. Pietikäinen, Leading indicators of system safety–monitoring and driving the organizational safety potential, Saf. Sci. 50 (2012) 1993–2000.
[63] J. Inouye, J. Dony, K. Smith, K. Knee, Practical Guide to Leading Indicators, Metrics Case Studies & Strategies, 2015.
[64] F. Khan, H. Abunada, D. John, T. Benmosbah, Development of risk-based process safety indicators, Process Saf. Prog. 29 (2010) 133–143.
[65] R.N. Phinias, Benefits and challenges relating to the implementation of health and safety leading indicators in the construction industry: a systematic review, Saf. Sci. 163 (2023) 106131.
[66] K. Bhagwat, V.S.K. Delhi, P. Nanthagopalan, Construction safety performance measurement using a leading indicator-based jobsite safety inspection method: case study of a building construction project, Int. J. Occup. Saf. Ergon. (2022) 1–12.
[67] L. Santos, A. Haddad, I.L. dos Santos, Process safety leading indicators in oil storage and pipelines: building a panel of indicators, Chem. Eng. Trans 77 (2019) 73–78.
[68] C. Butler, N. Healey, C. Sugden, Safety performance indicators in the explosives sector, 2012. https://www.hse.gov.uk/research/rrpdf/rr909.pdf.
[69] H. Mirderikvand, F. Razavian, A. Nakhaee, B.M. Ghiasabadi, R. Gholamnia, A barrier risk-based evaluation model for drilling blowouts, J. Loss Prev. Process Ind. 74 (2022) 104624.
[70] S. Mariappanadar, Health harm of work from the sustainable HRM perspective: scale development and validation, Int. J. Manpow. (2016).
[71] B.H.W. Guo, T.W. Yiu, Developing leading indicators to monitor the safety conditions of construction projects, J. Manag. Eng. 32 (2016) 4015016.
[72] P. Amir-Heidari, R. Maknoon, B. Taheri, M. Bazyari, A new framework for HSE performance measurement and monitoring, Saf. Sci. 100 (2017) 157–167.
[73] W.M. Alruqi, M.R. Hallowell, Critical success factors for construction safety: review and meta-analysis of safety leading indicators, J. Constr. Eng. Manag. 145 (2019) 4019005.
[74] P. Van Derlyke, L.S. Marín, M. Zreiqat, Discrepancies between implementation and perceived effectiveness of leading safety indicators in the US dairy product manufacturing industry, Saf. Health Work. (2022).
[75] S. Givehchi, E. Hemmativaghef, H. Hoveidi, Association between safety leading indicators and safety climate levels, J. Safety Res. 62 (2017) 23–32.
[76] P. Schmitz, G. Reniers, P. Swuste, K. van Nunen, Predicting major hazard accidents in the process industry based on organizational factors: a practical, qualitative approach, Process Saf. Environ. Prot. 148 (2021) 1268–1278.
[77] D. Kurian, F. Sattari, L. Lefsrud, Y. Ma, Using machine learning and keyword analysis to analyze incidents and reduce risk in oil sands operations, Saf. Sci. 130 (2020) 104873.
[78] G.M.A. Naji, A.S.N. Isha, A.-B.A. Al-Mekhlafi, O. Sharafaddin, M. Ajmal, Implementation of leading and lagging indicators to improve safety performance in the upstream oil and gas industry, J. Crit. Rev. 7 (2020) 265–269.
[79] S. Vosoughi, M.H. Chalak, R. Yarahmadi, J. Abolaghasemi, I. Alimohammadi, F. A. Kanrash, M. Pourtalari, Identification, selection and prioritization of key performance indicators for the improvement of occupational health (case study: an automotive company), J. UOEH. 42 (2020) 35–49.
[80] K. Versteeg, P. Bigelow, A.M. Dale, A. Chaurasia, Utilizing construction safety leading and lagging indicators to measure project safety performance: a case study, Saf. Sci. 120 (2019) 411–421.
[81] J. Inouye, An implementation guide to leading indicators, (2019).
[82] Z. Pawłowska, Using lagging and leading indicators for the evaluation of occupational safety and health performance in industry, Int. J. Occup. Saf. Ergon. 21 (2015) 284–290.
[83] H. Lingard, M. Hallowell, R. Salas, P. Pirzadeh, Leading or lagging? Temporal analysis of safety indicators on a large infrastructure construction project, Saf. Sci 91 (2017) 206–220.
[84] G. Zwetsloot, S. Leka, P. Kines, A. Jain, Vision zero: developing proactive leading indicators for safety, health and wellbeing at work, Saf. Sci. 130 (2020) 104890.
[85] S. Rajendran, Enhancing construction worker safety performance using leading indicators, Pract. Period. Struct. Des. Constr. 18 (2013) 45–51.
[86] S.D.S. Neamat, A comparative study of safety leading and lagging indicators measuring project safety performance, Indicators 1 (2019) 29.
[87] H. Lingard, R. Wakefield, P. Cashin, The development and testing of a hierarchical measure of project OHS performance, Eng. Constr. Archit. Manag. (2011).
[88] P. Kleindorfer, U.G. Oktem, A. Pariyani, W.D. Seider, Assessment of catastrophe risk and potential losses in industry, Comput. Chem. Eng. 47 (2012) 85–96.
[89] M. Grabowski, Z. You, H. Song, H. Wang, J.R.W. Merrick, Sailing on friday: developing the link between safety culture and performance in safety-critical systems, IEEE Trans. Syst. Man, Cybern. A Syst. Humans. 40 (2009) 263–284.
[90] S. Jain, S.K. Jauhar, A. Piyush, machine-learning-based framework for contractor selection and order allocation in public construction projects considering sustainability, risk, and safety, Ann. Oper. Res. (2024) 1–43.
[91] A. Costin, A. Wehle, A. Adibfar, Leading indicators—A conceptual IoT-based framework to produce active leading indicators for construction safety, Safety 5 (2019) 86.
[92] J. Manjourides, J.T. Dennerlein, Testing the associations between leading and lagging indicators in a contractor safety pre-qualification database, Am. J. Ind. Med. 62 (2019) 317–324.
[93] H. Golabchi, A.D. Abellanosa, L. Lefsrud, E. Pereira, Y. Mohamed, A comprehensive systematic review of safety leading indicators in construction, Saf. Sci. 172 (2024) 106433.
[94] M. Heydari, G. Heravi, R. Raeisinafchi, H. Karimi, A dynamic model to assess the role of site supervision systems in the safety performance of construction projects, J. Constr. Eng. Manag. 150 (2024) 4024001.
[95] F.K. Bitar, D. Chadwick-Jones, M. Lawrie, M. Nazaruk, C. Boodhai, Empirical validation of operating discipline as a leading indicator of safety outputs and plant performance, Saf. Sci. 104 (2018) 144–156.
[96] M. Li, F. Yan, R. Niu, N. Xiang, Identification of causal scenarios and application of leading indicators in the interconnection mode of urban rail transit based on STPA, J. Rail Transp. Plan. Manag. 17 (2021) 100238.
[97] J. Zara, S.M. Nordin, A.S.N. Isha, Influence of communication determinants on safety commitment in a high-risk workplace: a systematic literature review of four communication dimensions, Front. Public Heal 11 (2023) 1225995.
[98] D. Dyck, T. Roithmayr, Great safety performance: an improvement process using leading indicators, AAOHN J 52 (2004) 511–520.
[99] F. Brocal Fernandez, A. Sanchez-Lite, J.L. Fuentes-Bargues, M.Á. Sebastian, C. González-Gaya, Conceptual classification of leading indicators for the dynamic analysis of emerging risks in integrated, Management Systems, Appl. Sci. 11 (2021) 10921.
[100] I. Sarbat, S. Ozmehmet Tasan, Ergonomics indicators: a proposal for sustainable process performance measurement in ergonomics, Ergonomics 65 (2022) 3–38.
[101] M.Dadashi Haji, B. Behnam, M.H. Sebt, A. Ardeshir, A. Katooziani, BIM-based safety leading indicators measurement tool for construction sites, Int. J. Civ. Eng. 21 (2023) 265–282.
[102] C. Sugden, N. Healey, K. Howard, P. Rushton, Safety performance indicators in the explosives sector, Loss Prev. Bull. 212 (2010) 16–21.
[103] S.A. Basha, J. Maiti, Relationships of demographic factors, job risk perception and work injury in a steel plant in India, Saf. Sci. 51 (2013) 374–381.
[104] A.J. Al-Bayati, O. Abudayyeh, T. Fredericks, S.E. Butt, Managing cultural diversity at US construction sites: hispanic workers' perspectives, J. Constr. Eng. Manag. 143 (2017) 4017064.
[105] J. Hinze, S. Thurman, A. Wehle, Leading indicators of construction safety performance, Saf. Sci. 51 (2013) 23–28.
[106] M. Grabowski, P. Ayyalasomayajula, J. Merrick, J.R. Harrald, K. Roberts, Leading indicators of safety in virtual organizations, Saf. Sci. 45 (2007) 1013–1043.
[107] E. Lagerstrom, S. Magzamen, P. Kines, W. Brazile, J. Rosecrance, Determinants of safety climate in the professional logging industry, Safety 5 (2019) 35.
[108] M.T. Newaz, P.R. Davis, M. Jefferies, M. Pillay, Validation of an agent-specific safety climate model for construction, Eng. Constr. Archit. Manag. (2019).
[109] Y.-H. Cheng, Railway safety climate: a study on organizational development, Int. J. Occup. Saf. Ergon. 25 (2019) 200–216.
[110] K.H.D. Tang, S.Z.M. Dawal, E.U. Olugu, A review of the offshore oil and gas safety indices, Saf. Sci. 109 (2018) 344–352.
[111] T.W. Casey, X. Hu, L. Kanse, A. Varhammar, A tale of six climates: reflections and learnings after the development of six industry-specific safety climate scales, J. Safety Res. 82 (2022) 151–158.
[112] A.M. Dale, M. Barrera, R. Colvin, J. Strickland, B.A. Evanoff, Flow-down of safety from general contractors to subcontractors working on commercial construction projects, Saf. Sci. 142 (2021) 105353.
[113] S.S. McLinton, A. Afsharian, M.F. Dollard, M.R. Tuckey, The dynamic interplay of physical and psychosocial safety climates in frontline healthcare, Stress Heal 35 (2019) 650–664.
[114] S.E. Johnson, The predictive validity of safety climate, J. Safety Res. 38 (2007) 511–521.
[115] S. Amiri, H.A. Mahabadi, S.B. Mortazavi, M.G. Kakavandi, Investigation of safety climate in an oil industry in summer of 2014, Heal. Scope. 4 (2015).
[116] C.H. dos Santos Grecco, M.C.R. Vidal, C.A.N. Cosenza, I.J.A.L. dos Santos, P.V. R. de Carvalho, Safety culture assessment: a fuzzy model for improving safety performance in a radioactive installation, Prog. Nucl. Energy. 70 (2014) 71–83.
[117] S. Ahmad, T. Iqbal, The role of management commitment in adoption of occupational health and safety at higher education institutions, Entrep. Sustain. Issues. 9 (2022) 103.
[118] O. Ahmadi, S.B. Mortazavi, H.A. Mahabadi, M. Hosseinpouri, Development of a dynamic quantitative risk assessment methodology using fuzzy DEMATEL-BN and leading indicators, Process Saf. Environ. Prot. 142 (2020) 15–44.
[119] S.N.N. Syed-Yahya, M.A. Idris, A.J. Noblet, The relationship between safety climate and safety performance: a review, J. Safety Res. (2022).
[120] S.R. Mohandes, S. Durdyev, H. Sadeghi, A. Mahdiyar, M.R. Hosseini, S. Banihashemi, I. Martek, Towards enhancement in reliability and safety of construction projects: developing a hybrid multi-dimensional fuzzy-based approach, Eng. Constr. Archit. Manag. 30 (2023) 2255–2279.
[121] T. Ji, H.-H. Wei, J. Chen, Understanding the effect of co-worker support on construction safety performance from the perspective of risk theory: an agent-based modeling approach, J. Civ. Eng. Manag. 25 (2019) 132–144.
[122] S.M. Conchie, S. Moon, M. Duncan, Supervisors' engagement in safety leadership: factors that help and hinder, Saf. Sci. 51 (2013) 109–117.
[123] H. Sadeghi, X. Zhang, S.R. Mohandes, Developing an ensemble risk analysis framework for improving the safety of tower crane operations under coupled Fuzzy-based environment, Saf. Sci. 158 (2023) 105957.
[124] J. Xu, C. Cheung, P. Manu, O. Ejohwomu, J. Too, Implementing safety leading indicators in construction: toward a proactive approach to safety management, Saf. Sci. 157 (2023) 105929.
[125] S. Dekker, T. Conklin, Safety Differently, CRC Press London, 2014.
[126] R.H. de Almeida, New approach for safety management in radiopharmaceutical production facilities, Lat, Am. J. Pharm. 31 (2012) 1199–1202.
[127] H. Hameed, M.A. Sarfraz, Measuring vital signs of process safety culture, Process Saf. Prog. 41 (2022) 111–119.

[128] H. Landis, Considerations for a balanced scorecard of leading and lagging indicators for your electrical safety program: leading and lagging indicators, IEEE Ind. Appl. Mag. 28 (2022) 16–20.
[129] Center for Chemical Process Safety, Process Safety metrics: guide for selecting leading and lagging indicators, 2022. https://www.aiche.org/sites/default/files/docs/pages/ccps_process_safety_metrics_-_v4.1.pdf.
[130] eCompliance, The definitive guide to leading indicators, 2016. https://go.ecompliance.com/White-Paper-Guide-To-Leading-Indicators.html.
[131] OSHA, Using leading indicators to improve safety and health outcomes, US Dep, Labor (2019).
[132] OSHA, Recommended practices for safety and health programs, Occup. Saf. Heal. Adm. Washington, DC, USA (2016).
[133] T. Stauffer, D. Chastain-Knight, Do not let your safe operating limits leave you S-O-L (out of luck), Process Saf. Prog. 40 (2021) e12163.
[134] A. Jebelli, M. Omidvari, R. Kazemi, K. Samradjah, Providing A model for evaluation the performance of Ohs using the safety scorecard method-case study of gas supply In Tehran province, Iran Occup. Heal. 19 (2022) 255–269.
[135] F.-L. Chen, P.Y. Chen, C.-C. Chen, T.-H. Tung, Development and validation of an integrated healthy workplace management model in Taiwan, Saf. Health Work. 13 (2022) 394–400.
[136] D.A. Lee, Safe operations using advanced operator graphics, Process Saf. Prog. 39 (2020) e12119.
[137] D. Oswald, Safety indicators: questioning the quantitative dominance, Constr. Manag. Econ. 38 (2020) 11–17.
[138] P. Knijff, L. Allford, P. Schmelzer, Process safety leading indicators—A perspective from Europe, Process Saf. Prog 32 (2013) 332–336.