JURNAL KESEHATAN LINGKUNGAN
JURNAL DAN APLIKASI TEKNIK KESEHATAN LINGKUNGAN

ISSN 1829-9407 (Print)
ISSN 2581-0898 (Online)

Volume 23, No. 1, January 2026 ; Page: 183-192; DOI: https://doi.org/10.31964/jkl.v23i1.1124

Review

A SYSTEMATIC REVIEW OF LEAN–SAFETY INTEGRATION FOR PREVENTING FIRE AND EXPLOSION HAZARDS IN INDUSTRIAL SYSTEMS

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Article Info

Article history:

Received January 30, 2026
Revised February 3, 2026
Accepted February 7, 2026

Keywords:

Lean Manufacturing
Industrial Safety
Fire Prevention
Risk Management
Operational Efficiency

ABSTRACT

A Systematic Review of Lean–Safety Integration for Preventing Fire and Explosion Hazards in Industrial Systems. *Fires and explosions in industrial environments pose major risks to personnel, assets, and the environment. Lean thinking, traditionally used to improve operational efficiency by eliminating waste, has increasingly been applied to safety management. This study presents a systematic literature review (SLR) of 50 peer-reviewed articles to synthesise current evidence on how lean principles support fire and explosion hazard prevention in industrial settings. The review followed a structured search and selection process based on PRISMA guidelines using major scientific databases. The synthesis indicates that lean contributes to safety improvement through three main mechanisms: (1) enhancing workplace organisation and process visibility, which reduces hazard accumulation; (2) supporting early identification of risk sources through structured process analysis; and (3) strengthening continuous improvement cultures that sustain safety practices. Rather than acting as standalone solutions, lean approaches are most effective when integrated with formal safety and risk assessment methods such as HAZOP and Six Sigma. This review consolidates dispersed knowledge on lean–safety applications and identifies current research trends and gaps. The findings highlight lean as a complementary strategy for systematic hazard prevention while maintaining operational performance. Future research directions include quantitative validation and integration with digital monitoring technologies.*

INTRODUCTION

The manufacturing industry faces various safety risks, including fire and explosion hazards that can result in material losses, casualties, and environmental impacts[1]. Incidents such as gas leaks, ignition of flammable materials, or equipment failure are often caused by operational waste, such as excessive accumulation of goods or non-standard work procedures [2]. Therefore, a systematic approach is needed to identify and mitigate these risks proactively. One method that is increasingly being adopted is *lean manufacturing*, which was originally developed to improve production efficiency but has now been proven effective in improving workplace safety [3].

The application of lean in preventing fire and in factories has become increasingly critical to maintain workplace safety[4]. Lean is a managerial approach that aims to reduce waste and improve the efficiency of industrial processes[5]. Although the main focus of lean is efficiency,

there is great potential in implementing its principles to reduce fire and explosion risks in industrial environments[6]. This study aimed to identify, evaluate, and summarize existing evidence on the application of lean in preventing fire and explosion hazards[7]. Lean manufacturing focuses on eliminating waste through principles like 5S (sort, set in order, shine, standardize, and sustain), just-in-time (JIT), and continuous improvement (kaizen)[5]. In the context of fire and explosion prevention, lean can help reduce the accumulation of hazardous materials, improve factory layout, and strengthen emergency response procedures[8]. Several studies show that integrating lean with safety management systems, such as Occupational Health and Safety Management Systems (OHSMS), can reduce fire incidents by up to 40%[9]. However, there is still a gap in the literature on how lean tools can be specifically utilized to mitigate fire and explosion hazards in industrial environments.

Previous studies have examined the relationship between lean and occupational safety, but few have focused on fire and explosion hazards[10]. A study by Pereira[11] found that value stream mapping (VSM) could identify fire-prone points in the production flow, while the 5S technique reduces the risk of irregularities in chemical storage. On the other hand, the literature also shows that lean alone is not sufficient and should be combined with other approaches, such as Six Sigma or HAZOP, for more in-depth risk analysis[12]. Therefore, this study aimed to fill this gap by analyzing the effectiveness of lean in preventing fires and explosions based on empirical evidence from Scopus, Web of Science (WoS), ScienceDirect, SpringerLink, Google Scholar, and IEEE Xplore.

The main challenges in implementing lean for fire safety are employee resistance to change and the lack of understanding about the relationship between lean and risk management[13]. Intensive training and management commitment are key to successful implementation[14]. In addition, technological developments, such as the Internet of Things (IoT) and artificial intelligence (AI), can strengthen early fire detection systems through data-driven lean principles[15]. Recent studies have shown that smart sensors and real-time monitoring systems can be integrated with the lean framework to cut down incident response time[16].

This study employed a systematic literature review of 50 articles published from 2014 to 2024. The selection of sources was conducted using keywords such as “Lean Manufacturing,” “fire and explosion prevention,” “industrial safety,” and “risk management” in reputable databases like Scopus, WoS, ScienceDirect, IEEE Xplore, Google Scholar, and SpringerLink[17–18]. The inclusion criteria were empirical studies, case studies, and quantitative/qualitative research discussing the application of lean in the context of fire prevention. Thematic analysis was used to identify patterns, challenges, and best practices from various industries[19].

The literature review revealed that the application of lean could significantly reduce fire risks through several mechanisms, such as: (1) 5S to organize storage areas for flammable materials, (2) VSM to optimize evacuation routes, and (3) *jidoka* (autonomation) to detect equipment anomalies that can potentially trigger fires[20]. However, the success of implementation is highly dependent on the organization's safety culture and technological support[21]. This study contributes to the literature by presenting a comprehensive synthesis of how lean can be adapted as a fire prevention tool, while also providing practical recommendations for the industry.

This article is structured as follows: Section 2 discusses a literature review on lean and fire safety; Section 3 explains the method; Section 4 presents the main findings; Section 5 discusses theoretical and practical implications; and Section 6 summarizes the conclusions and offers suggestions for future research. By analyzing 50 reliable references, this study is expected to serve as a guide for industry and academia in integrating lean into fire and explosion prevention strategies.

MATERIALS AND RESEARCH METHODS

Research Design

This study adopted a Systematic Literature Review (SLR) approach to identify, evaluate, and synthesise existing empirical evidence on the application of lean principles for fire and explosion hazard prevention in factory environments. The SLR method was selected due to its ability to provide a structured, transparent, and replicable synthesis of prior research, particularly for interdisciplinary topics involving lean management and industrial safety [9_42].

The review process was conducted in accordance with the PRISMA 2020 guidelines, ensuring methodological transparency, traceability, and consistency across the identification, screening, and selection stages[41].

Research Questions

To ensure analytical focus and relevance, this review was guided by the following research questions:

RQ1: How are lean principles and tools applied in fire and explosion hazard prevention in factory settings?
RQ2: Which lean techniques have been empirically demonstrated to be effective in mitigating fire and explosion risks in industrial contexts?
RQ3: What challenges and opportunities are reported in implementing lean approaches for factory safety improvement?

The formulation of research questions follows established SLR practices to define the scope of analysis and support systematic evidence synthesis[39_40].

Data Sources and Search Strategy

The literature search was conducted across five major international academic databases: Scopus, WoS, ScienceDirect, SpringerLink, Google Scholar, and IEEE Xplore, which are widely recognised for their comprehensive coverage of engineering, management, and safety-related research.

A structured search strategy was applied using Boolean operators and predefined keywords, as follows:

("Lean Manufacturing" OR "Lean Production") AND ("Factory" OR "Industrial Plant" OR "Manufacturing Industry") AND ("Fire Prevention" OR "Explosion Prevention")

The search was limited to peer-reviewed journal articles and international conference proceedings published in English between 2014 and 2024, ensuring relevance to contemporary industrial practices and safety standards. All retrieved records were exported to reference management software (Mendeley and EndNote) to support systematic screening and duplication removal.

Study Selection and Eligibility Criteria

The selection of studies was conducted through a systematic multi-stage screening process in accordance with the PRISMA framework, which involved title screening, abstract review, and full-text assessment. Studies were included if they were empirical in nature and examined the application of lean principles or tools in manufacturing or industrial settings, explicitly addressed fire prevention, explosion prevention, or industrial safety risks, and integrated lean practices with safety management, risk mitigation, or hazard control. Conversely, studies were excluded if they were purely theoretical or conceptual without empirical evidence, were not related to fire or explosion hazards, or consisted of editorials, opinion articles, or non-peer-reviewed publications. The application of these inclusion and exclusion criteria was intended to ensure that only high-quality and contextually relevant studies were included in the review.

Data Extraction and Synthesis

Data extracted from the selected studies included publication details, industrial sector, lean tools applied, safety outcomes, hazard types addressed, and reported implementation challenges. A thematic synthesis approach was employed to identify recurring patterns, dominant lean practices, and emerging trends related to fire and explosion risk prevention.
The synthesis focused on mapping lean tools to safety functions and identifying how lean contributes to hazard prevention through organisational, procedural, and behavioural mechanisms.
To maintain the reliability of the review results, all selected articles were assessed using the Critical Appraisal Skills Programme (CASP) to ensure method quality and content validity[43]. This assessment covered aspects of research design, analysis method, accuracy of interpretation, and potential bias in reporting[39]. Articles that demonstrated adequate methodological strength and high relevance were included in the final synthesis[40]. With this approach, it is hoped that the results of the SLR can make a significant contribution to the development of lean practices for fire and explosion prevention in the manufacturing industry (Figure 1).

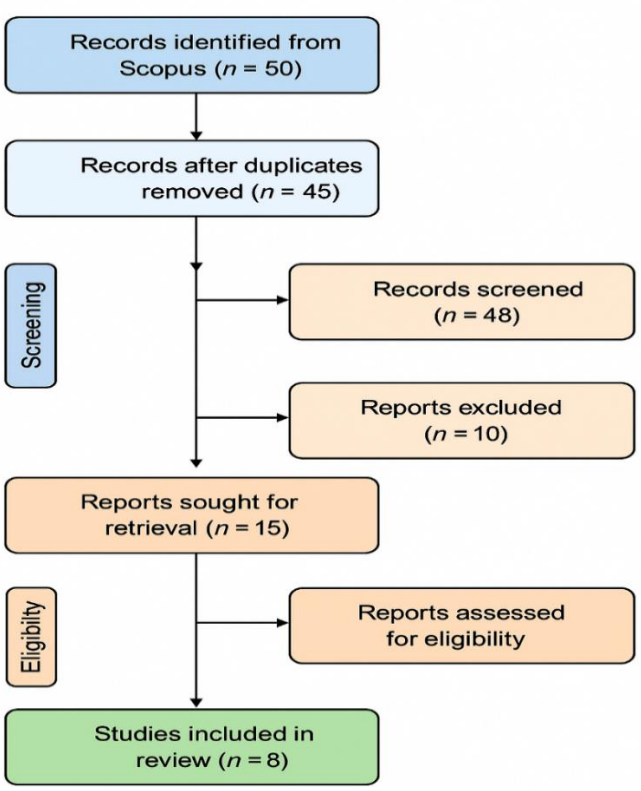

Figure 1. The PRISMA 2020 Diagram for Article Selection

Table 1. Article Selection Process

Selection Process	Number of Articles (N)
Records identified through database searching (Scopus, Web of Science, ScienceDirect, SpringerLink, IEEE Xplore)	980
Additional records identified through other sources (manual searching, citation tracking)	45
Total records identified	**1025**
Records after duplicates removed	950
Records screened (title and abstract)	950
Records excluded (not relevant, not in English, theoretical papers only)	800
Full-text articles assessed for eligibility	150
Full-text articles excluded, with reasons (lack of empirical data, irrelevant focus, poor quality)	100
Studies included in the qualitative synthesis	**50**

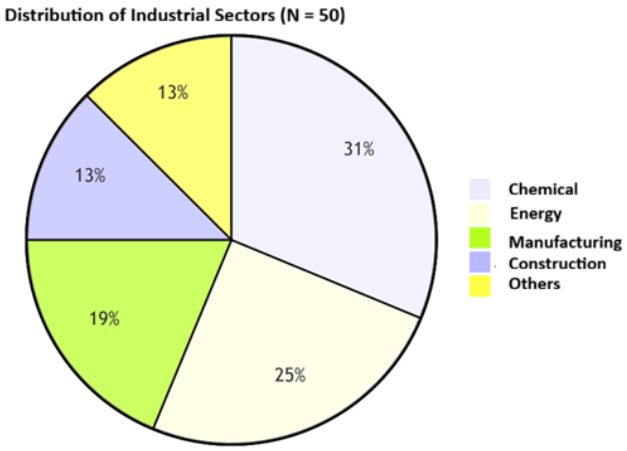

Figure 2. Distribution of Industrial Sectors in the Reviewed Articles (N=50)

The search strategy included the stages of identification, screening, eligibility, and inclusion. Initially, 50 articles were found through a search on Scopus, WoS, ScienceDirect, SpringerLink, Google Scholar, and IEEE Xplore. After eliminating duplicates, the remaining articles were selected through a review of the titles and abstracts to evaluate their relevance to the research topic. Articles that did not explicitly discuss the relationship between lean and fire or explosion prevention were excluded from further analysis.

The inclusion criteria applied included articles that specifically discussed the application of lean principles, such as 5S, Kaizen, Poka-Yoke, *jidoka*, and total productive maintenance (TPM), to improve industrial safety. Conversely, exclusion criteria included articles that only discussed lean for improving production efficiency without considering safety aspects, non-scientific articles (e.g., editorials), and articles with inaccessible full texts. The data extraction process was carried out by constructing an SLR table that recorded important information from each article, including: author and year, research objectives, methods, lean principles adopted, impact on fire/explosion prevention, and research limitations. The collected data were analyzed using a thematic synthesis approach, with the aim of identifying patterns of lean implementation that effectively contribute to reducing the risk of fire and explosion in factories.

To maintain the quality and accuracy of the analysis, each article that passed the eligibility stage was read thoroughly. In addition, internal validation was carried out by discussing the results of the selection and data extraction with colleagues in the fields of industrial engineering and occupational safety. This was done to minimize subjective bias in the data interpretation process. Finally, the findings from this SLR are presented in the form of analytical narratives, which are expected to provide theoretical and practical contributions

to the implementation of lean manufacturing to improve occupational safety in the industrial sector. This study also identifies areas that have received less attention, which can be recommendations for future research.

The main objective of this study was to synthesize a comprehensive overview of how lean principles can be applied in fire and explosion prevention in factories[38], identify the challenges faced in their implementation[34], and develop practical recommendations for the industry in adopting lean strategies to improve workplace safety[23]. The criteria for selecting articles in this study were: Inclusion: articles that discuss the application of lean in the manufacturing industry, related to fire or explosion prevention, and published in peer-reviewed scientific journals[27]. Exclusion: Articles that do not focus on lean or are not relevant to the topic of fire and explosion[1]. Language: Only articles published in English or Indonesian were considered[29].

The search was conducted through journal databases, namely Google Scholar, Scopus, ScienceDirect, and SpringerLink, using keywords such as "lean manufacturing," "fire prevention," "explosion prevention," "industrial safety," and "risk management"[31]. This process included articles published from 2000 to 2024[33]. The identified articles were screened in two stages. Stage one: The author examined the titles and abstracts to ensure they met the inclusion and exclusion criteria. Stage two: Full reading of the articles to assess the quality and relevance of their content to the research topic. The quality of the selected articles was evaluated using the Critical Appraisal Skills Programme (CASP) to assess the validity of the methodology, results, and relevance of the study to the topic discussed[20]. This assessment helped ensure that the articles included in this review are reliable for further analysis. After relevant articles were selected, the next step was to synthesize the findings from existing studies. The collected data were grouped based on several main themes: lean principles applied to fire prevention[22], lean strategies for reducing explosion risk in factories[25], challenges and obstacles in implementing lean in industrial safety[32], and case studies and real-world applications of lean concepts in the manufacturing industry. The results of this synthesis are presented by discussing various findings related to the application of lean in reducing fire and explosion risks[29]. This discussion includes an evaluation of the effectiveness of lean techniques, as well as their relationship to worker safety and operational sustainability[37].

RESEARCH RESULTS AND DISCUSSION

The application of lean principles in the manufacturing industry has been proven to improve operational efficiency and reduce waste[5]. However, lean has also shown a significant potential in the context of safety, especially in fire and explosion prevention. Several studies show that the lean approach can contribute to identifying and reducing fire risks through better material management and improved operational processes[38]. For example, by optimizing material flow and eliminating waste, the potential accumulation of flammable materials can be minimized[6].

Lean Principles and Their Application to Fire and Explosion Safety

Lean principles, such as 5S (sort, set in order, shine, standardize, sustain), can be used to set up a more organized and safer work environment[5]. The application of 5S can prevent the accumulation of hazardous materials, which increases the risk of fire and explosion[7]. In addition, *kaizen* (continuous improvement) is also applied to continuously improve processes and identify vulnerable areas that can cause workplace accidents, including fires and explosions[30].

Lean Application Strategies in Explosion Prevention

The application of lean in the chemical and manufacturing industries also shows that stricter control over production processes and the use of safer materials can reduce explosion risks[33]. The implementation of visual controls in manufacturing processes has also been proven to detect potential hazards more quickly and reduce accidents due to negligence[25].

Challenges in Lean Implementation for Safety

However, the main challenge in applying lean in fire and explosion prevention is resistance to change within the organizational culture. Some studies have shown that lean implementation often encounters obstacles in the form of employees' inability to adapt to new procedures and more structured managerial approaches[32]. Furthermore, lean implementation requires intensive training and commitment from all levels of the organization to optimize safety potential[37].

Lean Integration with Traditional Safety Practices

Integrating lean principles with traditional safety approaches like risk analysis and standards-based safety management (e.g., NFPA) can improve the effectiveness of fire and explosion prevention. Several studies show that this approach, which combines systematic methods with lean principles, results in improved safety and reduced accidents in high-risk factories[31]. However, implementation must be tailored to the specific characteristics of each industry to achieve optimum results[34].

CONCLUSIONS AND RECOMMENDATIONS

This study shows that the implementation of lean can greatly contribute to the prevention of fires and explosions in factories. Although there are challenges in its implementation, especially in terms of organizational cultural resistance, a lean approach integrated with traditional safety systems can significantly improve operational safety. Further in-depth and applied research is needed, especially in high-risk industrial sectors. Successful lean implementation requires commitment from all parties, from management to field workers, and will have a positive impact on long-term operational safety and efficiency.

Based on the findings of this study, there are several recommendations for future research and the application of lean principles in fire and explosion prevention in factories: 1). 5S and Kaizen Implementations to Improve Safety, The application of lean principles, such as 5S and Kaizen, is required in all aspects of factory operations to ensure that the work environment remains clean and free from materials that can cause fire or explosion. For example, the implementation of 5S in hazardous chemical storage areas can prevent the accumulation of flammable materials[5_6]. 2). Education and Training to Minimize Cultural Barriers, Employees must be given adequate training on lean principles and the relationship between lean and occupational safety. Improving understanding of how lean can contribute to safety will help overcome resistance to change within the organizational culture[32]. A more comprehensive and structured training program will facilitate the adoption of new safety procedures[27]. 3). Collaboration with Traditional Safety Practices, The integration of lean with existing safety systems, such as NFPA-based procedures or risk-based safety management systems, will improve the effectiveness of hazard control in factories. This implementation requires adjustments in each industry, especially in high-risk sectors[7_37]. Thus, a research-based approach that connects the two disciplines is needed. 4). Continuous Monitoring and Assessment, In applying lean for safety, companies must conduct continuous monitoring and assessment to evaluate the effectiveness of the strategies implemented. The use of clearer, more measurable safety performance indicators will help ensure the success

of lean implementation in preventing fires and explosions[23_26]. 5). Future Research on Specific Industrial Sectors, It is necessary to conduct further research that focuses on specific industrial sectors, such as the chemical, gas processing, and oil industries, where the risk of fire and explosion is higher. These future studies should identify specific factors that influence the successful implementation of lean when it comes to safety in these sectors[10_24_25_36]. And 6). Technology Use to Accelerate Lean Implementation, Advanced technologies, such as the Internet of Things (IoT) and Big Data, can be used to accelerate the implementation of lean principles in factories. The use of sensors to monitor machine and material conditions in real time can prevent potential fire or explosion hazards[6_28]. Therefore, companies should explore the use of technology to improve safety in the operation of lean systems.

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