Implementing Safety Leading Indicators in Construction: Insights on Relative Importance of Indicators

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Abstract

Lagging indicators have been widely used in the construction industry to measure and improve safety performance for decades; however, they are criticised for providing insufficient information to generate continuous improvement because they only indicate safety outputs. Against this backdrop, industry and academia have investigated safety leading indicators in addition to traditionally used lagging indicators. Leading indicators are proactive in nature because they measure safety initiatives that provide an early indication of impending adverse events, which in turn allows management to initiate corrective steps. Although leading indicators are an emergent area of research, there is limited knowledge to guide their implementation in terms of their selection and use. Having insight regarding their relative importance could thus be useful. To address the knowledge gap, this study conducted a systematic literature review on safety leading indicators in construction which resulted in the identification of 16 safety leading indicators. A subsequent two-round Delphi technique involving industry experts was used to determine the relative importance. The results show that organisational commitment, client engagement, main contractor engagement, supply chain engagement, and designer engagement are perceived by the industry experts as being among the topmost important indicators for safety management performance. The findings would enhance the construction industry's understanding of safety leading indicators and help organisations prioritise efforts to enhance their safety performance.

Keywords: Construction safety; Delphi technique; Safety leading indicators; Safety performance measurement

Introduction

Safety performance in construction has been found to have plateaued in many developed countries. Traditionally, lagging indicators, such as lost time injury frequency rates (LTIFRs)

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and total recordable injury frequency rates (TRIFRs), have been widely used to manage safety performance in construction. The effectiveness of using lagging indicators to improve safety performance, however, often does not meet the needs on making long-term and continuous improvement because they are retrospective and reactive in nature and can trigger only short-term actions in a case-by-case way. Recent studies look beyond lagging indicators to shed light on leading indicators that measure safety initiatives (e.g. Hinze et al., 2013).

Safety leading indicators feature a proactive approach to managing safety because they can provide an early indication of impending adverse events and drive preventive actions. Furthermore, the process of implementing and measuring proactive management activities provides knowledge beyond individual incidents, allowing for continuous learning and an adaptive safety system. Despite the various leading indicators that have been proposed in construction management research, the industry lacks empirical insights to guide the implementation of indicators in practices. Consequently, questions have been raised regarding the 'ideal' indicators or 'ideal set of indicators' when using leading indicators as part of a health and safety management system (Hinze et al., 2013). Under the circumstances, this paper sought to: 1) identify safety leading indicators used to manage safety performance in construction; and 2) identify their relative importance.

Literature Review: Safety Leading Indicators in Construction

To achieve the above aims the research team conducted a systematic literature review and found that safety leading indicators were commonly recognised as measures of the safety management system, which consists of safety rules and resources as well as actors with the aim of creating and sustaining the safety of a workplace (Guo et al., 2017). In construction, safety leading indicators measure safety management processes and practices of firms and projects. The measurements precede the occurrence of adverse safety outcomes (e.g. Kjellén, 2009). They provide early signals of situations that might increase levels of risk or lead to adverse safety outcomes (e.g. Leveson, 2015). Therefore, leading indicators can prompt proactive measures in response to the current state in order to address the deficiencies or further develop the safety management system (Hallowell et al., 2013; Hinze et al., 2013).

To conduct the systematic literature review, 226 peer-reviewed journal papers in Scopus and Web of Science that contain key words "safety", "leading indicator", "safety", "lead indicator", "upstream indicator", "predictive indicator", "positive indicator" and "heading indicator" were first reviewed. In addition, five industry reports regarded as highly relevant (i.e., Autralian Constructors Association 2015; Campbell Institute 2015; Center for Chemical Process Safety 2019; eCompliance 2016; Health and Safety Executive 2006) were added to the review pool. After three rounds of reviews and filtering, 30 articles and one report were finally selected for detailed analysis because they are directly related to the safety of people working in construction.

The analysis of the 30 articles was facilitated by MAXQDA 2018, a software for qualitative data analysis. Indicators and their descriptions were manually coded by the terms used in the original articles. Initial codes were then extracted across all articles to conduct in-depth analysis and make sense of the indicators in terms of what they were revealing about safety management and the level of measurement. This process refined the initial findings by collating codes referring to the same safety management measures. In addition, the robustness of the research methods was also taken into consideration. Table 1 summarised the 16 safety leading indicators in construction identified from the literature. They were grouped under firm, project, and group and individual level.

Table 1: List of 16 construction safety leading indicators

Safety leading indicator	Description	Examples of measures (in a specific time frame)	Examples of literature sources
Firm level			
1. Organisation commitment	Client, designer, principal contractor and subcontractor commitment to safety	- Total safety expenditures/total expenditures	Guo et al. (2017)
2. Safety auditing	The process of collecting independent information on the efficiency, effectiveness and reliability of the safety management system and drawing up plans for preventive actions.	- Frequency of completed audits completed according to schedule	Mitchell (2000)
3. Training and orientation	Improving skills, knowledge, attitudes and experiences of employees to effectively manage safety	- Hours of training received	Alruqi and Hallowell (2019)
Project level			
4. Client engagement	Client is engaged in construction safety throughout a project.	- Frequency of meetings between client's safety professional and designer teams	Alruqi and Hallowell (2019)
5. Designer engagement	Principal designer and other designers are engaged in construction safety throughout a project.	- Number of meetings with main contractors per role	Mitchell (2000)
6. Principal contractor engagement	Principal contractor is engaged in construction safety throughout a project.	- Frequency of a safety professional's onsite safety inspection	Rajendran (2013)
7. Supply chain and workforce engagement	Subcontractors, suppliers and self-employed workers	- Number of safety inspection conducted by a	Guo et al. (2016)

	are engaged in construction safety throughout a project.	subcontractor/supplier/self-employed worker	
8. Safety design	Preventing accidents during construction is considered as one of the objectives of design.	- Number of hazards/risks highlighted and addressed in the design	Mitchell (2000)
9. Plan for safety	Safety in construction is considered in the planning process	- Number of hazards and risks highlighted and addressed in site logistics and layout plans	Agumba and Haupt (2012)
10. Hazard identification and control	The process and outcome of identifying and controlling hazards and risks in workplace.	- Percentage of high-risk items identified	Alruqi and Hallowell (2019)
11. Safety learning	Learning from accidents, incidents and relevant experiences.	- Number of safety reports with actions implemented	Biggs and Biggs (2013)
12. Recognition and reward	Mechanisms to motivate workforce to comply with safety rules and actively participate in safety improvement activities	- Percentage of individuals or groups recognised	Guo et al. (2017)
13. Site communication	Familiarising operatives with a job, informing risks and improving task-specific competence to prevent accidents	- Percentage of operatives who receive induction prior to commencement of work	Versteeg et al. (2019) Lingard et al. (2017)
Group and individual level			
14. Safety climate	Employees' perception of the priority an organisation and workgroup placed on safety-related policies, procedures and practices.	- Use of quantitative scales e.g. a five-point scale for measuring perceived management commitment and supervisor safety responses on safety matters	Chen et al. (2018);
15. Worker involvement	Workers' level of involvement in	- Percentage of attendance of workers at safety events,	Aksorn and Hadikusumo (2008)

	establishing, operating, evaluating, and improving safety practices.	e.g., training and induction/toolbox meeting	
16. Competence	Ensuring that employees have the skills, knowledge, attitudes and experience to safely carry out assigned tasks.	- Number of certification cards	Hinze et al. (2013)

Delphi Technique

Based on a systematic literature review, the study identified the 16 key safety leading indicators. To determine the relative priority/importance of the safety leading indicators to safety performance management, a two-round Delphi technique used to collate expert opinion. The Delphi technique is an iterative process used to collect experts' opinions/responses regarding an issue through the use of several rounds of questionnaires which are interspersed with feedback (Skulmoski et al., 2007). The round of questionnaire administration stops when consensus among the experts is attained or saturation (i.e. point where sufficient information has been exchanged) is attained. Consensus was determined by the use of Kendall's concordance (*W*).

For this study, the 16 safety leading indicators were incorporated in a questionnaire distributed to nine industry experts who joined an industry committee workshop in September, 2019. All the experts have over 20 years of work experience in construction and their profiles are summarised in Table 2. In the first round, the questionnaire requested the participants to rank the 16 leading indicators based on their level of importance to safety management performance. In the second round, the median ranks for the 16 indicators were presented to the experts who were then asked to reflect on the information (i.e. their responses and the median ranks) and then rank the indicators again. After using two rounds of Delphi method, consensus was reached. The median ranks of the 16 indicators at the end of the second round were then used as the basis to rank the indicators in the order of their importance to safety management performance.

Table 2 Participant information

Organisation Type	Position
Client 1	Health, Safety Environment Business Partner
Client 2	Principal Estates and Facilities Health and Safety Manager
Client 2	Performance and Systems Manager
Contractor 1	Head of Health and Safety
Contractor 2	Head of Health and Safety

Contractor 3	Safety, Health, Environment and Quality Director
Project Management Consultancy	Principal Consultant and CDM Principal Designer Manager
H&S Professional Membership Organisation	Chairman
Government Agency	Health and Safety Inspector

Results and Discussion

Table 3 shows the results of the ranking of the 16 indicators as well as the Kendall's concordance (*W*).

From the perspective of the experts, the top five leading indicators in sequence are: organisational commitment, client engagement, main contractor engagement, supply chain engagement, and designer engagement. Organisation commitment was the most important indicator for safety management and is an indicator at the firm level. Organisation commitment has been argued to be the foundation for effective safety management (e.g. Hallowell et al., 2013) because it enables the creation and maintenance of safety culture within the organisation that can affect employees' attitudes and behaviour toward safety (Choudhry et al., 2007). The level of commitment is reflected in the organisation's strategies and policies, which specify the safety-related goals and imply the relevant importance of safety compared with other functional priorities such as production (Mahmoudi et al., 2014).

The second to fifth most important indicators were related to key stakeholders' engagement in construction safety at the project level. Specifically, clients' engagement with designers can mitigate safety risks early in design. Selection and early involvement of competent contractors can ensure risks recognised in design are addressed in execution and sufficient preventive measures have been put in place (Suraji et al., 2006). Establishing a project safety committee consisting of designers, contractors and supply chain partners and regular site walkthroughs by the client can align divergent interests and build a mutual understanding of safety issues among various stakeholders (Evans, 2008). Last but not least, clients' proactive involvement communicates the message that safety is valued in daily operations, hence promoting a safety culture within projects (Hallowell et al., 2013).

Table 3: Ranking of safety leading indicators

Indicators	Round 1 (N=9)				Round 2 (N=9)			
	Median rank	Overall rank (based on median)	Kendall's W	Sig.	Median rank	Overall rank (based on median)	Kendall's W	Sig.
Organisation Commitment	1	1	0.241	0.005	1	1	0.470	0.000
Safety Auditing	13	16			13	13		
Training and Orientation	9	11			10	10		
Client Engagement	3	2			3	2		
Designer Engagement	3	2			3	2		
Main Contractor Engagement	4	4			3	2		
Supply Chain Engagement	5	5			5	5		
Design and Planning	7	6			5	5		
Hazard Identification and Control	7	6			7	7		
Incident Reporting and Investigation	11	14			13	13		
Reward and Enforcement	8	10			13	13		
Site Induction	12	15			13	13		
Safety Climate	9	11			10	10		
Workforce Involvement	7	6			8	8		
Competence	7	6			8	8		
Wellbeing	10	13			10	10		

The designer's level of engagement determines the level of risk before construction and the level of prevention to address residual design risks during construction (Hallowell et al., 2013). The designer's knowledge and skills affect the client's and contractors' ability to manage safety (e.g. Suraji et al., 2006), which in turn are enriched by the experience of learning with other parties, particularly about the underlying accident causes that include the effects of design and the design process (e.g. Suraji et al., 2006).

Principal contractor engagement influences the level of prevention and control in construction. Through early involvement in projects, principal contractors can help identify safety risks in design so that potential incidents can be mitigated through changing unsafe structures, layout or materials at the early stage of a project (Saurin, 2016). Formal and informal control of subcontractors and suppliers, such as auditing subcontractors' management systems and rewarding safety behaviour, can help improve the performance during execution (e.g. Hallowell et al., 2013).

Conclusions

Although lagging indicators, such as fatal injury rates, have been widely used in the construction industry to measure safety performance of projects and companies for decades because of their easy-to-measure nature, they are criticised as insufficient indicators to generate continuous improvement as they only indicate how bad or good the performance is. Against this backdrop, industry and academia have investigated safety leading indicators in addition to traditionally used lagging indicators. Leading indicators are proactive in nature because they measure safety initiatives that provide an early indication of impending adverse events, which in turn allows management to initiate corrective steps in a short period of time.

Leading indicators are an emergent area in both research and practice with a wide range of indicators being suggested. However, there is insufficient guidance to the industry on what and how indicators should be used in different levels of organisation and different stage of construction projects. To address this knowledge gap, this study conducted a systematic literature review to identify safety leading indicators in construction, and then applied a two-round Delphi technique to determine their relative importance. The findings reveal that safety indicators relating to organisation commitment and stakeholders' engagement are among the most important that need to be prioritised in the implementation of a safety leading indicator programme. The findings would enhance the construction industry's understanding of safety leading indicators and help organisations prioritise efforts to enhance their safety performance.

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References

Agumba, J.N., Haupt, T.C., 2012. Identification of health and safety performance improvement indicators for small and medium construction enterprises: A Delphi consensus study. Mediterr. J. Soc. Sci. 3, 545–557.

Aksorn, T., Hadikusumo, B.H.., 2008. Measuring effectiveness of safety programmes in the Thai construction industry. Constr. Manag. Econ. 26, 409–421.

Alruqi, W.M., Hallowell, M.R., 2019. Critical Success Factors for Construction Safety: Review and Meta-Analysis of Safety Leading Indicators. J. Constr. Eng. Manag. 145, 10.1061/(ASCE)CO.1943-7862.0001626, 04019005-1–11.

Autralian Constructors Association, 2015. Lead Indicators Safety Measurement in the Construction industry. Australia.

Biggs, H.C., Biggs, S.E., 2013. Interlocked projects in safety competency and safety effectiveness indicators in the construction sector. Saf. Sci. 52, 37–42.

Campbell Institute, 2015. Practical Guide to Leading Indicators: Metrics, Case Studies and Strategies. US.

Center for Chemical Process Safety, 2019. Process Safety Metrics: Guide for Selecting Leading and Lagging Indicators. US.

Chen, Y., McCabe, B., Hyatt, D., 2018. A resilience safety climate model predicting construction safety performance. Saf. Sci. 109, 434–445.

Choudhry, R., Fang, D., Mohamed, S., 2007. Developing a model of construction safety culture. J. Manag. Eng. 23, 10.1061/(ASCE)0742-597X(2007)23:4(207), 207–212.

eCompliance, 2016. Definitive Guide to Leading Indicators. US.

Evans, M., 2008. Heathrow Terminal 5: health and safety leadership. Proc. Inst. Civ. Eng. - Civ. Eng. 161, 16–20.

Guo, B.H.W., Yiu, T.W., 2016. Developing leading indicators to monitor the safety conditions of construction projects. J. Manag. Eng. 32, 10.1061/(ASCE)ME.1943-5479.0000376, 04015016.

Guo, B.H.W., Yiu, T.W., González, V.A., Goh, Y.M., 2017. Using a Pressure-State-Practice Model to Develop Safety Leading Indicators for Construction Projects. J. Constr. Eng. Manag. 143, 10.1061/(ASCE)CO.1943-7862.0001218, 04016092.

Hallowell, M.R., Hinze, J.W., Baud, K.C., Wehle, A., 2013. Proactive construction safety control: measuring, monitoring, and responding to safety leading indicators. J. Constr. Eng. Manag. 139, 10.1061/(ASCE)CO.1943-7862.0000730, 04013010.

Health and Safety Executive, 2006. Developing Process Safety Indicators. UK.

Hinze, J., Thurman, S., Wehle, A., 2013. Leading indicators of construction safety performance. Saf. Sci. 51, 23–28.

Kjellén, U., 2009. The safety measurement problem revisited. Saf. Sci. 47, 486–489.

Leveson, N., 2015. A systems approach to risk management through leading safety indicators. Reliab. Eng. Syst. Saf. 136, 17–34.

Mahmoudi, S., Ghasemi, F., Mohammadfam, I., Soleimani, E., 2014. Framework for continuous assessment and improvement of occupational health and safety issues in construction companies. Saf. Health Work 5, 125–130.

Mitchell, R., 2000. Development of PPIs to monitor OHS performance in the Australian Construction Industry. J. Occup. Heal. Saf. 16, 325–331.

Rajendran, S., 2013. Enhancing construction worker safety performance using leading indicators. Pract. Period. Struct. Des. Constr. 18, 45–51.

Skulmoski, G.J., Hartman, F.T. and Krahn, J. (2007), "The Delphi method for graduate research", Journal of Information Technology Education, Vol. 6, pp. 1-21

Suraji, A., Sulaiman, K., Mahyuddin, N., Mohamed, O., 2006. Rethinking construction safety: An introduction to total safety management. J. Constr. Res. 7, 49–63.

Versteeg, K., Bigelow, P., Dale, A.M., Chaurasia, A., 2019. Utilizing construction safety leading and lagging indicators to measure project safety performance: A case study. Saf. Sci. 120, 411–421.