Joint CSCE Construction Specialty & CRC Conference 2025
Conférence conjointe spécialisée en construction de la SCGC et CRC-2025

Montreal, Quebec
July 28-31, 2025 / *28-31 juillet 2025*

A Structured Roadmap to Safety Excellence: Implementing Leading Indicators in Construction

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ABSTRACT: The construction industry remains one of the most hazardous sectors globally, with occupational incidents continuing to pose significant risks despite notable advancements in safety standards and regulations. Traditional safety management practices often focus on lagging indicators which, while useful for retrospective analysis, fail to proactively address emerging risks or cultivate a forward-thinking safety culture. In contrast, safety leading indicators offer a predictive approach by identifying potential hazards and risks before they materialize. However, the adoption of these indicators in the construction sector has been limited by the absence of a structured and systematic framework to guide their implementation effectively. This research introduces the Construction Safety Advancement Framework (CSAF), a comprehensive model tailored to help construction organizations progress from basic compliance toward advanced, proactive safety management systems. The CSAF is structured around five progressive stages, enabling firms to systematically enhance their safety performance through strategic integration of leading indicators and continuous improvement mechanisms. The development of the framework followed a rigorous methodology, beginning with a systematic literature review to identify critical safety leading indicators and their applications. This was complemented by semi-structured interviews with safety professionals across various construction domains, providing practical insights and validating theoretical concepts. Thematic and content analysis revealed recurring patterns and factors influencing the efficacy of leading indicators, such as the importance of management commitment, worker engagement, and the organizational safety culture. The findings underscore the dynamic interplay between leading indicators and broader organizational factors, demonstrating how their implementation can significantly improve risk anticipation and operational efficiency. By transitioning from reactive to proactive safety strategies, construction firms can achieve a more resilient and adaptive safety culture. This study contributes to the body of knowledge by integrating qualitative and quantitative insights into a cohesive and actionable framework. Practically, the CSAF provides industry professionals with a clear roadmap to embed leading indicators into their safety management systems, offering a path to improved safety outcomes, reduced incident rates, and enhanced overall productivity.

1. INTRODUCTION

The construction industry is widely recognized as one of the most hazardous sectors globally, with occupational incidents continuing to pose significant risks to workers and organizations alike. Despite notable advancements in safety standards and regulatory frameworks, the persistent reliance on traditional safety management practices, which predominantly emphasize lagging indicators, limits the industry's ability to proactively address emerging risks (Hallowell et al. 2013). While lagging indicators provide valuable retrospective insights into safety performance, they often fall short in fostering a forward-thinking safety culture that anticipates and mitigates hazards before they materialize.

In response to these limitations, there is a growing recognition of the potential of safety leading indicators. However, the adoption of leading indicators within the construction sector remains inconsistent and underutilized (Golabchi et al. 2024). One of the primary challenges lies in the absence of a structured and systematic framework that enables construction organizations to effectively integrate these predictive tools into their safety management systems (Oswald 2020).

To address this gap, this study introduces the Construction Safety Advancement Framework (CSAF), a comprehensive and progressive model designed to guide construction organizations in transitioning from basic regulatory compliance to advanced, proactive safety management practices. By emphasizing the strategic integration of leading indicators and fostering continuous improvement mechanisms, the CSAF aims to enhance safety performance and cultivate a resilient organizational safety culture.

The development of the CSAF was informed by a rigorous methodological approach, combining a systematic review of the literature with empirical insights gathered through semi-structured interviews with safety professionals across diverse construction domains. Through thematic and content analysis, this research identifies critical factors influencing the effective implementation of leading indicators, including management commitment, worker engagement, and the broader organizational safety culture.

This paper contributes to the existing body of knowledge by providing a cohesive and actionable framework that bridges the theoretical and practical dimensions of safety management in construction. By adopting the CSAF, construction firms can achieve improved risk anticipation, reduced incident rates, and enhanced operational efficiency, marking a significant step toward achieving safety excellence in one of the most challenging industries.

2. LITERATURE REVIEW

Lagging indicators, such as injury rates, lost time injuries, and workers' compensation claims, remain central to safety performance measurement in the construction industry (Pereira et al. 2017). While these indicators provide quantifiable metrics, they are inherently retrospective and do not prevent future incidents (Lingard et al. 2011). Studies have shown that relying exclusively on lagging indicators can lead to a false sense of safety, as organizations with low incident rates may overlook underlying hazards or emerging risks (Hallowell et al. 2013). This reactive approach hinders the development of a proactive safety culture, where potential risks are identified and mitigated before they escalate.

Leading indicators have gained prominence as predictive tools that measure proactive safety activities and conditions, providing early notices of potential risks (Hallowell et al. 2020). Unlike lagging indicators, leading indicators focus on prevention and continuous improvement (Pereira et al. 2020). Common examples include safety training participation rates, safety audits, and worker observations (Versteeg et al. 2019; Reiman & Pietikäinen 2012). Research suggests that leading indicators can enhance organizational safety performance by fostering a culture of accountability, awareness, and engagement (Hopkins 2009).

Despite their demonstrated potential to enhance safety outcomes, the widespread adoption of leading indicators in the construction industry is hindered by several significant challenges (Alruqi et al. 2019). One major barrier is the lack of a standardized framework to guide the identification, measurement, and integration of leading indicators into existing safety management systems (Hallowell et al. 2013). The absence of such a structured approach limits their practical application and results in inconsistencies across organizations (Alruqi et al. 2019). Without clear guidelines, firms struggle to implement leading indicators in a manner that aligns with their operational realities and safety objectives.

Another challenge lies in data collection and analysis (Pereira et al. 2017). Construction firms often lack the requisite tools, technologies, and expertise to collect and interpret leading indicator data effectively. The industry’s reliance on manual processes further exacerbates this issue, hindering the ability to derive actionable insights from safety data (Golabchi & Hammad 2023; Phinias 2023). As a result, organizations are unable to fully leverage the predictive power of leading indicators to anticipate and mitigate risks. Resistance to change also poses a significant obstacle (Neamat 2019). Organizational inertia, compounded

by a lack of buy-in from both management and workers, frequently impedes the transition from traditional, reactive safety practices to proactive safety management.

Finally, the project-specific challenges inherent in the construction industry further complicate the implementation of leading indicators. Construction projects are characterized by their temporary nature, diverse teams, and varying operational contexts. These factors make it difficult to ensure consistency in the application of leading indicators across different sites, teams, and project phases (Oswald 2020). The fragmented nature of construction workflows further adds to the complexity, requiring tailored approaches to accommodate the unique dynamics of each project (Golabchi & Hammad 2023; Lingard et al. 2011).

The review underscores a critical need for a structured and systematic framework to guide the adoption of safety leading indicators in the construction industry. Such a framework should address the identified challenges, provide clear guidance on integrating leading indicators into existing safety management systems, and promote continuous improvement. This study seeks to fill this gap by introducing the CSAF, a model designed to enable construction organizations to transition from reactive to proactive safety practices.

3. METHODOLOGY

The development of the CSAF followed a rigorous and systematic methodology, ensuring both theoretical robustness and practical relevance. The methodological approach was structured into three primary phases: (1) Leveraging findings from an existing systematic literature review on safety leading indicators; (2) Qualitative data collection through semi-structured interviews; and (3) Thematic and content analysis to synthesize findings and inform the framework's design (Figure 1).

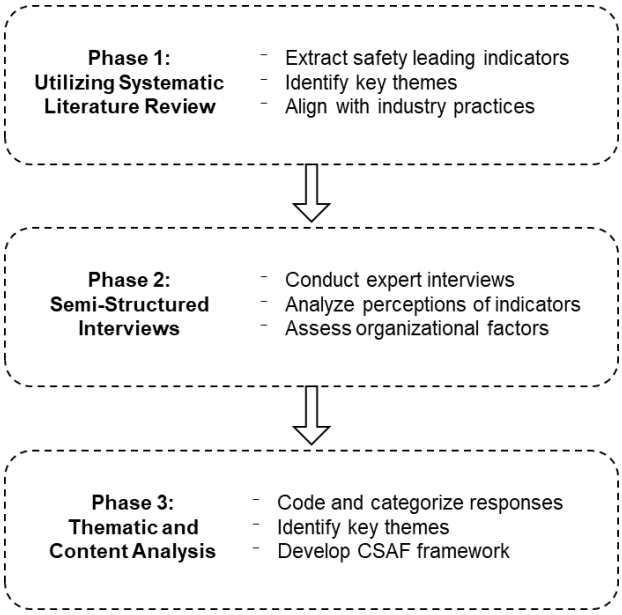

Figure 1: Research methodology overview

Instead of conducting a new systematic literature review, this study systematically extracted relevant findings from a validated systematic review on safety leading indicators by Golabchi et al. (2024). This approach ensured that the research was built upon existing knowledge while maintaining methodological rigor. The systematic review had already consolidated evidence on the roles, effectiveness, and integration of safety leading indicators into organizational safety practices.

The extraction process focused on identifying key leading indicators relevant to the construction industry, particularly those related to leadership commitment, safety culture, and risk management. The selected

indicators served as the foundation for further empirical validation through industry perspectives, ensuring that the framework development was grounded in both theoretical insights and practical applications (Table 1).

Table 1: Safety leading indicators extracted from literature review

Category	Safety Leading Indicators
Organizational Indicators	Management commitment Stakeholders engagement Subcontract selection
Operational Indicators	Jobsite audits Safety training Hazard identification Incentives Communication and consultation Safety rules and procedures Substance abuse and drug tests Housekeeping program Toolbox meetings Safety record
Behavioral Indicators	Safety climate Worker involvement Worker safe behavior observation

Building on insights from the literature review, the second phase involved qualitative data collection through semi-structured interviews with safety professionals across various construction domains. Participants included safety managers, project supervisors, and industry consultants with extensive experience in safety management. A purposive sampling strategy was employed to ensure diversity in representation based on organizational size, project type, and geographic location. Table 2 summarizes the characteristics of the interviews and the participants.

Table 2: Characteristics of the semi-structured interviews

Criteria	Details
Participants	15 industry experts
Executive Roles	Safety Managers (5), Project Supervisors (6), Industry Consultants (4)
Industrial Experience	5-10 years (8), 11-20 years (5), 21+ years (2)
Objective	To assess safety leading indicators, identify challenges, and gather expert insights to develop the CSAF
Interview Format	Virtual (9), In-Person (6)
Interview Duration	60-90 minutes
Data Collection Method	Audio-recorded, transcribed for thematic and content analysis

The interview protocol was carefully designed to extract in-depth insights into: (1) The current state of safety management practices and challenges; (2) Perceptions and experiences related to the use of leading indicators; and (3) Recommendations for integrating leading indicators into existing safety management systems. Interviews were conducted virtually or in person, depending on participants' availability, and were audio-recorded with consent to ensure accuracy during transcription and analysis.

Qualitative data obtained from the interviews were analyzed using a combined thematic and content analysis approach. This process ensured that the findings were systematically categorized to reveal meaningful insights regarding the application and impact of leading indicators.

Thematic analysis involved: (1) Familiarization with data: Transcripts were reviewed to identify recurring concepts; (2) Open coding: Initial themes such as “safety training,” “worker involvement,” and “data-driven decision-making” were identified; (3) Theme identification: Codes were refined into overarching themes aligned with the framework’s core dimensions; and (4) Review and validation: The identified themes were cross-checked against the literature and expert feedback to ensure validity.

Content analysis provided quantitative insights into the prevalence of key themes. The process involved: (1) Coding Framework Development: A structured coding framework was developed to categorize responses based on frequency and relevance; (2) Quantitative Measurement: The frequency of key themes such as “incentives,” “jobsite audits,” and “toolbox meeting participation” was analyzed; (3) Comparative Analysis: The prevalence of specific themes was compared across different organizational contexts, identifying variations in leading indicator adoption and implementation challenges.

3.1 Analytical Framework Development

Thematic and content analysis played a pivotal role in shaping the CSAF, ensuring that the framework was both theoretically grounded and practically applicable. By analyzing qualitative data from industry professionals, key themes emerged that informed the structure and focus of CSAF.

1. Defining Core Dimensions: The thematic analysis revealed recurring discussions on leadership, culture, technology, and sustainability. These themes consistently appeared across different organizations, reinforcing their importance in advancing safety management practices. These four core dimensions became the foundation of CSAF, as they encapsulated the fundamental factors driving successful integration of leading indicators into construction safety frameworks.

2. Shaping CSAF’s Progressive Stages: Content analysis provided a quantitative view of how frequently different themes were mentioned by participants, allowing for a structured categorization of organizational maturity in safety management. The analysis showed that organizations adopted leading indicators at different levels, depending on their existing safety culture and leadership commitment. Based on these findings, a phased approach was developed to help organizations gradually integrate leading indicators based on their readiness and resource availability. This phased model ensured that organizations at varying levels of safety maturity could implement CSAF incrementally without overwhelming their operational capacity.

3. Emphasizing Leadership and Culture: The interviews highlighted leadership commitment and worker engagement as the two most frequently mentioned factors influencing the effectiveness of safety leading indicators. Participants emphasized the need for visible management participation in safety initiatives, structured communication channels for safety concerns, and reinforcement of safety culture through incentives and feedback mechanisms. Given this strong emphasis, CSAF was designed to prioritize leadership involvement and worker engagement as key drivers of safety transformation, integrating specific strategies such as management-led safety discussions, participatory safety audits, and culture-building programs.

4. Incorporating Predictive Analytics: The findings suggested that organizations with more advanced safety practices were already transitioning toward predictive safety models, leveraging AI-driven analytics and real-time monitoring systems to anticipate hazards. Content analysis revealed a growing interest in using predictive analytics to assess risk trends, making AI integration a necessary component in the later stages of CSAF. As a result, predictive safety mechanisms, including real-time hazard tracking and AI-based risk assessments, were embedded into the optimization and leadership stages of CSAF to support data-driven decision-making and proactive risk mitigation.

Through this structured analytical approach, CSAF was developed as a dynamic and adaptable framework, ensuring that construction organizations can systematically advance their safety management practices using validated insights. The integration of thematic and content analysis allowed for an evidence-based framework that directly addressed industry needs, fostering a shift from reactive to proactive safety cultures in construction.

4. FINDINGS

The findings of this study provide critical insights into the application and integration of safety leading indicators in construction safety management, highlighting their potential to drive proactive safety cultures and continuous improvement. Through the systematic analysis of qualitative and quantitative data, key factors influencing the adoption of leading indicators were identified, including barriers and enablers of implementation. This study advances existing knowledge by demonstrating that safety leading indicators can shift organizations from compliance-driven safety management to predictive and proactive risk mitigation strategies. Unlike previous research that treats leading indicators as static metrics, this research provides empirical evidence that their integration fosters an adaptive safety management system which evolves based on real-time data and worker engagement.

The analysis revealed three primary ways in which leading indicators contribute to construction safety:
1. Leading Indicators as a Predictive Tool: Near-miss reporting and hazard identification metrics were found to provide an early-warning system that enables risk anticipation rather than retrospective hazard response.
2. Leading Indicators as a Workforce Engagement Mechanism: Safety training participation and behavior-based observations were found to significantly increase worker commitment to safety culture by making safety a shared responsibility.
3. Leading Indicators as an Operational Efficiency Enhancer: The use of safety audits and compliance tracking correlated with measurable improvements in site productivity, reinforcing that strong safety cultures drive efficiency gains.

This research also challenges the traditional assumption that all leading indicators are equally effective. Instead, findings suggest that the impact of leading indicators varies depending on organizational maturity, leadership commitment, and technological integration levels. This calls for a more tailored approach to implementation, which CSAF provides through its structured progression model.

4.1 Organizational Factors Impacting Implementation

While the study confirmed that leading indicators drive safety improvements, it also identified key enablers and barriers that influence their successful adoption. The most critical factors shaping implementation include leadership commitment, worker engagement, and technological integration, each playing a distinct role in the effectiveness of safety leading indicators.

Thematic and content analysis revealed quantitative patterns in these factors. Management commitment was the most frequently cited enabler, mentioned in 93% of interviews (14 out of 15 participants), followed by worker engagement (80%, 12 participants) and safety training participation (73%, 11 participants). Near-miss reporting systems were discussed in 67% of cases (10 participants), while safety audits and hazard identification appeared in 60% (9 participants) and 53% (8 participants), respectively. Predictive analytics, though impactful, was noted less frequently (40%, 6 participants), primarily by larger firms with advanced technological capabilities.

Leadership commitment and data-driven decision-making emerged as primary enablers of successful adoption. Thematic analysis revealed that organizations where managers actively engaged in leading indicator tracking exhibited a significantly higher degree of workforce compliance and engagement. Firms that integrated discussions of leading indicators into safety meetings observed an improvement in near-miss reporting, underscoring the tangible impact of managerial involvement. These findings suggest that

data-driven decision-making processes, supported by leadership commitment, can reinforce a proactive safety culture and foster continuous improvement in risk management.

Worker engagement and psychological safety also played a pivotal role in shaping the effectiveness of leading indicators. The study revealed that fear of disciplinary consequences served as a major barrier, reducing near-miss reporting in firms with rigid, top-down safety structures. Conversely, organizations that cultivated participatory safety cultures and maintained open communication channels demonstrated a higher utilization of behavioral safety indicators. This shift was associated with a decline in incident rates, reinforcing the importance of trust and inclusivity in ensuring that safety data is accurately reported and effectively acted upon.

Technological integration and digitalization were identified as key facilitators in advancing the predictive capabilities of safety management systems. Organizations that adopted digital tracking mechanisms, such as real-time monitoring systems, experienced notable improvements in risk identification accuracy. This improvement underscores the role of automation in strengthening predictive analytics and enhancing proactive risk mitigation. Additionally, firms leveraging AI-based predictive safety models demonstrated smoother transitioning from reactive hazard response to preemptive safety interventions, further validating the role of technological advancements in modern safety management practices.

4.2 Barriers and Challenges in Adopting Leading Indicators

Despite the clear advantages, this study identified several barriers that hinder the successful integration of leading indicators. Interview data revealed that 87% of participants encountered at least one major barrier, with smaller firms facing disproportionately higher challenges compared to larger organizations. Among the most prevalent issues, resource and expertise gaps emerged as critical constraints, with over 70% of small and medium-sized enterprises citing budget limitations as a primary obstacle to adopting advanced analytical tools. This financial constraint was compounded by a lack of trained personnel, as 60% of safety managers reported insufficient staff to properly collect and interpret leading indicator data. As one safety manager from a mid-sized civil firm noted, "We recognize the value of leading indicators, but without dedicated resources or specialized software, we remain trapped in a reactive safety management cycle."

Project-specific complexities further exacerbated implementation difficulties. The transient nature of construction workforces and frequent subcontractor turnover disrupted data continuity in 80% of cases, while only 33% of firms had successfully standardized leading indicators across all projects. Cultural resistance presented another substantial barrier, with fear of blame reducing near-miss reporting in 47% of organizations, particularly those maintaining punitive safety policies. Additionally, 53% of participants described "compliance fatigue" as a significant challenge when attempting to transition from traditional checkbox-style audits to more proactive safety practices.

Technological limitations also hindered progress, with 40% of firms struggling to integrate new safety metrics with legacy systems, many of which still relied on paper-based tracking methods. The adoption of real-time monitoring tools remained particularly low among smaller firms, with 73% of SMEs reporting they lacked the necessary infrastructure or expertise to implement such solutions. These findings collectively underscore the need for the CSAF's flexible, staged approach, which specifically addresses these barriers through practical, incremental implementation strategies tailored to organizational capacity and resource availability. The framework's emphasis on low-cost entry points, such as anonymous near-miss reporting systems, provides a viable pathway for firms to overcome initial adoption hurdles while building toward more advanced safety analytics capabilities.

4.3 Construction Safety Advancement Framework (CSAF)

The CSAF is a scientifically robust and practically applicable model designed to systematically integrate safety leading indicators into construction safety management. Unlike conventional frameworks, CSAF recognizes that not all organizations are at the same stage of safety maturity, and thus provides a roadmap for gradual progression from basic compliance to predictive safety leadership (Table 3). By structuring the advancement of safety practices through progressive stages, CSAF ensures that organizations can

incrementally develop their safety capabilities in alignment with their operational complexity and available resources.

Table 3: Progressive stages of the CSAF

Stage	Focus	Key Activities	Impact on Safety and Operations
Stage 1: Foundational Compliance	Ensuring compliance with existing regulations and establishing safety basics	- Conduct a gap analysis to ensure adherence to OSHA or equivalent standards. - Develop site-specific safety policies and standard operating procedures (SOPs). - Initiate lagging indicator tracking (e.g., incident frequency rate). - Implement basic safety training and awareness programs.	- Compliance with legal safety standards. - Clear, documented safety procedures. - Baseline safety performance metrics for future reference.
Stage 2: Awareness and Exploration	Identifying potential leading indicators and testing their feasibility	- Introduce near-miss reporting systems with anonymous submission options. - Train supervisors on identifying and documenting unsafe conditions. - Pilot data collection for indicators such as training hours per worker and safety audit completion rates. - Conduct engagement workshops to strengthen workforce involvement.	- Initial dataset on leading indicators. - Increased worker engagement and safety awareness. - Identification of practical indicators specific to the organization's operations.
Stage 3: Structured Implementation	Scaling up and standardizing the use of leading indicators	- Develop a centralized database for storing and analyzing safety data. - Mandate regular safety audits and observations as part of project schedules. - Define benchmarks and targets for selected indicators (e.g., 100% toolbox meeting attendance).	- Comprehensive database for leading indicator trends. - Clearly defined performance benchmarks. - Standardized safety processes across all projects.
Stage 4: Optimization and Integration	Embedding leading indicators into organizational processes	- Integrate safety metrics into project management software (e.g., Primavera, Procore). - Use predictive analytics to identify high-risk trends and recommend mitigations. - Conduct cross-departmental workshops to align safety practices with operational goals. - Expand workforce training on the use of digital safety tools.	- Real-time monitoring of leading indicators. - Improved inter-departmental collaboration. - Actionable insights for proactive safety decisions.
Stage 5: Proactive Safety Leadership	Cultivating a proactive and innovative safety culture	- Develop a feedback-driven system for continuously updating safety programs based on emerging risks, industry innovations, and lessons learned. - Foster a learning culture through knowledge-sharing initiatives such as case studies, industry presentations, and conferences. - Encourage research collaborations to develop and implement cutting-edge safety technologies.	- Industry recognition for safety leadership. - Continuous evolution of safety practices. - High worker morale and reduced incident rates.

	- Organize internal safety innovation challenges to promote engagement and leadership at all levels.

A fundamental advantage of CSAF is its ability to operationalize safety leading indicators in a structured and scalable manner. Traditional safety management approaches often rely on lagging indicators, which, while useful for retrospective analysis, fail to provide the necessary foresight for risk prevention. CSAF bridges this gap by embedding leading indicators at each stage of organizational safety maturity, allowing for data-driven decision-making that proactively reduces incidents.

Each stage of CSAF is designed to build upon the previous one, creating a continuous improvement cycle that aligns safety initiatives with organizational goals. The “foundational compliance” stage ensures that organizations establish a regulatory baseline before progressing toward more data-intensive approaches. The “awareness and exploration” stage introduces leading indicators in a controlled environment, allowing organizations to test their applicability and relevance to their specific operations. “Structured implementation” then standardizes the use of these indicators, ensuring consistency in data collection and application. “Optimization and integration” embed leading indicators into project workflows, leveraging technological advancements such as predictive analytics and project management software. Finally, “proactive safety leadership” ensures that organizations not only maintain safety excellence but also contribute to industry-wide innovations in safety management.

Unlike generic frameworks, CSAF is designed to accommodate variability in construction project environments. The construction industry is characterized by diverse project types, dynamic workforces, and evolving operational risks, necessitating a flexible model that can be adapted to different organizational contexts. CSAF allows organizations to tailor safety management practices to specific project needs while maintaining a structured progression towards predictive safety leadership. This adaptability is particularly important for organizations operating across multiple regions or working with different subcontractor teams, where consistency in safety practices is challenging to achieve.

Furthermore, CSAF provides practical implementation strategies that address common barriers in leading indicator adoption. One of the persistent challenges in the industry is the reluctance to move beyond compliance-driven safety models due to concerns about feasibility and resource constraints. CSAF mitigates these concerns by ensuring that organizations can adopt a phased approach, gradually integrating leading indicators based on their capacity and resources.

5. CONCLUSION

This study underscores the transformative potential of safety leading indicators in revolutionizing safety management practices within the construction industry. The findings emphasize that while occupational hazards remain a persistent challenge, leading indicators provide a proactive mechanism for identifying and mitigating risks before incidents occur. This shift from reactive to predictive safety management enhances not only safety outcomes but also contributes to operational efficiency, reinforcing a resilient and adaptive safety culture across organizations.

The research highlights critical enablers for the successful adoption of leading indicators, including strong management commitment, active worker engagement, and a well-established safety culture. However, significant barriers such as resource limitations, fragmented project environments, and the absence of standardized implementation guidelines impede widespread adoption. These challenges necessitate a structured approach to integrating leading indicators into existing safety management systems, ensuring consistency and effectiveness across diverse organizational contexts.

To address these challenges, this study introduces the CSAF, a scientifically grounded, staged model designed to facilitate the progressive integration of safety leading indicators. By drawing on both theoretical insights and empirical findings, CSAF offers a scalable and adaptable solution that enables construction firms to transition from basic compliance-driven safety measures to a predictive, data-driven safety culture.

Its phased approach allows organizations at varying levels of maturity to incrementally implement and refine safety practices, fostering continuous improvement and long-term sustainability.

The practical implications of this study are significant. Through the adoption of CSAF, organizations can achieve measurable reductions in incident rates by shifting from lagging to leading indicators. Enhanced risk anticipation and hazard prevention can be realized through real-time data analytics and predictive safety insights. Additionally, improved worker engagement reinforces a shared commitment to safety, ensuring that employees are active participants in maintaining a safe working environment. Operational efficiencies can also be enhanced by reducing downtime and costs associated with workplace incidents, demonstrating that proactive safety management contributes not only to worker well-being but also to overall project performance and sustainability.

Furthermore, the framework provides a structured pathway for embedding safety within organizational processes, ensuring that proactive risk management becomes an integral part of daily operations. The CSAF also serves as an industry benchmark, positioning proactive safety management as a defining characteristic of high-performing construction organizations. The integration of advanced safety analytics and digital monitoring tools within the framework reinforces its adaptability to emerging industry trends, ensuring its long-term relevance in the evolving construction sector.

Future research should focus on validating CSAF across diverse construction environments, assessing its effectiveness in different project scales and regulatory landscapes. The integration of advanced technologies such as AI-driven predictive models and digital twin simulations should be further explored to refine predictive capabilities. Additionally, longitudinal studies are needed to assess the long-term impact of leading indicator adoption on safety performance metrics and broader organizational efficiency. Investigating behavioral and cultural shifts within organizations as they transition through CSAF's staged progression would also provide valuable insights into optimizing framework implementation.

By advancing the adoption, standardization, and practical application of leading indicators, this study contributes to bridging the gap between academic research and industry implementation. The CSAF is more than a conceptual model; it serves as a practical tool designed to empower construction professionals, policymakers, and safety practitioners in fostering a culture of prevention, innovation, and continuous learning. As the construction industry evolves, embracing leading indicators as the foundation for predictive and proactive safety management will be instrumental in achieving safety excellence, operational resilience, and industry-wide transformation.

REFERENCES

Alruqi, W.M. and Hallowell, M.R., 2019. Critical success factors for construction safety: Review and meta-analysis of safety leading indicators. *Journal of construction engineering and management*, *145*(3), p.04019005.

Golabchi, H., Abellanosa, A.D., Lefsrud, L., Pereira, E. and Mohamed, Y., 2024. A comprehensive systematic review of safety leading indicators in construction. *Safety science*, *172*, p.106433.

Golabchi, H. and Hammad, A., 2023. Estimating labor resource requirements in construction projects using machine learning. *Construction Innovation*, (ahead-of-print).

Hallowell, M.R., Bhandari, S. and Alruqi, W., 2020. Methods of safety prediction: Analysis and integration of risk assessment, leading indicators, precursor analysis, and safety climate. *Construction Management and Economics*, *38*(4), pp.308-321.

Hallowell, M.R., Hinze, J.W., Baud, K.C. and Wehle, A., 2013. Proactive construction safety control: Measuring, monitoring, and responding to safety leading indicators. *Journal of construction engineering and management*, *139*(10), p.04013010.

Hopkins, A., 2009. Thinking about process safety indicators. *Safety science*, *47*(4), pp.460-465.

Lingard, H., Wakefield, R. and Cashin, P., 2011. The development and testing of a hierarchical measure of project OHS performance. *Engineering, Construction and Architectural Management*, *18*(1), pp.30-49.

Neamat, S.D.S., 2019. A comparative study of safety leading and lagging indicators measuring project safety performance. *indicators*, *1*, p.29.

Oswald, D., 2020. Safety indicators: questioning the quantitative dominance. *Construction Management and Economics*, *38*(1), pp.11-17.

Pereira, E., Ahn, S., Han, S. and Abourizk, S., 2020. Finding causal paths between safety management system factors and accident precursors. *Journal of Management in Engineering*, *36*(2), p.04019049.

Pereira, E., Han, S., AbouRizk, S. and Hermann, U., 2017. Empirical testing for use of safety related measures at the organizational level to assess and control the on-site risk level. *Journal of Construction Engineering and Management*, *143*(6), p.05017004.

Phinias, R.N., 2023. Benefits and challenges relating to the implementation of health and safety leading indicators in the construction industry: A systematic review. *Safety science*, *163*, p.106131.

Reiman, T. and Pietikäinen, E., 2012. Leading indicators of system safety–monitoring and driving the organizational safety potential. *Safety science*, *50*(10), pp.1993-2000.

Versteeg, K., Bigelow, P., Dale, A.M. and Chaurasia, A., 2019. Utilizing construction safety leading and lagging indicators to measure project safety performance: A case study. *Safety Science*, *120*, pp.411-421.