ELECTRIC POWER RESEARCH INSTITUTE

# Program on Technology Innovation: Comparative Analysis of Companies with High Injury Rates with Companies with Low Injury Rates

## Phase 1 – Methodology and Pilot Study

2020 TECHNICAL REPORT

# Program on Technology Innovation: Comparative Analysis of Companies with High Injury Rates with Companies with Low Injury Rates

Phase 1 – Methodology and Pilot Study

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# ABSTRACT

As organizations seek to use safety resources efficiently, it is vital to understand the primary drivers of performance. To this end, this study identified differentiators of safety performance from a comprehensive review of literature, statistical meta-analysis, and group brainstorming. A data collection instrument was created from these results and was pilot tested with an investor-owned utility with generation, transmission, and distribution assets. The instrument was reviewed by an industry panel and was pilot tested in late 2019 at one utility to assess feasibility. The result will be a research-validated data collection instrument with the potential to be used to identify the primary drivers of safety success. Full-scale data collection is anticipated in 2020.

### Keywords

Business factors
Leading indicators
Occupational health
Predictive analytics
Safety climate
Worker safety

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**PRIMARY AUDIENCE:** Occupational health and safety professionals

**SECONDARY AUDIENCE:** Safety officers, environmental and health safety leadership, and sustainability leaders

## KEY RESEARCH QUESTION

This effort explores the question: What perceptions, measures of safety activities, and business factors should be considered when differentiating safety performance, and how can they be measured reliably?

## RESEARCH OVERVIEW

The rates of serious injury and fatality (SIF) have plateaued across industries, including the electric utility sector. Ongoing efforts have attempted to address this trend with empirical research into the predictors of safety performance. These studies have revealed that measures of employee perceptions (climate), measures of activities performed to promote safety (leading indicators), and attributes of the organizational structure (business factors) explain variability in safety performance. However, this body of research is fragmented and dispersed across industries—and the various factors have been considered in isolation. By aggregating the results of previous studies across project-based industries, this study offers the first customized and unified approach to safety differentiation. To this end, a comprehensive literature review of safety performance factors was conducted, empirical data were extracted, and a statistical meta-analysis was conducted to identify the factors with the highest potential to be differentiators. Then, brainstorming was performed with a panel of electric utility occupational health and safety leaders to identify potential factors to supplement the current knowledge. An assessment strategy was crafted to measure these potential differentiators, which was subsequently reviewed by the industry panel and revised based on the recommendations. Finally, the assessment instrument was pilot tested with an investor-owned utility with electric power generation, transmission, and distribution assets. The feedback confirmed the practicality of the questions and feasibility of the data collection protocol. The results and subsequent interview with the pilot organization's representatives were used to make refinements to the data collection protocol. Full-scale data collection with 20+ companies is planned for2020.

## KEY FINDINGS

- A review of existing literature and statistical meta-analysis identified potentially useful factors to determine critical safety climate and leading indicators.
- Brainstorming sessions with an expert panel and a review of existing literature were used to determine critical organizational and project-related factors deemed predictive of safety performance.
- A comprehensive data collection instrument was created that simultaneously measured safety climate, safety leading indicators, business factors, and safety outcomes.
- The data collection instrument was pilot tested with an EPRI member, which resulted in suggested minor adjustments in data collection that should be adopted when the full-scale study is launched in 2020.

## WHY THIS MATTERS

This study codifies and summarizes a fragmented and dispersed body of literature in safety prediction. The study also involved the creation of a data collection instrument that can be deployed in future studies to conduct a full-scale comparative assessment. A pilot study was conducted with an investor-owned utility to test the feasibility of the data collection instruments and protocol. The results indicated that with minor refinement to the proposed methodology, the proposed Phase 2 study is feasible and will generate the desired results. A full study is planned to commence in the second quarter of 2020 with 20 or more electric utilities. In the full study, research will seek to determine whether quantitative relationships exist among culture, leading indicators, and business factors with safety outcomes.

## HOW TO APPLY RESULTS

The survey instrument can be used to efficiently and effectively assess potential differentiators of safety performance, including safety climate, leading indicators, and business factors. Users may wish to adopt this survey instrument or the subsections when conducting assessments of safety performance. After completing a pilot study with one EPRI-member company, EPRI intends to conduct a full study in 2020 using the methodology developed in this Phase 1 effort.

## LEARNING AND ENGAGEMENT OPPORTUNITIES

The impetus for this project came from the development of the white paper on state of knowledge/state of practice of using human performance and behavior approaches to reduce serious injuries and fatalities in the electric utility industry. Interviews with subject matter experts for the white paper—and the resulting discussions in the EPRI Human Performance Research Workshop, held in Irving, Texas, in October 2018—identified the need for this project. Readers may wish to read the workshop summary and the white paper contained in the appendix of the 2018 EPRI report 3002013834, *Program on Technology Innovation: Assessing Human Performance and Behavior Approaches to Reduce Serious Injuries and Fatalities—Workshop Summary and Research Opportunities.*

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# CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# 1 INTRODUCTION

Academic literature related to differential injury rates exists but is highly fragmented and dispersed. There is also an inconsistent lexicon related to safety predictors and differentiators that makes consuming research in the domain challenging. For example, the terms *leading indicators*, *precursors*, *risk factors*, and others are used loosely and sometimes interchangeably, although they theoretically measure different and synergistic safety factors. This study elucidates and categorizes the types of safety differentiators that organizations may wish to consider and proposes a multi-dimensional approach to safety differentiation. Importantly, this study is limited to actionable differentiators that the organization can change and control (for example, implementation of safety programs and organizational structure) and not on indirect factors (such as weather or political climate).

This report provides the necessary foundation for an empirical assessment of safety differentiators among electric utilities. Therefore, great care was taken to review all relevant literature, use robust statistics to uncover the factors with the highest potential to be differentiators, draft a survey instrument, and refine the instrument with input from industry partners and eventually pilot testing. The wording of all questions was also reviewed with an industry panel[1] to ensure that the survey is easy to comprehend and uses the common language among safety professionals who would take the survey on behalf of their organizations. The survey was also pilot tested with an investor-owned utility, which confirmed the feasibility and efficacy of the data collection protocol.

The result of this work is a research-validated safety assessment protocol that combines the best features among existing protocols and incorporates new factors that relate to contemporary safety practices. This work addresses a critical need in the industry by identifying the primary drivers of safety success so that practitioners can direct resources to the most cost-effective safety strategies. In this way, the safety system may be optimized, and the greatest return can be realized from safety investments.

The Electric Power Research Institute (EPRI) intends to use the methodology developed in this report to conduct a study in 2020 of 20 or more EPRI-member companies. The impetus for this report and the intended study resulted from an industry white paper on the state of practice with human performance initiatives as well as a research workshop with human performance practitioners, representatives of nonutility sectors, and EPRI-member companies.[2]

In addition to providing the methodology for the planned 2020 project, the safety climate assessment and the leading indicators described here may have immediate usefulness to EPRI-

[1] The industry panel consisted of member company representatives to EPRI's two standing working groups in Program 62, Occupational Health and Safety—Human Performance and Predictive Analytics—in addition to the EPRI program manager.

[2] *Program on Technology Innovation: Assessing Human Performance and Behavior Approaches to Reduce Serious Injuries and Fatalities—Workshop Summary and Research Opportunities*. EPRI, Palo Alto, CA: 2018. 3002013834.

member companies. Because these metrics have been validated (as reported in Sections 4 and 5 of this report), EPRI-member companies may wish to compare their current climate assessment tool and leading indicators to those reported here and consider including metrics from this report in future assessments and analyses. Therefore, the results of this project have immediate applications to enhance current company approaches.

# 2
# BACKGROUND AND FRAMEWORK

When making predictions, research has shown that there are two primary families of predictions: short-term and long-term. Short-term safety predictors tend to use information about an immediate work period (for example, physical characteristics of the work, conditions of the workforce, and the environment) to make predictions of the likelihood and outcomes of an injury during that work period. Alternatively, long-term predictive methods tend to use information about prevailing trends and characteristics of the organization (for example, employee perception and satisfaction with safety, measures of the activities performed in the safety program, and business factors) to make predictions of injury rates over months, quarters, or years. When differentiating safety performance at the organizational level, long-term predictive methods are relevant because they are comparatively stable, comparable, and can be consistently defined [1].

In this study, the position was taken that variables that predict future safety outcomes are also the best differentiators of safety performance across organizations. For example, research has shown that measures of employee perception of safety predict future safety performance. The corollary is that measures of safety climate in the present time are potential future differentiators of safety performance across organizations. This is important because much of the literature reviewed is discussed in the context of predictive safety.

Three types of long-term safety differentiators were considered in this study. Because the terminology of safety prediction and differentiation in current literature is applied inconsistently, we offer the following definitions and simplify the categorization in Figure 2-1.

The first category of organizational safety differentiators is *safety climate*, defined as the aggregate measure of employee **perception** of safety culture over a specific period [2]. In this report, any measure of employee perception of organizational safety is an element of safety climate. Simply, safety climate measures how employees feel about safety.

The second category is *safety leading indicators*, defined as measures of activities that an organization performs to prevent occupational injuries [3]. Leading indicators can be differentiated from other business factors because they are any resourced activity, program, policy, or procedure implemented with the primary intent of preventing occupational injuries [4]. Simply, leading indicators are measures of what an organization does to keep workers safe.

The third category is *business factors*, defined as measures of organizational structure and behavior that may impact safety. These business factors are not resourced activities with specific focus on safety; rather, they are attributes of the business that may impact safety indirectly [5–8]. Simply, business factors are measures of how an organization is structured that indirectly affect safety outcomes.

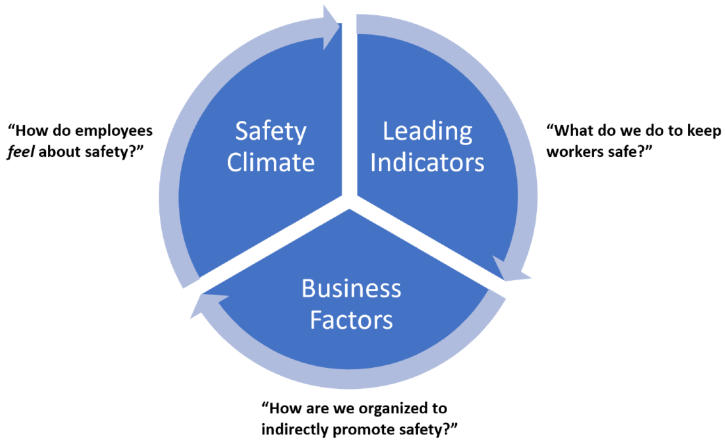


**Figure 2-1**
**Main categories of actionable safety differentiators**

Subsequent sections of this report provide further detail on these categories and introduce relevant sub-categories. Figure 2-2 has been produced to enable a consistent understanding of categories and sub-categories and to communicate how the categories are related but different. Safety climate, passive and active leading indicators, and business factors are included; however, control factors and externalities (that is, elements outside the direct control of the business) are not included because they are not directly actionable.

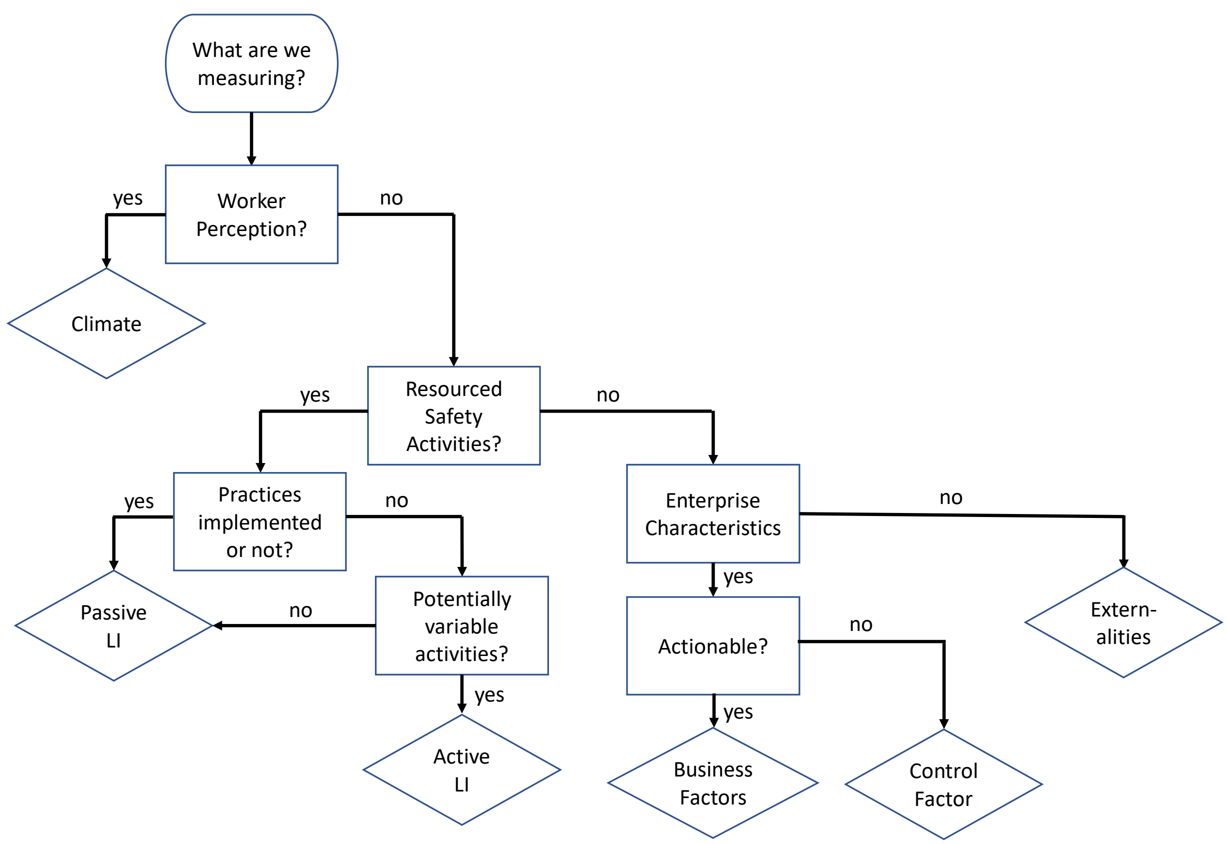


**Figure 2-2**
**Flow chart illustrating the relationships among categories of differentiators**

# 3
# OVERALL APPROACH

This study was conducted in three main phases. This linear approach involved building an assessment protocol on a foundation of current literature and the relevant body of knowledge, refining the protocol with feedback from the industry panel, and testing the feasibility of the protocol in a case deployment.

The study began with a comprehensive review of existing scientific literature in safety climate, leading indicators, and business factors that differentiate safety performance. Literature was identified by searching Google Scholar, Engineering Village, and SCOPUS. The literature was then filtered to describe trends and themes in past research and identify studies with empirical data. Using empirical data from key literature, a statistical meta-analysis was then performed to determine the measures that best correlate to future performance.

Statistical meta-analysis leverages years of statistical data across multiple studies to uncover prevailing themes and uncover salient metrics. Meta-analysis is a robust statistical procedure that measures the strength of relationship (effect size and power) by leveraging the findings from multiple past empirically driven research. By aggregating the data from all relevant studies that have previously examined a relationship between two variables, the true nature of the relationship may be statistically examined and an overall effect size estimated. In this study, research that demonstrated empirical correlations between safety climate or leading indicators and safety performance was targeted.

Meta-analysis was performed through the following activities:

1. Conducting a comprehensive literature search on published studies
2. Extracting information from relevant studies
3. Computing standardized effect sizes for each study to make them comparable
4. Computing the global effect size

Appendix A provides full details on the meta-analysis protocol implemented to identify key dimensions of safety climate and leading indicators. A meta-analysis ensures that, of potentially thousands of differentiators, only those with the highest potential are used. This efficiency will be vital to the Phase 2 data collection and subsequent data analysis. The results of the meta-analysis are interpreted in the subsequent sections of this report and are communicated in terms of the strength of the relationship between the factor and safety performance as shown in Table 3-1.

**Table 3-1**
**Interpretation of strength**

| Strength | Analytical Rigor |
|---|---|
| High | Meta-analyzed |
| Medium | Repeated and correlation |
| Low | Correlation |

The results of the literature review and meta-analysis were then used to create a draft assessment tool with the factors that have the greatest potential to differentiate safety performance among organizations. The draft survey was created by the research team, and language for the questions was derived from survey instruments included in validated literature.

To ensure the feasibility of the assessment protocol, the initial draft was reviewed with a panel of electric utility health and safety leaders from EPRI Program 62, Occupational Health and Safety—specifically those with interests and expertise in human performance and predictive analytics. The panel provided feedback to the research team over a series of phone calls. The research team iterated with the panel to arrive at a data collection instrument that was research-validated, refined, and feasible for data collection.

In fourth quarter 2019 into first quarter 2020, this methodology was pilot tested at an EPRI-member company to demonstrate feasibility and illustrate the data obtained from the deployment of the survey instrument. Initiation of the full study undertaken by EPRI, with minor adjustments in the methodology from learnings from the pilot, is planned for second quarter 2020.

The following sections of this report show the results of the literature review, meta-analysis, creation of survey questions, and pilot study learnings. The report is organized by predictor type, including climate, leading indicators, and business factors. Each type is defined and discussed in detail.

# 4
# SAFETY CLIMATE

Although intangible, safety culture can be indirectly measured and characterized through safety climate surveys of the workforce and management. Dimensions of safety climate may include perceptions of safety resources, leadership, prioritization of safety, and shared goals. Safety climate studies neither give an absolute measure of risk nor are the solicited perceptions an objective metric. Perceptions in general are prone to cognitive and social biases but may capture information not captured by the other categories of safety differentiation. Therefore, conclusions from safety climate analysis need to be treated with appropriate caution and combined with other metrics in a multi-dimensional approach.

When studying safety climate, the researcher reviewed literature and performed a statistical meta-analysis to determine the dimensions of safety culture that best correlated to safety performance, assessed the feasibility of safety climate surveys of various length and content, and created a standardized safety climate assessment methodology. Theoretically, safety climate is driven by the organization's efforts to prevent injuries and mediates the relationship between safety effort and safety performance.

Most safety climate studies use questionnaires [2, 9, 10, 11] or interviews [12, 13] to collect data. Typically, safety climate surveys solicit perceptions of safety as a priority in the organization, the extent to which management cares about safety and the well-being of the workforce, and the effectiveness of management programs [2, 12]. Questionnaires have also been used and modified to include measures of awareness of risk and risk tolerance. For example, questionnaires in References [9], [14], and [15] assessed the value workers place on following rules and procedure, personal risk-taking habits, and perceived likelihood of injury that can be used to improve training modules.

Past studies have found that there is a positive association between overall safety climate and reduced rates of accidents and injuries on-site [4, 7]. Specifically, safety climate scores have been validated as predictive, where higher safety climate scores are associated with stronger future safety performance [16–22]. Typically, safety climate surveys are subdivided into a variety of safety climate factors such as management's commitment to safety, rules and regulations, training, and supervisor's role in safety. Multiple researchers have studied how safety climate dimensions like these relate to injury rates. A formal meta-analysis was performed using these empirical studies to identify the safety climate dimensions with the best predictive capacity because these are likely to be the best differentiators of safety performance. The safety climate dimensions identified in this review are described in Table 4-1. The interpretation of the predictive strength is shown in Table 3-1.

**Table 4-1**
**Dimensions of safety climate***

| Dimension | Definition | Strength |
|---|---|---|
| Upper management's commitment to safety | The perception of the emphasis that upper management places on organizational safety | High |
| Safety rules and procedures | The perception of the degree to which workers are willing to remain compliant with rules and regulations | High |
| Personal risk-taking behavior | The perception of the degree to which individuals are willing to engage in risky activities | High |
| Safety training | The perception of the education provided by the organization as it relates to work | High |
| Supervisor's commitment to safety | The perception of the involvement and commitment of first-line supervisors in managing safety of day-to-day activities | High |
| Worker involvement | The perception of how much management involves employees when making decisions regarding safety rules and policies | High |
| Safety communication | The perception of the quality of communication between top management and workers related to safety concerns, feedback, and protocols | Medium |
| Worker safety priority | The perception of the extent to which the organization emphasizes safety as a priority | Medium |
| Workload pressure | The perception of the amount of work pressure experienced by workers | Medium |
| Competence of coworkers | The perception of the knowledge, skill level, and qualifications of coworkers to ensure safe operations | Medium |
| Interpersonal conflicts | The perceptions of conflicts experienced at work | Medium |
| Coworker safety | The perceptions of risk-taking behaviors of coworkers | Medium |
| Safety consciousness | The perceptions of personal awareness of safety concerns, resources, and policies | Medium |
| Harassment and discrimination | The perception of the organization's commitment to control any inappropriate behavior toward a gender, race, or individual | Medium |
| Physical and psychological symptoms | The perception of challenges that workers face at work that increase stress and the likelihood of injuries | Medium |
| Exposure | The perception of exposure to hazards and hazardous condition on the job site | Low |

* See References [2, 4, 7, 9, 10, 12–22].

Because the academic literature is vastly dispersed and there is general lack of consistency in the usage of factors and associated questions to measure safety climate, there was a need to develop a scientifically validated ubiquitous survey tool to measure safety climate that is not a resource-intensive endeavor but applicable for all construction safety contexts. The meta-analysis results were used to prioritize the many possible dimensions of safety climate. Findings from meta-analysis showed that statistically, the most valuable dimensions of safety climate are *management's commitment to safety, supervisor's role in safety, training, safety rules and procedures, communication,* and *training.* Each of these dimensions is defined in Table 4-1; Appendix A provides a detailed review with a sample calculation of the meta-analysis procedure used to arrive at the result.

To be complete, two common and previously validated survey questions are provided for each safety climate dimension in Table A-3. As dimensions of safety climate were considered by industry partners, the list of questions was truncated to arrive at a survey of reasonable length that includes the dimensions and associated questions with the highest potential to be differentiators. The shortened survey is shown in Table 4-2. To represent the organization, safety climate responses may be averaged. The aggregate response of a large and representative sample of employees provides a characterization of current safety perceptions. In addition to elucidating strengths and weaknesses, the aggregate measures have shown repeatedly to be predictors of future safety performance.

**Table 4-2**
**Survey for safety climate***

| Please rate your level of agreement with the following statements: | | | | | |
|---|---|---|---|---|---|
| | **Strongly Disagree** | **Disagree** | **Neutral** | **Agree** | **Strongly Agree** |
| Management takes immediate and positive action when a safety concern is raised. | | | | | |
| Management considers safety to be equally important as productivity. | | | | | |
| Some health and safety rules are difficult to understand and follow. | | | | | |
| I follow all the correct procedures even if they take additional time. | | | | | |
| Risk-taking is unnecessary in any circumstance. | | | | | |
| I feel comfortable refusing to work in unsafe conditions. | | | | | |
| Safety training is effective and covers most situations that I encounter in work. | | | | | |
| Training sessions make me feel confident in my ability to identify and manage potentially hazardous work. | | | | | |
| My direct supervisor believes safety is very important. | | | | | |
| My direct supervisor engages regularly in safety-related activities. | | | | | |
| I am encouraged by my managers to provide input on job site safety, and my ideas are valued. | | | | | |
| I am adequately involved in safety planning, management, and new initiatives. | | | | | |

**Table 4-2 (continued)**
**Survey for safety climate***

| Please rate your level of agreement with the following statements: | | | | | |
|---|---|---|---|---|---|
| | **Strongly Disagree** | **Disagree** | **Neutral** | **Agree** | **Strongly Agree** |
| Management clearly communicates safety, near misses, and good catches to all levels within the organization. | | | | | |
| Management brings safety information and new initiatives to my attention. | | | | | |
| I often speak up and explain safety challenges to peers and supervisors. | | | | | |
| Work should be stopped immediately if a safety concern is identified. | | | | | |
| I am pushed to work faster than I would like. | | | | | |
| Some safety protocols get in the way of productivity targets. | | | | | |
| My coworkers are very skilled at their jobs. | | | | | |
| My coworkers are engaged and competent employees. | | | | | |
| I occasionally get into arguments with others at work. | | | | | |
| There are resources available to resolve interpersonal conflicts. | | | | | |
| My coworkers never take risks intentionally. | | | | | |
| My coworkers are willing to have conversations about safety. | | | | | |
| It is only a matter of time before I get injured on-site. | | | | | |
| I am aware of the safety risks involved in my job. | | | | | |
| In the past month, I experienced aggressive behavior from my coworkers or managers. | | | | | |
| Management acts effectively to manage harassment and discrimination. | | | | | |
| In the past month, I have generally been in poor health. | | | | | |
| In the past month, I feel active and alert at work. | | | | | |
| I am exposed to unreasonable hazards at work. | | | | | |
| I am exposed to uncomfortable environmental conditions at work. | | | | | |

* Note that some items will be reverse-scaled during analysis.

# 5
# LEADING INDICATORS

*Leading indicators* are the direct measures of the safety system that characterize the extent to which safety activities are adopted and implemented to prevent injuries [23]. Examples of leading indicators are job site orientation sessions, pre-task plans, near-miss and accident reporting, owner safety walk-throughs, safety incentive programs, and drug and alcohol testing [23, 24, 25]. Simply, leading indicators are the primary levers of safety change in an organization.

Leading indicators are usually characterized as either active or passive. *Passive leading indicators* are defined as the indicators that are implemented before activities on-site and remain generally stable across time. They are binary (for example, yes or no) measures of whether an organization is doing an activity or not. For example, a passive leading indicator could be the organization's adoption of a personal protective equipment (PPE) policy (for example, hard hat, steel toe boots, or fall protection) that applies broadly across projects. *Active leading indicators*, on the other hand, are measures of the implementation of specific safety activities and usually take the form of the frequency with which they are implemented. For example, the organization may measure the frequency of pre-job meetings, safety observations, or positive reinforcements of safety behavior. Unlike passive leading indicator data that take a binary form, active leading indicators are typically continuous variables. Figure 2-2 illustrates the practical differences between the two.

Most passive indicators inquire whether the organization implements a particular safety activity, and there are often corresponding active leading indicators that measure the frequency with which the activity is performed [26]. For example, a passive leading indicator would be the presence of a pre-job safety meeting; the corresponding active leading indicator would be the measure of how frequently pre-job safety meetings are performed. Although some passive leading indicators have an active counterpart, others—such as standard safety clauses in contracts—do not because they are not performed in discrete events [4].

The predictive nature of both passive and active safety leading indicators is well-established. In fact, researchers have performed longitudinal studies that confirmed the hypothesis that the frequency of some safety management efforts predicts future injury rates using empirical data across multiple industrial sectors. Although past researchers have most often measured leading indicators at the project level, small changes in the data collection instrument make the leading indicators relevant at the organization level. For example, on a project one may ask, how often are safety audits conducted on this project? The question may be transformed to an organization-level question by asking, how often are safety audits conducted on the average project? Some active leading indicators are measured as a frequency (for example, how often a safety activity is performed) while others are measured as a proportion (percentage of work with a specific safety activity performed).

The leading indicator dimensions identified through the literature review are summarized in Table 5-1. This table shows the predictive strength of general leading indicator types and applies broadly across both passive and active indicators. The predictive strength of each dimension was obtained by conducting another meta-analysis (procedure summarized in Appendix A). Only leading indicator dimensions with high and medium predictive strength are included. The passive leading indicators in Table 5-2 with a corresponding active leading indicator in Table 5-3 are denoted with (†), and passive leading indicators with an open-ended active leading indicator question are denoted with (††).

The specific questions targeted for measuring the passive leading indicators are included in Table 5-2, and the questions for active leading indicators are provided in Table 5-3 and Table 5-4. Note that some feasible leading indicators in each group are not included because they do not pass the inclusion criterion of being meta-analyzed to show potential as a differentiator. Some active leading indicators identified by industry partners but not yet apparent in existing literature are also included in these tables.

**Table 5-1**
**Dimensions of leading indicators***

| Dimension | Definition | Strength |
|---|---|---|
| Safety record | Reporting of safety-related incidents and observations | High |
| Safety resources | The availability of safety resources on a project | High |
| Upper management involvement | The participation level of management in safety-related activities on a project | High |
| Staffing for safety | Personnel dedicated solely to safety on a project | High |
| Training/orientation | Safety-related training and orientation sessions provided to workers on a project | High |
| Personal protective equipment | The availability of necessary PPE on a project | High |
| Incentives | Safety incentive programs for workers on a project | High |
| Safety inspections and observations | Conducting safety audits on a project | High |
| Pre-task safety meetings | Daily safety-related meeting with workers on a project | High |
| Upper management involvement | The participation level of upper management in safety-related activities on a project | Medium |
| Work planning and hazard analysis | Programs involving the identification, assessment, and control of job site hazards | Medium |
| Worker involvement | The participation level of workers in safety-related activities on a project | Medium |
| Substance abuse | Conducting random drug and alcohol tests on the work site | Medium |
| Safety data analysis | Methods employed to collect and analyze safety-related data | Panel |
| Other programs | Emerging safety programs | Panel |
| Work orders | Safety work order aging and completion | Panel |
| Corrective actions | Corrective action results | Panel |

* See References [4, 23–31].

**Table 5-2**
**Survey items for passive indicators assessment**

| Dimension | Passive Leading Indicator Questions |
|---|---|
| Safety record | Is a written or electronic report required for all incidents resulting in injuries including first aid?<br>Is it mandatory for personnel to report and record any near-miss incident?<br>Are accident investigations performed for all incidents including first aid and near misses?<br>Are the accident reports formally written and distributed among impacted personnel? |
| Safety resources | Are first aid kits and trained personnel available at all work sites?<br>Are workers provided with educational information on substance abuse?<br>Are workers provided with information on medical assistance to deal with work stress? |
| Upper management involvement | Does the upper management (for example, presidents, senior vice presidents, and vice presidents) participate in safety walk-throughs? †<br>Does the upper management attend safety orientation sessions? † |
| Staffing for safety | Is a minimum safety supervisor–to-worker ratio required and enforced? ††<br>Is every site supervised by a full-time safety professional? †† |
| Training/orientation | Are all workers required to attend safety orientation before starting work? † |
| Personal protective equipment | Do you enforce policies regarding 100% use of required PPE?<br>Does your organization provide all the required PPE to workers? |
| Incentives | Do you have a non-monetary safety incentive or recognition program? † |
| Safety inspections and observations | Do you have a safety observation program? †<br>Do you perform safety audits? †<br>Does the organization have a behavior-based safety program?<br>Does the organization have designated human performance staff or department? |
| Work planning and hazard analysis | Are comprehensive written safety plans required for all projects?<br>Are formal safety risk assessments or job hazard reviews performed during project planning and scheduling?<br>Are pre-task safety meetings required each day before work commences on a job site? ††<br>Does the organization have a formal prevention through design process where safety is explicitly considered? †† |
| Worker involvement | Is feedback on safety policies and procedures solicited formally from workers through a structured process? †<br>Are safety climate surveys conducted? †<br>Are workers or on-site supervisors involved in the development of safety policies/rules/policies? † |

**Table 5-2 (continued)**
**Survey items for passive indicators assessment**

| Dimension | Passive Leading Indicator Questions |
|---|---|
| Substance abuse | Are all workers in the company required to participate in a randomized drug and alcohol testing program? † |
| Safety data analytics | Does the organization track and act upon safety leading indicators?<br>Do you have dedicated staff who analyze safety-related data? |
| Other programs | Does the organization have a formal management of change program?<br>Does the organization have a "no discipline" safety observation program?<br>Does the organization have a just culture* program?<br>Does the organization have a contractor safety management program?<br>Does the organization record contractor near misses?<br>Does the organization recognize (monetarily or otherwise) the lagging indicators of safety performance of contractors?<br>Does the organization pre-qualify or disqualify contractors from work based on lagging indicators (for example, historical injury rates)?<br>Does the organization have and advertise a "zero injury" goal? |

* A "just culture" exists where an atmosphere of trust encourages individuals to provide information.

**Note:** The passive leading indicators in Table 5-2 with a corresponding active leading indicator in Table 5-3 are denoted with (†), and passive leading indicators with an open-ended active leading indicator question are denoted with (††).

**Table 5-3**
**Active leading indicator frequency questions**

| For the Organization as a Whole | Less Than Once per Month | Once per Month | Twice per Month | Once per Week | More Than Once a Week |
|---|---|---|---|---|---|
| How often does the average upper manager (president, SVP, VP) participate in a safety walk-through of an active work site? | | | | | |
| How often does an upper management representative participate in safety orientations? | | | | | |
| How often are safety training and orientation provided to the average worker? | | | | | |
| How often are injury-related monetary incentives/recognitions provided to the average worker? | | | | | |
| How often are injury-related non-monetary incentives/recognitions provided to the average worker? | | | | | |
| How often are safety observations performed for the average crew? | | | | | |
| How often are safety audits performed for the average crew? | | | | | |
| How often is safety feedback solicited from the average worker? | | | | | |
| How often are safety climate surveys administered with the average worker? | | | | | |
| How often does the average worker participate in the development of safety policies/rules/procedures? | | | | | |

**Note:** The passive leading indicators in Table 5-2 with a corresponding active leading indicator in Table 5-3 are denoted with (†), and passive leading indicators with an open-ended active leading indicator question are denoted with (††).

**Table 5-4**
**Active leading indicator proportion questions**

| | % |
|---|---|
| What percentage of workers are directly supported by a full-time safety professional? | |
| For what percentage of jobs are pre-job safety meetings performed? | |
| For what percentage of jobs are written job hazard assessments performed? | |
| For what percentage of safety policies/rules/procedures are workers involved in development? | |
| For what proportion of design elements do operators provide input? | |
| Approximately what percentage of workers pass random drug and alcohol testing? | |
| For what proportion of project design elements do field employees provide input? | |

# 6
# BUSINESS FACTORS

Although safety climate and leading indicators have been studied repeatedly (albeit independently) and linked to safety performance, studies have rarely considered the validity of business factors (for example, organizational structure, budget, contract type, and workforce characteristics) in differentiating safety performance. While some aspects of the business structure are relatively rigid and cannot be changed for the sake of safety (such as type of work performed, demographics of the workforce, and geographical location), others are actionable (for example, relationship between safety and the supply chain, safety reporting in the corporate structure). Therefore, the researchers divided business-related measures into two categories—the first, business factors are **actionable** and are within the scope of this study; the others are referred to as *control factors*, which are **not actionable** but may be necessary to assess in order to ensure consistent comparisons of organizations.

The dimensions of actionable business factors identified in the relatively dispersed body of literature are summarized in Table 6-1. Because the literature was sparse and dispersed, the research team and panel brainstormed additional factors to include in Phase 2 of this research. The questions associated with these business factors are included in Table 6-2 through Table 6-5. These dimensions, though based in theoretical underpinning, will require robust empirical validation to determine targeted strategies to improve safety performance.

**Table 6-1**
**Dimensions of business factors**

| Factor | Definition |
|---|---|
| Performance evaluations | Inclusion of safety-related considerations in the performance evaluations of upper management |
| Management stability | Changes in leadership |
| Liquidity | Financial flexibility through immediate access to funds |
| Safety in organizational structure | Representation of safety interests in the organizational structure |
| Safety R&D | Investment in research and development in safety |
| Technological change | The frequency with which new technology is introduced and personnel are given training for using it |
| Skilled workforce availability | The level of ease in finding and hiring required skilled personnel on a project |
| Customer relationships | Organization’s approach to maintaining positive relationships with customers |
| Subcontracting | Amount and type of work contracted in lieu of self-performance |
| Safety in the supply chain | How safety is managed with suppliers and vendors |
| Project delivery and procurement | Contracting and payment methods used to structure projects and relationships among project teams |
| Risk management | Maturity and robustness of identification, analysis, response, and management of organizational risks |
| Constructability | Performance of constructability reviews early in design and planning |
| Overtime | Prevalence of overtime and long work hours in current work |
| Life-cycle costs | The preparation and use of a life-cycle cost assessment for key decisions regarding investments on a project |
| Capitalization | The value of the company in USD and the total number of employees |
| Budgeting | Normalized budget for safety |
| Investment in R&D | The amount of investment made into research to improve different facets of the construction process |

**Table 6-2**
**Survey items for passive business factors**

| | Yes | No |
|---|---|---|
| Are injury rates specifically considered in the performance evaluation of managers? | | |
| Are leading indicator metrics used in the performance evaluations of managers? | | |
| Has there been a change in upper management (president, SVP, VP) in the last 6 months? | | |
| Has there been significant change in safety management or safety professionals in the last 6 months? | | |
| Has the liquidity of the organization increased by more than 20% in the last 6 months? | | |
| Has the liquidity of the organization decreased by more than 20% in the last 6 months? | | |
| Does the organization invest in research and development related to safety? | | |
| Are there new forms of automation and technology being introduced for field safety applications? | | |
| In the last 2 years, has it been unusually difficult to hire skilled trades workers? | | |
| Does the organization conduct customer satisfaction surveys? | | |
| Has the amount of subcontracted work increased by more than 10% in the last year? | | |
| Is safety explicitly and systematically considered in the management of the supply chain? | | |

**Table 6-3**
**Survey questions for active business factors**

| For your portfolio of projects and work orders: | Never<br>0% | Rarely<br>Less Than 20% | Sometimes<br>20% to 80% | Often<br>More Than 80% | Always<br>100% |
|---|---|---|---|---|---|
| How often do you use alternative project delivery methods (for example, design-build, construction manager at-risk*, integrated project delivery**)? | | | | | |
| How often do you use alternative procurement/payment methods? | | | | | |
| How often do you conduct formal risk assessments of assets, construction, operations, and maintenance? | | | | | |
| What percentage of major assets construction, operational, and maintenance projects is subcontracted? | | | | | |
| On what percentage of projects do you conduct formal constructability reviews as part of project design planning? | | | | | |
| On what percentage of projects do you conduct formal project close-out reviews? | | | | | |
| How often are crews working overtime? | | | | | |
| How often is the work understaffed? | | | | | |
| How often is a life-cycle cost assessment performed? | | | | | |

* *Construction manager at-risk* is an alternative project delivery type. In such arrangements, a management firm is hired to manage the project by the owner/client so the owner/client does not need to do so. It is more common with larger projects or where the client has limited bandwidth to directly oversee the contractor(s) performing the work.

** In integrated project delivery, a team is used that includes the architect, key technical consultants, general contractor, key subcontractors, owner, fabricators, building engineers, and others as the "master builder" working collaboratively through the construction process.

**Table 6-4**
**Injury information**

| For each of the last four quarters: | Q1 | Q2 | Q3 | Q4 |
|---|---|---|---|---|
| How many work-hours were performed? | | | | |
| What are the numbers of near misses? | | | | |
| What are the numbers of first aid injuries? | | | | |
| What are the numbers of recordable injuries? | | | | |
| What are the numbers of injuries resulting in days away from work, restricted duty, or transfer (DART)? | | | | |
| What are the numbers of serious injuries and fatalities? | | | | |
| What are the numbers of potential serious injuries and fatalities? | | | | |

**Table 6-5**
**Business demographics**

| | Business Demographics |
|---|---|
| What is the value of this company in USD? | |
| What is the organization’s approximate annual revenue? | |
| What is the organization’s approximate operating budget? | |
| What is the safety budget in your organization? | |
| What is the R&D budget for safety? | |
| How many personnel are staffed in the HR department? | |
| How many employees does the company employ? | |
| What proportion of customers has provided a positive response on a satisfaction survey? | |
| What proportion of the work is subcontracted? | |

# 7
# PILOT SUMMARY

The development of the data collection instruments focused on identifying safety climate, safety leading indicators, and business factors that differentiate safety performance. Using the scan from literature and statistical meta-analysis, the list of factors was converted into a series of data collection instruments. These included one survey on safety climate that is to be completed by front-line employees, one survey on safety leading indicators to be completed by safety professionals, and one survey on business factors to be completed by a cognizant representative of management.

Once finalized, the data collection instruments were pilot tested with one electric utility with transmission, distribution and generation assets. The pilot test was conducted over a four-week period in the months of November and December 2019, with analysis completed in January 2020. Two contacts at the company coordinated the data collection activity and assigned the respective surveys to samples of employees, safety professionals, and a senior safety leader. After the data were analyzed, a discussion was held between the researcher and the pilot coordinators to debrief on the results and the feasibility of the survey instruments.

## 7.1 Safety Climate Survey Results

In total, 46 paper responses were received for the climate survey from front-line employees. Of these, 27 provided a complete response and 39 answered at least 30 of the 32 questions. This response rate is considered strong given that the survey was voluntary and that no question was marked as mandatory. There were no discernable trends in which questions the participants answered and which were left blank.

Some survey questions were reverse-scaled. Some climate questions were stated in the positive (for example, "I am aware of the safety risks involved in my job.") while others were stated in the negative ("I am exposed to unreasonable hazards at work."). Reverse scaling was used to ensure that the participants read each question carefully and answered each question thoughtfully. The results indicate that many low-scoring climate questions were those that were reverse-scaled (that is, stated in the negative instead of the positive). This may indicate that some participants did not carefully read all the questions.

When analyzing the safety climate responses, averages and variance can be reported, which allows the analyst to identify the organizational strengths and weaknesses. Variance measures the agreement within the organizational sample. Both mean and variance are needed when testing for statistical differences within and among organizations. In addition to statistical tests to determine the differentiators of safety performance, each organization visualizes its own distribution of safety climate scores (see Figure 7-1). To preserve the privacy of the pilot organization, the x-axis was normalized by dividing the climate score by the maximum climate score obtained. This graph is provided to illustrate the distribution of the data received and shows the variance in the data received. The variance in responses is important because it shows the level of agreement among employees, which itself may be a potential differentiator of safety performance.

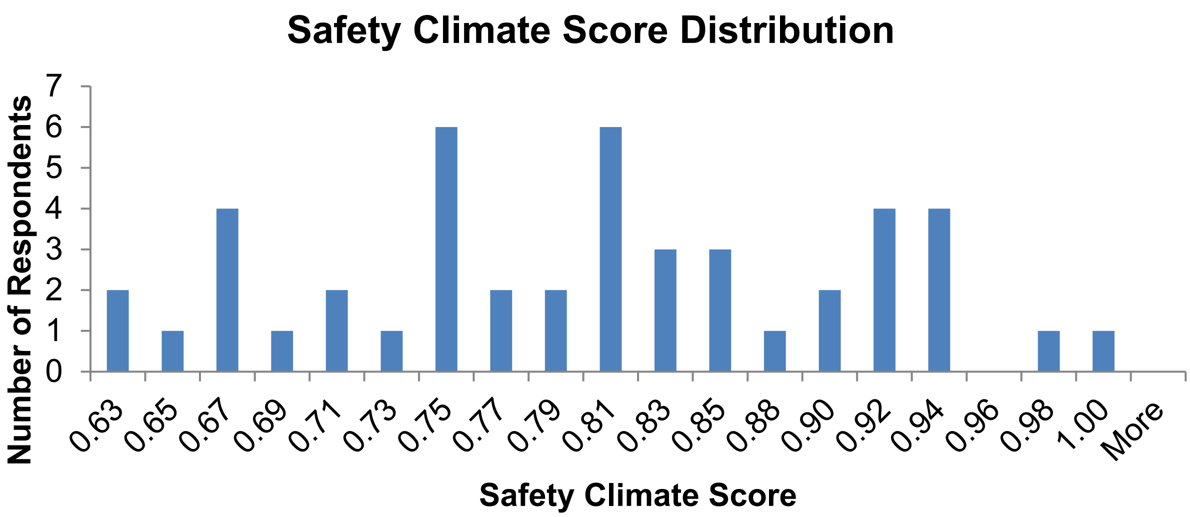


**Figure 7-1**
**Distribution of normalized safety climate scores for pilot test organization**

Regarding feasibility, the pilot organization indicated that the questions were easy to understand and there were no suggestions to change the wording. The survey required about 12–15 minutes of time, and the partners indicated that a paper survey for the front-line employees was necessary to promote the perception of confidentiality and to address some resistance to technology. The pilot organization also indicated that asking the employees to complete the survey at one designated time promoted a higher response rate.

## 7.2 Safety Leading Indicator Results

The safety leading indicator survey was completed by 10 safety professionals. These were embedded safety leaders, known within the organization as safety coordinators. For the first part of the survey (passive leading indicators), all questions were in a yes or no (dichotomous) format, and all questions were answered by all respondents. The second part of the survey included Likert-style questions on a 1 to 5 scale (categorical), and all questions were answered by all participants. The final part of the leading indicator survey included two open-ended questions. These questions were completed by approximately 80% of the respondents; most responses were one to three sentences in length. The open-ended questions require more time to answer but provide very rich information that explains the strengths and weaknesses that may be identified in the numerical analysis. Additional responses may be warranted if the organizations feel that the responses are valuable and worth the time investment.

The median response for all questions was considered to represent the pilot company. The most common responses (that is, median) are used to represent the business. For all yes or no questions, the percent agreement was reported, which can range from 50% (perfect disagreement in which half the respondents answered yes and the other half answered no) to 100% (perfect agreement in which all respondents indicated the same response). These data are important because they indicate the level of alignment among safety professionals regarding what safety management activities the organization does and does not perform. Ideally, the agreement would be close to 100% where all safety professionals are aware of the elements of the safety program. In fact, the level of agreement itself may be a possible differentiator of safety performance. It is important to note that disagreement may be the result of different safety professionals supporting different units of the business (for example, generation and transmission and distribution) that have different safety activities and programs. Therefore, in future data collection, the surveys should ask which unit of the business the safety professional supports.

The questions with 60% or less agreement are listed in Table 7-1. These items would be candidates for further discussion because safety professionals strongly disagree about whether the organization performs the activity. If the same questions appear to have low agreement across multiple case studies, this may indicate a flaw or inconsistency related to the question. However, no limitations in the question wording was noted by the pilot organization. Again, as noted by the pilot organization, differences shown in Table 7-1 may exist because the responding safety professionals support different units of the business.

**Table 7-1**
**Passive leading indicator questions with high variance**

| Passive Leading Indicator Question | Most Common Response | Percent Agreement |
|---|---|---|
| Is it mandatory for personnel to report and record any near-miss incident? | Yes | 60% |
| Are the accident reports formally written and distributed among impacted personnel? | No | 60% |
| Does the upper management attend safety orientation sessions? | No | 60% |
| Are comprehensive written safety plans required for all projects? | No | 60% |
| Is feedback on safety policies and procedures solicited formally from workers through a structured process? | Yes | 60% |
| Are safety climate surveys conducted? | Yes | 60% |
| Does the organization track and act upon safety leading indicators? | Yes | 60% |
| Do you have dedicated staff who analyze safety-related data? | No | 50% |
| Does the organization have a formal contractor safety management program**? | No | 50% |
| Does the organization recognize (monetarily or otherwise) the lagging indicators of safety performance of contractors? | No | 50% |

One section of the leading indicator survey inquired about the frequency with which key safety management activities were performed in the organization. The frequency options ranged from less than once per month to more than once per week. Nearly all responses for the pilot were less than once per month, indicating that further differentiation may be needed in the scale options to allow for greater differentiation across organizations or among business units in the same organization.

Regarding feasibility, the pilot organization noted that the survey required about 20 minutes to complete and that the coordinators required several reminders to complete the survey. To overcome this challenge, the pilot organization suggested that the survey be completed individually but in one setting when the coordinators are assembled for a meeting. Further, the high variability was likely the result of differing perceptions about whether the organization performed the activity as described. Despite this challenge, the pilot organization indicated that the wording in the survey was appropriate because it was general in nature and that different terminology across the industry will have to be reconciled by the future study participants. One final challenge was the wording related to the term *supervisor*. Given the wide variety of job titles and organizational structures, the term *supervisor* can take on many different meanings. The pilot organization suggested that any terms related to job function are clearly defined and that a statement be provided to note the objectives and expected outcomes of the study to motivate participants.

## 7.3 Business Factor Results

This section of the survey includes highly objective questions. The pilot organization completed all but two of these questions. Some questions are yes or no (dichotomous), some are on a Likert scale (categorical), and others are continuous responses. All key data needed to compute the dependent variables (for example, near-miss, recordable, serious injury and fatality [SIF], and fatality rates) were provided. Importantly, some data for SIFs were reported to be 0. If 0 is a common response, the statistical tests will be limited to dichotomization, where organizations with SIFs or fatalities are compared to those without. Two questions were left unanswered by the pilot organization: customer satisfaction survey results and proportion of work subcontracted. This information was not readily available to the coordinators of the pilot. However, later discussions revealed that these questions are answerable but that information was difficult for them to obtain. Future participating companies may have challenges for different questions depending on their data collection and storage methods. However, the researchers believe that this information is relevant to the conduct of the study and should remain in the study design.

The pilot organization indicated that discussions with five representatives within the company were required to obtain the responses because they relate to finance, organizational structure, customer service, human resources, and other factors generally not known by one individual. The pilot organization also noted that, without knowing the specific objectives of the study, some questions such as customer satisfaction seemed irrelevant. Therefore, it would be helpful to provide the executives with a brief summary of the study objective sand expected results. The organization noted that, although interesting, some of the business factors are not actionable—such as size of company and revenue. Therefore, the importance of these questions was questioned. Once explained, the pilot organization understood that these data would be needed for normalization of the data for other questions (for example, the safety budget will be defined as a proportion of revenue or operating budget) and that not every question was intended to be a differentiator.

## 7.4 Suggested Changes to Study Design

Based on the pilot study, the following changes are recommended for application in the full study planned for 2020 with 20 or more participating companies:

1. For all parts of this series of surveys, **respondents should indicate which major business unit they support (such as transmission/distribution or generation) so that differences among business units can be explored**. This is important, for example, when the business units have different safety programs and activities that would lead to significant variation in leading indicator measurements.
2. **Climate surveys should be completed electronically whenever possible.** As the volume of data increases substantially, it will not be feasible to collect and manually enter hundreds or thousands of paper survey responses. In addition, when handwriting or marking is unclear or if some surveys are left incomplete, errors may emerge that could compromise the validity of the results. However, because the pilot organization felt that the paper surveys offered greater perceived privacy and were easier to administer because of typical resistance to technology, the researchers should clearly communicate the strengths of electronic surveys (decreased data entry burden, ability to require complete responses, and increased privacy) and help address the weaknesses (for example, perceived lack of privacy and cumbersome administration). Given the relative strengths and weaknesses, the researchers will likely need to remain flexible with the data collection format.
3. **All questions in all surveys should be marked as mandatory.** As data are collected from multiple companies and the predictive validity of the various factors is studied, incomplete survey responses cannot be used because they compromise the internal validity of the research.
4. The survey directions should **clearly note that some questions are stated in the negative and some in the positive** and that every question should be read carefully so that the response can be included in the analysis.
5. Each safety climate dimension includes two questions. In the full rollout, **one question for each dimension should be stated in the positive and one question in the negative** (that is, reverse-scaled). Then, paired t-tests can be used to statistically test whether each respondent read and carefully answered each question. This test can be objective grounds to remove the data point to preserve data quality.
6. For the active leading indicator section, nearly all responses for the pilot were "Less than once per month." **This indicates that the scale provided needs to be shifted to less frequent to allow for better differentiation among organizations.** For example, the scale could be changed to more than once per month, once per month, once every other month, once every three weeks, and once per quarter.
7. **For the business factors section, the data collection coordinator should be aware that he or she will likely need to contact and seek information from many individuals.** This may include contacting organizational functions such as finance, human resources, and customer service among others.
8. **All surveys should include a brief statement of the objectives and expected results of the study so that participants can see the value for their time and effort**. This may motivate greater participation and attention to the surveys. In addition, a glossary will be needed to define certain terms, for example, *supervisor*.
9. **The survey duration should be one month in length**, which should encourage participation but not allow attention to lapse.

# 8 CONCLUSION AND RECOMMENDATIONS

Existing methods of safety prediction and differentiation are dispersed across many scientific domains ranging from safety to engineering. The first step of the study was to codify literature into themes. Three major families of safety differentiation emerged: perception of employees (climate), measures of the effort an organization makes to prevent injuries (leading indicators), and business factors. Although there is a wealth of information related to the capacity of safety climate and leading indicators to differentiate performance, there is a dearth of information about business factors. Further, previous studies examine these potential differentiators individually. The objectives of this study were to review available literature where empirical connections had been made between a measure of the safety system and performance, conduct a meta-analysis to identify the most promising differentiators, and create a complete but efficient survey instrument to measure the most promising differentiators.

The survey instruments and data collection protocols were reviewed by an industry panel and subsequently pilot tested with an EPRI-member investor-owned utility company. The results confirmed the feasibility of the methodology and planned Phase 2 study. A full study is planned in 2020 with 20+ companies to empirically determine which of the identified factors best differentiate safety performance. By collecting data simultaneously for safety climate, leading indicators, and business factors, the potential relationships among these factors can be statistically examined. For example, the productivity, efficiency, and structure of an organization can be considered alongside measures of safety activities and worker perceptions to make a leading safety assessment.

The result of such a study may elucidate the primary determinants of safety success and result in actionable recommendations. Finally, the results would allow for the objective reduction of the survey length for future assessment and benchmarking studies.

In addition to providing the methodology for the planned 2020 project, the safety climate assessment and the leading indicators described here may have immediate usefulness to EPRI-member companies. Because these metrics have been validated (as reported in Sections 4 and 5 of this report), EPRI-member companies may wish to compare their current climate assessment tool and leading indicators to those reported here and consider inclusion of metrics from this report in future assessments and analyses. Therefore, the results of this project have immediate applications to enhance current company approaches.

# 9
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# A
# META-ANALYSIS PROTOCOL

Meta-analysis is a robust statistical procedure that measures the strength of relationship (effect size and power) by leveraging the findings from multiple past empirically driven research [32]. By analyzing all relevant studies that have previously examined a relationship between two variables, we can model the nature of the relationship accurately and reliably.

Meta-analysis was performed by the following [33]:

1. Conducting a comprehensive literature search on published studies
2. Extracting information from relevant studies
3. Computing standardized effect sizes for each study to make them comparable
4. Computing the global effect size

The following sections provide details on how meta-analysis was used to determine the core dimensions of safety climate. This process was replicated to determine the key dimensions of leading indicators.

1. **Conducting a comprehensive literature search.** The objective of this step was to locate all published construction safety climate studies. The research was performed using a single or combined word such as *safety climate*, *construction safety*, *safety perception*, and *safety performance*. Our search of major scientific databases included Google Scholar, Web of Science; Engineering Village; PubMed; PsychInfo; and the American Society of Civil Engineering.
2. **Extracting information from relevant studies.** A total of 13 studies were included in the meta-analysis conducted in this report. Only 13 studies were included because not all published studies in safety climate a) were empirical, b) reported all necessary statistics, or c) examined the relationship between desired variables. In other words, studies that have qualitatively examined safety climate and studies that did **not** test relationship between dimensions of safety climate and injury rates cannot be used in meta-analysis. Table A-1 shows an example of how findings from selected studies were codified and recorded for statistical dissemination.

**Table A-1**
**Codification of studies for meta-analysis**

| Study ID | Author | Reference # | Safety Climate Level | Dependent Variable | N | Correlation (r) |
|---|---|---|---|---|---|---|
| 1 | Probst et al. | [34] | Project level | Injury rate | 985 | 0.28 |
| 2 | Marín et al. | [35] | Project level | Injury rate | 256 | 0.17 |
| 3 | Goldenhar et al. | [17] | Individual level | Self-reported injury | 408 | 0.15 |
| 4 | Cigularov et al. | [36] | Individual level | Self-reported injury | 235 | -0.11 |

Upon extraction of the relevant information from the 13 studies, the correlation values (that is, *r*) were transformed using Fisher transformation. This was done to avoid any skewness (asymmetrical; non-normal distribution of data) associated with the correlation values. Applying statistical procedures to data that are skewed is not recommended because it yields sub-optimal results. Data transformation is essential to handle skewness and, in this instance, is critical to accurately determine the corresponding effect sizes. Equation A-1 is used to transform *r* to Fisher's transformed *r* ($Z_r$):

$$Z_r = 1/2 ln\left(\frac{1+r}{1-r}\right) \qquad \textbf{Eq. A-1}$$

Here, $Z_r$ represents the Fisher's transformation of *r*, and *r* is the correlation coefficient.

The standard error of Fisher's ($Z_r$) can be calculated using Equation A-2:

$$SE_{Zr} = \left(\frac{1}{\sqrt{N-3}}\right) \qquad \textbf{Eq. A-2}$$

Here, $SE_{Zr}$ is the standard error of $Z_r$ and *N* represents the sample size for each primary study.

1. **Computing standardized effect sizes.** The purpose of the standardization step is to obtain a common denomination that allows us to compare *apples to apples*. Many studies report different forms of effect sizes, and they are not directly comparable. To determine a global effect size, we need all the individual effect sizes in the unit.

For example, if a study reported Kendall's rank correlation and all other studies reported correlations as Pearson's *r*, in that case, Kendall's rank correlation should be transformed to Pearson's *r* using Equation A-3:

$$\boldsymbol{r_{Pearson} = \sin(0.5\pi * r_{Kendall's\,rank})} \qquad \textbf{Eq. A-3}$$

1. **Computing the global effect size.** The last step is to calculate the global effect size. Here, the individual effect sizes from each study were aggregated to obtain the global effect size that would reveal the true strength of the relationship between the two variables we are interested in. Table A-2 shows the equations that are required to perform this step and obtain the global effect size of the relationship between any two variables of interest.

**Table A-2**
**Equations and their description used to calculate the overall effect size of the relationship between workers safety priority and injury rate**

| Number | Equation | Description |
|---|---|---|
| Eq. A-4 | $w_i = \left(\frac{1}{SE_i^2}\right)$ | This equation is used to assign a weight to each study where $SE_i$ is the standard error for each individual study (calculated based on Equation A-2). Each study is weighted with the inverse of its standard error so that **studies with low error** (that is, higher accuracy) **receive more weight** in the computation of the global effect size [32, 33]. |
| Eq. A-5 | $\overline{ES} = \frac{\sum(w_i Es_i)}{\sum(w_i)}$ | The weighted average effect size that shows the overall effect size, where $w_i$ is the weight for study *i* (calculated using Equation A-4), and $Es_i$ is the effect size calculated from individual studies ($that\ is, Zr$ calculated based on Equation A-1*).* This is the general equation where the aggregated product of weight of individual studies and corresponding effect size is divided by the aggregated weight of the individual studies [33]. |
| Eq. A-6 | $Q = \sum(W_i\, ES^2{}_i) - \frac{(\sum(W_i\, ES_i))^2}{\sum W_i}$ | This equation is used to estimate the heterogeneity among included effect sizes. *Heterogeneity* measures the degree of agreement in findings between studies included in the meta-analysis. In other words, this equation explains whether all the included studies in the meta-analysis were measuring the same effect. Here *Q* = heterogeneity statistic; $w_i$ = weight of study *i*; and $ES_i$ = effect size estimate of the study. For example, in this report, for the relationship between worker safety priority and injury rate, a heterogeneity value of 2.70 was obtained—indicating a high degree of agreement between the studies included in the meta-analysis [33]. |
| Eq. A-7 | $\tau^2 = \frac{Q-(k-1)}{(\sum W_i) - \frac{(\sum W_i^2)}{(\sum W_i)}}$ | Between studies included in meta-analysis, the variance in the effect sizes parameters can be significant. The difference or variance is noted as $\tau^2$, which describes the true statistical distribution of effect sizes (strength of relationship). Consequently, the square root of this term reveals the standard deviation of the effect sizes across the studies that have been included in meta-analysis. Here, $\tau^2$ is random variance, $Q$ is the heterogeneity statistic, $k-1$ is the degrees of freedom of $Q$, *k* represents the number of included studies, and $W_i$ represents the weight for each individual study. For example, in this report, for the relationship between worker safety priority and injury rate, a value of 0.004 was obtained—indicating that there is negligible variance among studies included in this report [33]. |
| Eq. A-8 | $w_i = \left(\frac{1}{\tau^2 + SE_i^2}\right)$ | The weight given to an individual study using Equation A-1 is sufficient only for the fixed-effect model (that is, assuming that all the included effect sizes are identical), which might not be an accurate assumption for 100% of the cases. Therefore, a new weighted average effect size is calculated for the random effect model (that is, assuming that the included effect sizes are different from one study to another). Equation A-8 is used to calculate the weight for each random effect sizes, where $w_i$ is the weight for individual studies, $\tau^2$ is the random variance of the heterogeneity test (that is, Equation A-7), and $SE_i$ is the standard error of the effect size estimate for study *i* [37]. |

Table A-3 shows a sample of final relevant results obtained by following the steps outlined in Table A-2.

**Table A-3**
**Fixed and random effect calculation procedure for the relationship between workers safety priority and injury rate**

| Reference Number | Fixed-Effect Model | | | | Random Effects Model | | | |
|---|---|---|---|---|---|---|---|---|
| | $w_i$ | $w_i$ (%) | $w_i * Z_r$ | $(w_i * Z_r^2)$ | $w_i^2$ | $w_r$ | $w_r$ (%) | $w_i Es_i (w_r * Z_r)$ |
| [34] | 982 | 79.5 | 282.50 | 81.27 | 964,324.0 | 190.01 | 60.9 | 54.66 |
| [35] | 253 | 20.5 | 43.43 | 7.46 | 64.009.0 | 121.99 | 39.1 | 20.94 |
| **Sum** | **1,241.00** | **100** | **325.93** | **88.72** | **1,028,33.0** | **312.01** | **100** | **75.60** |

**Note:** $w_i$ = study weight (fixed-effect model); $w_r$ = study weight (random effects model).

To calculate the overall effect size for the relationship in Table A-3, Equation A-9 was used:

$$\overline{\boldsymbol{ES}} = \frac{\sum(\boldsymbol{w_i Es_i})}{\sum(\boldsymbol{w_i})} \quad \textbf{Eq. A-9}$$

Once the overall effect size has been determined, it needs to be transformed back to correlation value (*r*) when reporting the final meta-analysis results using Equation A-10:

$$\boldsymbol{r} = \left(\frac{\boldsymbol{e^{2z_r} - 1}}{\boldsymbol{e^{2z_r} + 1}}\right) \quad \textbf{Eq. A-10}$$

This explained meta-analysis procedure was replicated for each relationship between safety climate dimensions and safety performance, and the result of these individual meta-analysis have been detailed in Table A-4. **Results were considered statistically significant when p-value was determined to be equal to or less than 0.05.**

**Table A-4**
**Effect size findings summary: safety climate**

| Relationship | | K | N | Effect Size | 95% CI (CL-CU) | | p-value |
|---|---|---|---|---|---|---|---|
| Workers' safety priority | Injury rate | 2 | 1241 | 0.24 | 0.13 | 0.34 | 0.00 |
| Management commitment | Injury rate | 5 | 1755 | 0.16 | 0.03 | 0.28 | 0.01 |
| Supervisors' safety role | Self-reported injury | 4 | 3176 | 0.24 | 0.10 | 0.38 | 0.00 |
| Management commitment | Self-reported injury | 6 | 3293 | 0.23 | 0.19 | 0.26 | 0.00 |
| Supervisors' safety role | Injury rate | 4 | 1806 | 0.26 | 0.13 | 0.38 | 0.00 |
| Coworkers' safety role | Injury rate | 3 | 943 | 0.26 | -0.08 | 0.31 | 0.11 |
| Safety rules and procedure | Self-reported injury | 5 | 2856 | 0.17 | 0.04 | 0.30 | 0.01 |
| Communication | Self-reported injury | 3 | 1460 | 0.17 | -0.08 | 0.58 | 0.07 |
| Communication | Injury rate | 2 | 1241 | 0.14 | -0.08 | 0.34 | 0.11 |
| Training | Self-reported injury | 3 | 1633 | 0.08 | 0.03 | 0.14 | 0.00 |
| Workload pressure | Self-reported injury | 2 | 1225 | 0.36 | -0.25 | 0.76 | 0.13 |
| Individual responsibility | Self-reported injury | 2 | 1198 | 0.17 | 0.06 | 0.27 | 0.00 |

**Note:** *k* = number of studies, *N* = sample size, *r* = overall effect size, *95% CI* = confidence interval (lower-upper) around *r*.

Table A-5 presents an effect size findings summary for active and passive leading indicators.

**Table A-5**
**Effect size findings summary: active and passive leading indicators**

| Relationship | | K | N | Effect Size | 95% CI (CL-CU) | | p-value |
|---|---|---|---|---|---|---|---|
| Safety inspections and observations* | Injury rate | 2 | 1,608 | 0.51 | 0.30 | 0.67 | 0.00 |
| Pre-task safety meetings* | Injury rate | 2 | 875 | 0.45 | 0.32 | 0.57 | 0.00 |
| Safety record | Injury rate | 2 | 42 | 0.56 | 0.20 | 0.79 | 0.00 |
| Safety resources | Injury rate | 2 | 71 | 0.48 | 0.28 | 0.65 | 0.00 |
| Owner involvement | Injury rate | 2 | 42 | 0.45 | 0.16 | 0.67 | 0.01 |
| Staffing for safety | Injury rate | 3 | 111 | 0.44 | 0.12 | 0.68 | 0.02 |
| Training/orientation | Injury rate | 2 | 1,254 | 0.42 | 0.10 | 0.66 | 0.00 |
| Personal protective equipment | Injury rate | 2 | 71 | 0.40 | 0.17 | 0.58 | 0.00 |
| Incentives | Injury rate | 3 | 1,338 | 0.30 | 0.15 | 0.43 | 0.00 |
| Safety inspections and observations | Injury rate | 4 | 168 | 0.27 | 0.12 | 0.41 | 0.00 |

**Note:** * = active indicators, *k* = number of studies, *N* = sample size, *r* = overall effect size, *95% CI* = confidence interval (lower-upper) around *r*.

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