Proactive Construction Safety Control: Measuring, Monitoring, and Responding to Safety Leading Indicators

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Abstract: When constructing and updating the built environment, ensuring the safety of all parties involved is of utmost importance. Traditionally, safety has been measured and managed reactively, where actions are taken in response to adverse trends in injuries. Alternatively, safety-related practices can be measured during the construction phase to trigger positive responses before an injury occurs. Despite the potential benefits of such strategies, few have been identified in the literature and there has yet to be an organized effort to codify and investigate these methods. A mixed-methods research approach was used to (1) clearly identify and define elements of the safety management process that can be measured and monitored during the construction phase, (2) describe resource requirements for measurement, monitoring, and response, and (3) describe specific management actions required when any indicator fails to satisfy a desired value. To produce internally and externally valid and reliable results, data were triangulated from case studies, content analysis of award-winning projects, and focused discussions among construction safety experts. In total, over 50 proactive metrics were identified, 13 of which were selected as top priority by expert professionals. Use of these indicators has been connected to exceptional safety performance in industry-leading organizations. The implication of the findings is that very strong safety outcomes can be expected if contractors build upon a robust safety management foundation with the use of these methods of project safety control. **DOI:** 10.1061/(ASCE)CO.1943-7862.0000730.

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Introduction

In the past 40 years, workplace injuries and fatalities have decreased significantly. Despite the fact that 6–8% of the U.S. workforce is employed in construction, the industry still accounts for 17% of all fatalities. In fact, fatality and disabling injuries among construction workers are three times greater than the all-industry average (Center for Construction Research and Training 2008). Rajendran and Gambatese (2009) and many others claim that proactive safety management efforts have a strong, positive influence on performance. Strategies such as designing for safety (e.g., Gambatese et al. 1997; Toole 2002) and schedule-based safety management (Kartam 1997; Hinze et al. 2005) have been investigated and deemed effective in past research. However, to reach world-class performance, proactive methods of safety management should also occur during the construction phase. For example, pretask planning, stop work authority, and hazard recognition programs are all methods of identifying and controlling potential hazards before they result in injuries (Rajendran and Gambatese 2009; Zou 2011). These proactive strategies are rarely formally measured or monitored or used to initiate positive responses when targets are not met. Research was needed to better understand the strategies that may serve as predictors of safety performance and how they may be used to proactively measure, monitor, and control safety risk.

To address this gap in knowledge and deficiency in practice, a study was conducted with the aim to (1) clearly identify and define predictive indicators of safety performance that can be measured and monitored during the construction phase, (2) describe resources that are required to implement a management plan on actual projects, and (3) describe specific management actions required when an indicator fails to satisfy the desired value. These predictive indicators are referred to as leading indicators because they can be measured and adjusted as the project progresses to dynamically monitor and improve safety performance. Thus, leading indicators are safety-related practices or observations that can be measured during the construction phase, which can trigger positive responses. These safety indicators are analogous to health-related indicators (e.g., blood pressure and body composition indices) that serve as indicators of personal health concerns and comparable with other elements of construction project control such as cost and schedule variance.

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Literature Review

This study was built upon many years of high-quality foundational safety research. The topic of leading indicators crosses multiple topics of construction safety research, including the Construction Industry Institute's (CII) zero-injury strategies, roles and responsibilities of key project players, safety climate and culture, front-end planning, and many others. This review consists of a summary of the relevant body of literature.

Zero Injury Techniques

In order to comply with OSHA regulations and compete in an ever-changing environment, construction companies must research, develop, and implement safety management techniques. Rajendran and Gambatese (2009) found that there are over 300 different injury prevention strategies in the construction industry, such as job hazard analyses, written safety plans, safety audits, emergency response plans, personal protective equipment, and many others. The Construction Industry Institute funded a study and identified the following essential components of an effective construction safety program (Hinze 2001):

1. Demonstrated management commitment;
2. Staffing for safety;
3. Preproject and pretask planning;
4. Safety education and training;
5. Employee involvement;
6. Safety recognition and rewards;
7. Accident/incident investigations;
8. Substance abuse programs; and
9. Subcontractor management.

This finding is supported by other, related studies (e.g., Liska 1993; Jaselskis et al. 1996; Hallowell and Gambatese 2009). These nine strategies are discussed briefly because they serve as a basic foundation for safety management. Organizations without such program elements should first build the basic structure of a safety program before employing a program to monitor leading indicators.

Demonstrated Management Commitment

Safety performance is exceptionally strong when top management is visibly involved in safety. In fact, Hinze (2001) found that the time upper management spends with field safety representatives correlates positively with safety performance. Hallowell and Gambatese (2009) found supporting evidence in a Delphi study where experts agreed that active upper management support and commitment is the single most important factor for the reduction of injury rates.

Staffing for Safety

Resources should be allocated to support a full-time safety representative when more than 20 workers are employed on an ongoing project. As the number of workers on a project increases, it is important to proportionally increase the number of dedicated safety managers (Hinze 2001). In their role, safety managers should be knowledgeable of construction methods, included in project planning meetings, and intimately involved with pretask plans, safety audits, safety training, drug testing, and incident investigations during project execution (Gibb et al. 1995).

Preproject and Pretask Planning

Hazard identification and control must be conducted before the construction phase begins to ensure that safety challenges are avoided as the means, methods, and site layout is designed (Hill 2004; Hinze 2006). Once construction starts, workers and foremen must conduct pretask planning meetings every day to ensure that hazards are recognized and communicated prior to worker exposure. These meetings must take place at the location where the work will be conducted and should be incorporated as a normal component of a daily work routine.

Safety Education and Training

Injuries in the workplace are caused by a combination of hazardous exposures and unsafe worker actions (Hinze 2006). OSHA (2007) found that the inability of workers to identify hazards and respond appropriately is a principal cause of worker injuries. Thus, construction companies must invest resources in hazard recognition training programs and orientations to communicate protocol for appropriate response (Hinze 2001; Liska 1993).

Employee Involvement

Representatives from the workforce should be involved in all safety planning and execution efforts. Such involvement is effective because it encourages positive perceptions toward safety policies and workers adhere to policies that they help create (Hinze 2001; Hill 2004). Any safety changes that require worker buy-in to be effective should be developed with direct involvement of workers.

Safety Recognition and Rewards

Incentives are a controversial topic in safety literature. However, studies that have used empirical data have all supported the fact that positive reinforcement must be made in the form of verbal praise or public recognition for safe work behavior rather than safety outcomes (Hinze 2001). Such incentives are effective because workers are inclined to repeat those actions that resulted in the positive reinforcement. These positive reinforcements may be as simple as public recognition and only require that supervisors and managers understand how to recognize safe worker behavior (Hinze 2001).

Incident Investigations

Incident investigations should follow a specific protocol that focus on identifying root causes and developing methods to future incidents. Near misses should be included in investigations because they can serve as learning opportunities without injury occurrence (Hinze 2001). Incident investigations reveal trends in safety deficiencies, which can then be used for targeted efforts that can result in rapid and dramatic improvement.

Substance Abuse Programs

Hinze (1999) argued that substance abuse testing should occur before employment, randomly, and after the occurrence of any OSHA recordable injuries to be effective. There are organizations such as the Houston Area Safety Council that provide testing and tracking services for contractors and owners. In addition to testing, the organization should have consistent and clearly communicated policies regarding employees who fail a test. The policies may include rehabilitation efforts, which are generally directed toward first-time offenders.

Subcontractor Management

The owner and/or general contractor must ensure that subcontractors follow safety protocol and are integrated into the project safety culture. Because worksites typically involve many employers who influence project safety culture, it is important for the subcontractors to be included in orientation and training sessions, pretask planning activities, drug and alcohol testing, and all other programs

(Hinze 2001). When subcontractors are involved as essential members of the safety management process, communication may be improved and misunderstandings may be avoided.

Safety Roles

All stakeholders involved in a typical construction project play an important role in defining the resultant project safety performance. Influence on project safety starts with the owner as the project is conceived and priorities are established. Designers then play an important role as the project evolves from conception to final design because many construction hazards are avoidable with proper design control. Finally, contractors and subcontractors are responsible for avoiding hazards during the construction process.

Owner

Despite the lack of legal requirement, owners can play a pivotal safety role throughout the project lifecycle. Owners have the ability to set project priorities, direct funds, influence the design as it evolves, and monitor safety management activities during construction (Huang and Hinze 2006). Owners may also include safety requirements and prequalifications in contracts. During the construction phase owner representatives may actively participate in safety meetings, jobsite safety audits, accident investigations, safety committees, and other safety activities. Such visible demonstrated commitment to safety sends a clear message to the workforce that safety is a core value (Levitt et al. 1981; Hinze 2006).

Designers

Researchers found that 42% of the construction fatalities and 22% of the injuries are linked to decisions made during design. To facilitate designing for safety, Gambatese et al. (1997) created the CII-sponsored *Design for Safety Toolbox*, which packaged hundreds of design suggestions into a software tool that made the design suggestions available to designers during the design phase. This software was updated in 2009 as a user-friendly software module, entitled *Design for Construction Safety Toolbox, Version 2.0* (Hinze and Marini 2008). Although designing for safety has been shown to be effective, the focus of the present study was on leading indicators during construction.

Contractor and Subcontractors

Unlike owners and designers who are not legally required to explicitly consider safety, general contractors and subcontractors must implement safety programs in order to protect their workers and to comply with the OSHA Act's General Duty Clause and the Occupational Safety and Health Administration (OSHA) Construction Industry Regulations. These activities often include the aforementioned Zero Injury techniques. According to Molenaar et al. (2009) the suite of safety program elements implemented serves as the foundation of the site safety culture.

Vendor/Supplier

Safety is impacted by all organizations and individuals who work on or visit the site, including vendors and suppliers. Whatever organization controls access to the project site must ensure that vendors and suppliers comply with all safety rules and activities in connection with their work (Zou 2011). This is an important issue observed in the aerospace manufacturing industries as well because the safety culture on sites with many vendors is often dictated by the safety attitudes and behaviors of the vendors (Hallowell et al. 2009).

It should be noted that there is a dearth of literature on the topic of safety leading indicators. A thorough literature review reveals no previous academic research on the topic. Although the term safety leading indicators has been defined (Flin et al. 2000; Grabowski et al. 2007), no specific leading indicators have been identified or described. Consequently, this may be considered seminal work in the domain.

Contributions to Theory and Practice

The following constitutes the current body of knowledge of leading metrics of safety performance which occur during project execution. Although others have alluded to leading indicators, have provided anecdotal evidence, or analyzed small datasets to support their effectiveness (Hinze et al. 2013), this is the first study to codify the experiences of industry leaders, conduct observations and interviews on active projects, and validate the results with empirical data. These contributions to theory are enhanced by not only identifying effective safety control strategies, but also by defining proper methods of indicator measurement, proper response to safety deficiencies, and suggested methods of program implementation.

Research Approach

To achieve the aforementioned research objectives, a mixed-methods research approach was implemented using data from three distinct sources. Because implementation of leading indicators is a new concept that has not seen widespread use in the construction industry, the efforts were exploratory in nature. Three research efforts were implemented to cross-validate the findings (see Fig. 1). As shown, 19 case studies were conducted; a content analysis was

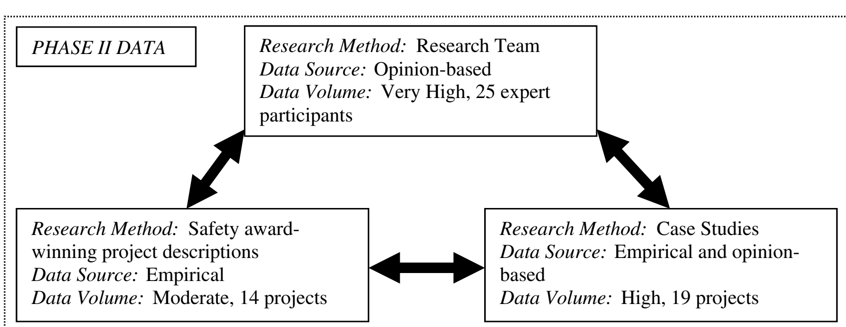

Fig. 1. Mixed-methods data collection approach [data from Hinze et al. (2012a)]

conducted on 14 reports from safety award–winning projects; and brainstorming sessions were conducted with an expert panel comprised of 25 construction safety experts. This mixed methods approach includes a combination of empirical and opinion-based data in order to promote the internal validity, external validity, and reliability of the results.

Case Studies on Active Projects

Projects were initially selected through contacts with Construction Industry Institute (CII) member companies, primarily through research team members. Additional projects were identified through the cooperative efforts of the Associated General Contractors (AGC) and through personal contacts of the research team members. Since this was an exploratory study, the comparative case studies goal was to conduct studies of relatively high-performing large or signature projects, which have the highest potential for implementing innovative safety methods. Having data from multiple projects allowed the team to look for patterns in the resulting data (Eisenhardt 1989). When selecting the number of projects, the literature suggests a minimum of four to ten cases when investigating complex contextual relationships (Eisenhardt 1989; Yin 2003). The summary of the case study demographics is provided in Table 1.

All case studies involved a site visit, interviews with project management, and the collection of supporting documentation. In all but three cases, the researchers conducted a site tour, interviewed owner representatives and workers, and conducted observations of work practices and safety meetings. Because an initial pilot study (Hinze et al. 2013) revealed that a common definition of leading indicators did not exist in the industry prior to the present study, the research team focused each case study around the following, related questions:

1. "Other than injury rates, how do you measure and monitor safety performance on your project?"
2. "How do you know if your project safety process is in good condition without measuring the number or rate of injuries?"

Table 1. Case Study Demographics [Data from Hinze and Hallowell (2012)]

Location	Project type	Scope	Host	Organization TRIR[a]	Project TRIR
MA	Bridge	$125 M	Contractor	4.3	5.47
CO	Building	$23 M	Contractor	[b]	1.8
DE	Building	$78 M	Owner	[b]	2.4
FL	Courthouse	$280 M	Contractor	0.6	6.38
GA	Dept. of Corrections	$106 M	Contractor	0.6	5
IL	Energy	$3.6 B	Contractor	0.26	0.42
TX	Energy	$2.3 B	Contractor	1	1.26
NY	Energy	$1400 M	Contractor	2.5	3.4
GA	Fire station	$4 M	Contractor	0.6	0
NY	Heavy civil	$680 M	Owner	2.1	0.98
WY	Highway	$23 M	Contractor	[b]	1
FL	Highway	$16 M	Contractor	2	2.35
ME	Highway	$35 M	Contractor	3.3	2.8
CO	Highway	$24 M	Contractor	[b]	3.5
CO	Highway	$50 M	Contractor	[b]	4.5
FL	Hospital	$280 M	Contractor	1.66	1.42
FL	Hospital	$300 M	Contractor	1.66	3.9
NJ	Industrial	[b]	Owner	[b]	0
NY	Marine	$1 B	Contractor	0.3	1.97

Note: M = million U.S. dollars; B = billion U.S. dollars.
[a]TRIR refers to the OSHA total recordable injury rate.
[b]Denotes that information was not made available.

As discussed by Taylor et al. (2009), case study research must be carefully designed to ensure internal validity, external validity, and reliability to promote confidence in the results. Internal validity was maximized by eliminating the influence of the research team's personal bias on the data collection process. This was achieved by asking the two questions above rather than leading with examples of leading indicators. External validity was preserved by examining a variety of project types with a wide geographical diversity, triangulating multiple data obtained from each case, and following a predefined protocol. Finally, reliability was enhanced by validating against other data sources, e.g., results of expert group brainstorming and findings from safety award–winning project reports.

Empirical Data from Safety Award–Winning Projects

The second data source involved the extraction of information from 14 detailed reports of the safety-related strategies used on completed, award-winning projects. These 14 projects are not a subset of the case study projects. Reports included a brief description of the project, the lagging indicators of safety performance (TRIR), and a description of the safety programs that were implemented. A detailed manual content analysis of these reports was conducted by two researchers to identify the leading indicators that were implemented. Indicators were identified by reading the project descriptions and noting safety efforts that were actually measured and tracked during construction. For example, a project highlighting the frequency of upper-level management participation in safety meetings over time on the project was said to include the leading indicator project management team safety process involvement.

Descriptions of award-winning projects were only available from two very large companies with collective annual revenues exceeding $9 billion and employing more than 10,000 workers. Furthermore, as shown in Table 2, the safety performance for the 14 award-winning case projects was 0.17 total recordable injuries per 200,000 worker-hours. Therefore, these data have only been tested on very large and quite safe construction projects.

Expert Group Discussion

The research team formed three subcommittees to address leading indicators that could be implemented by the following three groups: owners, contractors/subcontractors, and vendors/suppliers. Each of these subcommittees (1) identified and described the potential

Table 2. Safety Award–Winning Projects [Data from Hinze and Hallowell (2012)]

Project number	Worker hours	TRIR[a]
1	362,000[b]	0
2	741,360	0
3	244,600	0
4	445,100	0
5	55,335	0
6	440,364	0
7	259,970	0
8	959,453	0.18
9	500,000[b]	1.6
10	500,000[b]	0.54
11	531,400	0
12	500,000[b]	0
13	250,000[b]	0
14	318,149	0
Average	436,266	0.17

[a]TRIR refers to the OSHA total recordable injury rate.
[b]Denotes approximations.

leading indicators that applied to their group; (2) planned how these indicators could be measured; and (3) developed an action plan for when goals are not met. Each subgroup had at least three industry experts and one academic representative. To ensure consistency in the findings, the subcommittees reported quarterly to the entire research team. Expert group brainstorming was selected because leading indicators are not yet commonplace in the industry, so quantitative data were not readily available; the industry-based research team already involved industry leaders; and the research team had sufficient resources to conduct four related face-to-face meetings and four conference calls.

Finally, the expert group was comprised of 23 highly experienced safety professionals and two academics from diverse and geographically distributed organizations in the United States. As noted earlier, the research team had amassed considerable experience and knowledge in the area of construction safety. On average, the team member s had over 13 years of safety management experience. Additionally, 12 members of the team had bachelor's

Table 3. Proactive Metrics of Safety Performance

Proactive metrics	Suggested measurement	Resources required
	Contractor-led indicators	
Near miss reporting	Monitor a 3-month moving average of the number of near misses per 200,000 worker-hours exposure.	A standardized form for reporting near misses is required. Personnel must be available to input/track data.
Project management team safety process involvement	Frequency of participation of project management team members in field safety activities	Time commitment from the project management team members. A scorecard would be a simple mechanism by which each member's involvement would be visibly documented.
Worker observation process	A 3-month moving average of the number of safety observations conducted per 200,000 work-hours of exposure.	Time will be initially required to train the observers. All jobsite personnel should be educated on the intent and proper protocol for observation. Time will be needed to collect and enter data.
Stop work authority	The number of times that the stop work authority is exercised per 200,000 worker-hours.	The stop work authority is to be clearly communicated to workers in initial orientation and at regular intervals throughout each project.
Auditing program	Percentage of audited items in compliance.	Data must be regularly documented for tracking, trending, and closing of corrective actions. Personnel are required to input/track data.
Pre-task planning	The percentage of pretask plans prepared for work tasks. Management may wish to also measure the quality of the meetings using a rubric.	Pretask planning forms should be prepared and be readily available to all field crews. Personnel must be assigned to evaluate and score the pre-task plans and input and track the data.
Housekeeping program	A rubric for consistent scoring should be created as housekeeping is somewhat qualitative. Scores may be generated and compared once a rubric is created.	Personnel must be assigned to input, track and trend the results. Follow-up efforts will be required to ensure that corrective actions are promptly implemented.
	Owner-led indicators	
Owner's participation in worker orientation sessions	Percentage of orientation sessions in which the owner's project manager is an active participant.	The owner's project manager should prepare an outline or script to ensure that specific points are made and that consistent expectations are shared at the orientation sessions.
Foremen discussions and feedback meetings with the Owner's PM	Frequency of meetings and percentage of key members in attendance at each meeting. Total number of foremen attending the meetings versus the number of foremen on the project site. Percentage of action items that are closed on or before the target date.	A standing agenda should be maintained and meeting minutes should be kept. Action items should be enumerated and the close-out of these action items is to be tracked.
Owner safety walkthroughs	The frequency of walkthroughs per 200,000 worker-hours	A walkthrough checklist is needed to operationalize the observation and recording process. Personnel time is required for walkthroughs.
Pretask planning for vendor activities	Percentage of vendors entering site with appropriate safety planning as described	Supplier time (dependent on material supplied), contractor time (recording and processing), and management commitment are required.
	Indicators pertaining to vendors and suppliers	
Vendor safety audits	The percentage of vendors in compliance with site policies and procedures.	Staff time will be required to prepare and conduct audits and management time will be needed to review and respond to audit results.
Vendor exit debrief	Percent of exit interviews that include identified hazards, unsafe behaviors or incidents.	Measuring and monitoring this indicator requires time to gather information from vendors upon their departure. Entry to the site should be controlled and properly staffed.

Note: Table presents metrics that can be tracked as a project progresses (leading indicators).

degrees in construction, safety, or a related field; five had a master's degree; and two had earned a Ph.D. All degrees were earned in construction engineering and management, occupational safety and health, or a related field that contributed to their expertise in construction safety. Such expertise credentials are consistent with the safety literature (Hallowell and Gambatese 2009).

Results

The data sources for the leading indicators included case studies, project descriptions of safety award–winning projects, and expert brainstorming. These data were aggregated from these three sources The primary data source consisted of the expert brainstorming sessions because they yielded the most complete database of leading indicators and they were based on the collective expertise of the entire research team. The case study and award-winning project description data were used to cross validate the results generated by the research team members. In total, over 50 potential leading indicators were identified. Each member of the research team was then asked to independently and anonymously select what they believed were the 10 most promising indicators. The team then discussed the selections face-to-face and each team member provided a justification for their selections. The team did not use ratings; rather, the discussions drove the selection of 13 indicators that were promoted for subsequent development. During the face-to-face discussions the team achieved consensus. In general, the 13 leading indicators were selected as a priority because (1) the team believed that each metric is a strong indicator of future safety performance, (2) the indicators are measurable forms of efforts that many contractors and owners already implement but do not yet measure or track, and (3) collectively, they represent a diverse group of strategies involving leadership, workers, and vendors. These 13 leading indicators are identified in Table 3 along with their suggested metrics and expected resource requirements for implementation. Table 4 reports the suggested action plans for use when actual metrics fall outside target ranges. One will note that the thresholds reported by the team are not included. These tables are altered from *CII Research Team 284 Research Report 284* (Hinze and Hallowell 2012).

Thresholds were omitted from the data because threshold values are highly dependent on an organization's safety maturity. Thus, the

Table 4. Proper Responses When Company Tolerance Levels Are Not Met

Proactive measure	Action Plan
Near miss reporting	The project management team should oversee the near miss reporting program to ensure its success, publicly communicate near-miss reporting expectations to all employees, recognize employees who participate, and communicate corrective actions taken as a result of the near miss reporting.
Project management team safety process involvement	The team should address the involvement of each member in field safety activities at its regular meetings. When involvement is deficient on the part of one or more members, goals can be reiterated and suggestions can be offered on how to increase the level of involvement in field safety activities.
Worker observation process	Deficiencies in the program are typically linked to observers failing to document and track data obtained through the observations. The project management team should track data entry and reporting and connect such activities with performance evaluations.
Stop work authority	Throughout project execution, the support for the stop work authority program should be reiterated and stressed by the safety personnel. A lack of worker empowerment may be a symptom of poor safety culture.
Auditing program	Expectations should be communicated to field personnel and progress should be measured weekly. The project management team should build and maintain a visible field presence. Audit results should be communicated to project employees on a weekly basis.
Pretask planning	A member of the project management team should actively participate in pre-task planning sessions on a daily basis to ensure compliance with expectations. Feedback should be provided to the respective supervisor and crew, especially when expectations are not being met. When pretask plans fall below expected targets, supervisors and their respective crews should receive additional training, which may be in the form of short refresher/remedial training conducted in the field or more extensive training, as required.
Housekeeping program	Project leaders should make regular field observations, paying particular attention to housekeeping. Housekeeping should become a discussion topic at all daily/weekly supervisor meetings and a close-out item contained on the pretask plan as a post job or shift review.
Owner's participation in worker orientation sessions	The owner's project manager should promptly report to all new orientations and upper management should visibly track participation.
Foremen discussions and feedback meetings with the owner's PM	Regular meetings should be scheduled between the owner's PM and the contractor's foremen and attendance should be monitored and reported by upper management.
Owner safety walkthroughs	The owner's project manager should establish the safety walkthrough schedule and a random audit schedule that is labeled as a top priority. Upper management should establish a corrective action process for team members who do not meet expectations.
Pretask planning for vendor activities	Provide noncompliant vendors with guidance on what information is needed (examples). Contractor/owner management should address willful violations with the vendor's management with the understanding that repeated noncompliance will affect the future business potential. Deliveries may be rejected if pretask plans have not been prepared. Interview noncompliant vendors to explain why the pretask plan had not been completed. Inform vendors of the consequences of noncompliance.
Vendor safety audits	The frequency of vendor audits will be dictated by the percentage of noncomplying vendors. When vendors are not in compliance, formal communication should be made to describe appropriate procedures and consequences for lack of vendor compliance.
Vendor exit debrief	Vendors should be informed of the necessity of their feedback and reminded of their contractual obligation by a member of site leadership.

Note: For leading indicators in Table 3.

thresholds developed by the team would only be representative of world-class companies and would be misleading to less mature companies, i.e., threshold values change as a firm's safety efforts mature. We do believe that thresholds may be set as organizations initially implement and measure new leading indicators within their company culture.

In addition to the data obtained from the expert team, the case study visits and content analysis of the award-winning project reports revealed some interesting trends. First, on many projects, the role of the safety manager was critical because they were able to use feedback from employees as a leading indicator because of their positive connections with employees which fostered open dialogue. In fact, on two case study projects, the only leading indicator used was feedback from candid discussion between the safety manager and the workforce. Success of such a leading indicator requires a deep connection where feedback is honest and consistent. Second, world-class safety companies that have adopted leading indicators have done so carefully. They have established a protocol for measurement, provided training, devoted resources, and continuously monitored and improved their processes. An important lesson that one firm learned was that when a leading indicator does not lead to positive improvement, it should be removed from the program.

Study Limitations

Although the findings are consistent with previous research, there are some limitations. First, the team utilized a convenience sample with project contacts obtained primarily from the Construction Industry Institute and the Associated General Contractors. Thus, the findings are particularly applicable to firms affiliated with these two groups. Second, the projects were located in the United States, which limits the external validity of the results; however, this is not considered to be a serious concern. Third, most of the representatives interviewed were employed by large companies and the findings may not readily apply to smaller firms. Half of the participating companies had annual volumes of business exceeding $1 billion. Consequently, the results specifically represent projects in the United States, of primarily large contractors. There is strong logical evidence from the large volume of literature reviewed that these results should extend to other sectors of the construction industry.

Suggested Implementation Procedure

At the end of the research process, the expert group created a recommended approach for implementing the 13 high-priority safety management controls. Incorporating safety leading indicators into construction project management requires commitment, planning, education, execution, and periodic evaluation. Fig. 2 shows the outline of a step-by-step procedure for initial implementation and continuous improvement of a leading indicator program. A detailed implementation guide is available in *CII Research Team 284 Implementation Resource* (Hinze et al. 2012b).

The selection of proper indicators depends on existing safety programs and the safety culture. The research team recommends starting a leading indicators program by changing the organizational mindset from implementation of effective safety programs to the real-time measurement, monitoring, and control of these practices. For example, a company that is already implementing an auditing process may turn this practice into a leading indicator by using the data provided in Tables 3 and 4 to operationalize the definition of the practice, identify an actionable metric, and proper responses to deficiencies.

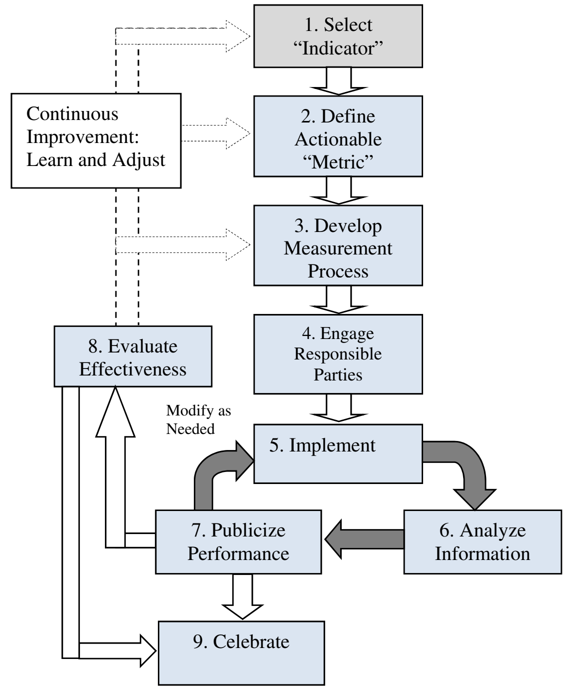

Fig. 2. Suggested implementation protocol [data from Hinze et al. (2012b)]

Once an organization has shifted its mindset to measuring, monitoring, and controlling performance for effective safety practices, new indicators can be added to the program. As previously indicated, organizations with relatively mature leading indicator programs have noted that new indicators should be added carefully. If an indicator does not lead to improvement in safety processes or cannot be objectively measured, it should be excluded from the program. Additionally, organizations should only use indicators that can be used to trigger positive response and are predictors of safety performance.

Conclusion

The intent of this research was to provide meaningful measures that can help both contractors and owners strive toward attaining and sustaining a zero-injury construction safety culture on their jobsites. None of these recommendations should be viewed as replacements to existing practices; but rather, they should be viewed as metrics that can help safety managers determine whether current practices, procedures, and policies are sufficiently robust to continue to improve safety. In addition, in making these recommendations, the authors assume that contractors or owners who jointly or independently endeavor to utilize these measures already have mature safety programs in place. Further, it is assumed that these programs strive to not only attain zero injuries, but also that they reflect a safety culture that is only satisfied with continuous improvement. Each organization's desire in implementing these metrics should be to realize an honest assessment that results in positive actions that, in turn, lead to new behaviors and employee beliefs that further strengthen the existing safety culture.

This study contributes to the existing knowledge base by building on a strong foundation of safety performance described by Liska (1993), Hinze (2001), and others by conducting the first comprehensive investigation into the elements of a safety management system that can be measured, monitored, and controlled during the construction process. The findings and suggested implementation plan also contribute greatly to practice as these metrics are the first of their kind.

It is important to note that this was largely an exploratory study because, during the study period, leading indicators were rarely fully implemented in practice as shown by the case study findings. Thus, the authors recommend that future researchers conduct field testing on these indicators to determine the extent to which they predict safety performance and, when implemented, improve safety outcomes and overall project performance. The present study provides critical knowledge for targeted field testing.

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