

INGAA
FOUNDATION

**Implementation of Standardized Leading
Safety Indicators in Contractor Safety
Management Programs**

TABLE OF CONTENTS

- Introduction 3
- Purpose and Applicability 4
- Approach and Methodology 5
 - Building Forward from Previous LSI Efforts 5
 - Collaboration across the industry in North America 5
 - Selection of Leading Safety Indicators 6
- Recommendations 8
 - Calculating Leading Safety Indicator Metrics..... 8
 - Pre-Qualification Phase..... 9
 - In-Job Monitoring..... 10
 - Post-Project Evaluation..... 10
 - Training 11
- Definitions..... 12
 - Responsibilities 13
- References 14
- Appendix A: *The Statistical Invalidity of TRIR as a Measure of Safety Performance* 15



INTRODUCTION

The INGAA Foundation has recognized the need for the construction industry to embrace leading indicators if it is to take substantive steps toward the reduction of serious injuries and fatalities. The publication of Leading Safety Indicator Program Guidance (CS-G-08) and Guidance for Serious Injury and Fatality Prevention (CS-G-09) have laid the groundwork for this critical evolution.

This report seeks to focus and standardize several key leading safety indicators (LSIs) that may serve as comparable and benchmarkable metrics in contractor safety performance evaluation. By selecting and defining a subset of leading indicators that serve as shared, standardized metrics, operators and construction services companies have a viable path away from over-reliance on lagging safety indicators such as Total Recordable Injury Rate (TRIR) and Experience Modification Rate (EMR), toward a future of safety performance management that is more supportive of the prevention of significant injuries and fatalities.



PURPOSE AND APPLICABILITY

As noted within the Leading Safety Indicator Program Guidance (CS-G-08), relying primarily on Total Recordable Injury Rate (TRIR) and other lagging safety indicators to assess contractor safety competence is highly problematic. TRIR has remained the dominate safety metric used to compare organizations, projects, year-over-year performance, etc., because it is a well-established, readily standardized metric shared by owner/operators, contractors, and government regulators. This paper aims to advance safety leading indicators to achieve the same degree of shared, standardized, and benchmarkable qualities of TRIR.

As such, this report was written with an eye toward Contractor Management Programs used for some of the highest profile construction applications in our industry: large capital expansion and maintenance construction programs. The metrics and the processes into which they are inserted (i.e., pre-qualification, in-job monitoring, post-project evaluation) were selected to enable the collective adoption of key leading safety indicators and their integration into shared industry practices. However, this does not preclude the adoption of these metrics, or the principles and approaches contained herein to other safety programs or contractor management programs. The report also speaks generally to “what good looks like” when building safety management systems and conforming to best practices with respect to management systems elements related to safety metrics, safety performance measurement, and contractor safety management.

APPROACH AND METHODOLOGY

Building Forward from Previous LSI Efforts

The case for leading safety indicators (LSI) has been set out within the Leading Safety Indicator Program Guidance CS-G-08. That guidance document also provided a library of LSIs in use across the INGAA Foundation membership that met the Guidance criteria. It encouraged and gave guidance to pipeline construction companies to initiate in-house leading safety indicator programs. It also suggested pipeline operator companies encourage these developments by requesting LSI programs and extending preferential treatment to construction companies with LSI programs with respect to judgements of safety capability, such as bid evaluations.

This document takes the next step and sets out a path forward for the industry to fully operationalize LSIs within Operators' Contractor Safety Management Systems. The goal is to go beyond merely encouraging LSI adoption, to actively incentivize LSI usage by integrating LSI's into Operators' Contractor Safety Management practices including:

- Contractor pre-qualification processes
- In-Job oversight
- Post-project evaluations

To operationalize LSIs within Contractor Safety Management processes, it was essential to choose the best leading indicator candidates for this particular use case (see References). A good LSI for an individual company may not necessarily make for a good LSI as an industry-wide model. Training, for example, is a good internal leading safety indicator but is a poor industry-wide LSI because it varies so much from organization to organization. In other words, the goal of this guidance is to establish core industry-wide LSIs. This does not preclude the use of additional LSIs internal to a company or added to specific projects where particular leading safety activity measurements are valued by the client. The selection approach described below was designed to arrive at indicators that were simple, practical, evidence-based, comparable, and adaptable to most existing contractor management processes and systems. Simplicity, practicality, and the ability to standardize the metric were viewed as essential to widespread adoption.

Collaboration across the industry in North America

Experience and history at the INGAA Foundation and CEPA Foundation indicate that the successful completion and adoption of any approach is dependent on the diversity and level of interest of various parties engaged in the development. This implementation will only be operationalized through collaboration between Contractors, Owners, Safety Information Management Platform Providers, and Technical Experts. To this end, the following list of companies were parties to the creation of this paper.

Company	Classification	Member
Boardwalk Pipelines	Owner-Operator	Clay Kennedy
CEPA Foundation	Canadian Industry Association	Rick Tofani
Cheniere	Owner-Operator	Seth Washington
Construction Safety Research Alliance	Technical Advisor	Dr. Matt Hallowell
Enbridge	Owner-Operator	Andy Reimer
ISN Software Corp.	Service Provider	Duane Duhamel
Kinder Morgan	Owner-Operator	Lee York
Michels	Mainline Contractor	Nate Healy
Quanta Services	Mainline Contractor	Sage Babin
TC Energy	Owner-Operator (co-leader)	Victor Flores
TC Energy	Owner-Operator	Skylar Anderson
Triad Solutions	Project Coordinator	Ramsey Robertson
Veriforce	Service Provider	Josh Ortega
Williams	Owner-Operator	John Todd
Wolfcreek	Mainline Contractor (co-leader)	Brad MacLean

The earliest decisions made by this group were to proceed with some form of implementation of LSIs as a metric within standard Contractor Safety Management Programs as practiced by industry operators typically via Safety Information Management Platform Providers. Furthermore, there was a desire to provide a model that diminished the dominance of lagging metrics. In alignment with the principles of design outlined below, the decision was that these metrics would be applied across the lifecycle of Contractor Safety Management and include pre-qualification, in-job oversight, and post-project evaluation.

This then set the stage for the bulk of the work which involved selecting and defining the best LSI candidates for this application. The goal was to arrive at a short-list of LSIs that were appropriately defined, simple, balanced, broadly applicable, and validated as supportive of Significant Injury and Fatality (SIF) prevention (CS-G-09). Furthermore, they also needed to be scale-able from small to large projects or companies with more mature safety management systems.

Selection of Leading Safety Indicators

Beginning with a set of twelve LSI's (whose selection was informed by CS-G-08, the professional experience of the task team, and the research of Dr. Matt Hallowell), the full group engaged in a survey exercise designed by Dr. Hallowell where each were evaluated based on the criteria below. The twelve LSI's evaluated by the team were:

- Safety Observations,
- Safety Audit Scores,
- Project Management Team Site Visits,

- Leadership Site Visits,
- Pre-Job Safety Briefs,
- Job Safety Analysis,
- Housekeeping Programs,
- Safety Self Assessments,
- Corrective Actions,
- Frequency of Drug Tests,
- Mental Wellness Programs, and
- Physical Wellness Programs.

The survey criteria used:

- Is it Measurable, Consistent, Actionable, Positive, Unidirectional, Predictive? (refer to 5.1.5 in CS-G-08 for further details on each of these qualities)
- Can it be standardized?
- Does this activity have the same general meaning and implementation across all companies?
- Is it a differentiator? (e.g., because drug testing is managed under statutory requirements it does not serve as a strong differentiator)

A robust consensus emerged that the following three LSIs would serve as the best candidates across the lifecycle of contractor safety management were proposed to become a Standardized Index of LSIs for adoption by the industry:

- Pre-Job Planning Briefs (may be known and referred to as JSAs, FLHAs, or other acronyms)
- Safety Observations
- Leadership Engagements

The final task was to develop concrete recommendations on how to operationalize these three LSIs within the demands of existing Contractor Safety Management programs. The outcome of those efforts is captured in the following recommendations.

RECOMMENDATIONS

Operators and Contractors should adopt the use of a Standardized Index of LSIs for Pre-Qualification, In-Job Monitoring, and Post-project Evaluation. This allows for cross-company comparisons, performance benchmarking, and consistent decision-making. The Standardized Index set out in this document should be considered as a necessary starting point. It should be revisited and updated periodically to stay current with construction safety performance metric research and as industry performance against the Index metrics becomes optimized over time.

Note: These criteria were developed and piloted for a similar purpose by the Edison Electrical Institute (EEI).

Calculating Leading Safety Indicator Metrics

Pre-Job Planning Briefs (e.g., JSA)

A Pre-Job Planning Brief is prepared and reviewed with a work crew before a specific work activity is conducted. They must identify hazards (real and potential) that are, or may be, present at the specific work location under current environmental conditions (weather, external impacts, etc.) and to prescribe the appropriate mitigation of the identified potential hazard(s).

To be “counted” in the Index, a pre-job planning brief must be *objectively assessed or verified* to include all the minimum quality elements listed below:

- Job Location - Enough information to summon emergency response personnel.
- Job Task - Enough information for a knowledgeable person to understand which overall task is being performed.
- Hazard Identification - Multiple specific hazards are identified that are linked to the job task.
- Mitigations/Controls: At least one specific control or mitigation identified for each hazard. Generic language (e.g., awareness, watch out for, discussed) does not suffice as a specific control or mitigation.
- Clearly identified person in charge.
- Emergency response plan that is appropriate for the task and location.

Metric: Number of Pre-Job Planning Briefs conducted per 200,000 worker hours (frequency).

Safety Observation Reports

These are documented observation reports produced by direct formal observation of a work site to identify the presence of controls, behaviors, and the use of safe work practices. For example, inspections are included but peer-to-peer observations are not.

Metric: Number of Observation Reports per 200,000 worker hours (frequency).

Leadership Site Engagements

A Leadership Site Engagement involves the following:

An identifiable leader (i.e., someone with influential status), visiting a work location that they are not routinely at or assigned to, engaging with field/craft employees for the purpose of promoting safety and/or creating motivation towards safe work, and learning from and supporting field staff in matters related to safety. These range in scale from a visit with an individual crew to a large “all hands” weekly safety meeting.

Metric: Number of Leadership Engagements conducted per 200,000 worker hours (frequency).

Pre-Qualification Phase

Pre-Qualification practices vary based on operator, contractor, project scope, etc. However, industry standard practice includes, at minimum, a (typically comparative) review of contractors’ historical performance metrics and disclosure of written safety programs and policies.

The two most common Safety Information Management Platform Providers used across the US pipeline industry allow contracting companies to provide evidence of meeting pre-qualification criteria set by hiring companies, typically with some form of verification and scoring provided by the platform to facilitate contractor pre-qualification. According to rough analysis of our industry by Veriforce and ISN Software Corporation, approximately 30% of this scoring algorithm is reserved for safety performance metrics. Typically, those metrics are Total Record Injury Rate (TRIR), Experience Modification Rate (EMR), Lost Time Injuries (LTI’s) and/or Days Away Restricted or Transferred (DART). This paper is focused on that 30% of pre-qualification scoring traditionally reserved for Lagging Safety Indicators. The remaining approximately 70% of the scoring algorithm is reserved for safety program descriptions, Certificates of Insurance, Fatalities, etc. The latter (approx. 70%) portion is deemed out-of-scope for this paper.

It is recommended that any lagging safety indicators used in Pre-qualification be counter-balanced with double the weighting of leading safety indicators (i.e., the Index weighted twice the lagging safety indicator value). This 2:1 ratio has been validated by research (Oguz Erkal, E. D. (2022). Predicting Serious Injury and Fatality Exposure in Construction Industry. University of Colorado Boulder, Boulder, Colorado). Other research has definitively discredited the use of TRIR as a predictor of future safety performance (see Appendix A: “The Statistical Invalidity of TRIR as a Measure of Safety Performance”). While specific guidance on lagging safety indicator categories or weighting was considered for this paper, it was deemed too complex and unnecessary if the recommended 2:1 ratio is maintained. In other words, using the 2:1 ratio would reduce any single lagging safety indicator (e.g., TRIR) to a minimal overall impact for pre-qualification judgements. For example, if 5% of a pre-qualification score is committed to TRIR and 5% of a pre-qualification score is committed to EMR, 20% should be committed to the Leading Safety Indicator Index.

For the purposes of Pre-Qualification, the Index uses the frequency experience of the contractor for the previous 3 years.

In-Job Monitoring

It is recommended the Index also be used to measure safety performance of construction contractors during in-job performance, with the following notes:

The Leading Safety Indicator data collected and judged during In-Job Monitoring would only be for data generated during the performance of current active project work.

The 2:1 ratio of the Index to Lagging Safety Indicators referenced for Pre-Qualification does not apply for In-Job Monitoring. Although Lagging Safety Indicators are still important data to collect and learn from, indicators such as TRIR or LTI are subject to the same challenges that are cited for statistically rare data (see Appendix A: “The Statistical Invalidity of TRIR as a Measure of Safety Performance”). As such they should NOT be used for safety performance measurement of projects with less than tens of millions of exposure hours.

While there may be other relevant and appropriate leading safety indicators that could be identified for a given project (see CS-G-08), this paper strongly recommends maintaining the Index as the core to all safety performance measurement models to allow for consistent cross-company comparisons, performance benchmarking, and informed decision-making.

Post-Project Evaluation

It is recommended the same Index of three Leading Indictors used to measure safety performance of construction contractors during post-project evaluations. As with In-Job monitoring, the Leading Safety Indicator data collected and judged during Post-Project Evaluations would be for data generated during the performance of just completed project work and should be used as an important input to safety-capability judgements for future work.



Training

Organizations implementing the principles of this paper need to educate key stakeholders along the full life cycle of their respective Contractor Management Programs. The creation and support of organizational incentives to operationalize and develop LSIs according to this report are essential for sustainability of the approaches and the promise of SIF reduction described herein. The training required will depend on the specific stakeholder and falls into one of the following topical areas:

- Training on the principles of leading vs lagging indicators including the scientific literature that points to the necessity of a shift towards leading indicators.
- Training on this paper, ensuring understanding of all content.
- Training those administrating this from the owner/operator standpoint (i.e. prequalification, in-job monitoring, and post project evaluation).
- Training those administering this from the contractor standpoint.

DEFINITIONS

Lagging Indicators: Lagging indicators are measurements and data from the past. They are reactive in nature and measure how many people were injured and how severely over a specified period of time. These indicators are the bottom-line descriptors of safety within an organization; however, they do not provide a strong method of determining the overall safety capability of a company or future performance, which severely limits the utility of lagging indicators for safety comparisons or forecasts. But, without such information, organizations would not know if their safety efforts ultimately yield long-term improvements in the target objective: completing long periods of work without incident.

Leading Indicators: There is no single definition of a safety leading indicator and the use of the term is inconsistent and hotly debated. In this paper, the definition set forth by Construction Industry Institute (CII) was adopted, which defines leading indicators as, “Safety-related practices or systems that can be measured during work and trigger positive responses.” Here, it is contended that leading indicators are not simply predictors; rather, they are measures of the activities that yield future performance. In other words, safety leading indicators are more than just predictive, they are the proactive agents of change.

Predictive: Predictive validity is the extent to which a score on a scale or test predicts scores on some criterion measure. The goal of a leading indicators program is to invest time and resources in the safety activities that afford the best chance of future success. As such, the best indicators are those that have shown correlation through predictive validity.

Pre-Qualification: The process performed by companies to evaluate a contractor’s performance before they may execute a project. Typically, this includes the evaluation of safety performance as part of the process.

Project Oversight: The process performed by companies to evaluate a contractor’s safety performance during a project. This should involve the use of leading indicators only (see section 6.5.1).

Post-Project Evaluation: The process performed by companies to evaluate a contractor’s safety performance after the conclusion of a project. This should include a mechanism to provide input into the pre-qualification process for future evaluation considerations.

Pre-Job Planning Briefs (e.g., JSAs, FLHAs): A Pre-Job Planning Brief is prepared and reviewed with a work crew before a specific work activity is conducted. They must identify hazards (real and potential) that are, or may be, present at the specific work location under current environmental conditions (weather, external impacts, etc.) and to prescribe the appropriate mitigation of the identified potential hazard(s).

Safety Observation Reports: These are documented observation reports produced by direct formal observation of a work site to identify the presence of controls, behaviors, and the use of safe work practices. For example, inspections are included but peer-to-peer observations are not.

Leadership Site Engagements: A Leadership Site Engagement involves the following:

- An identifiable leader (i.e., someone with influential status), visiting a work location that they are not routinely at or assigned to, engaging with field/craft employees for the purpose of promoting

safety and/or creating motivation towards safe work, and learning from and supporting field staff in matters related to safety.

- These may range in scale from a visit with an individual crew to a large “all hands” weekly safety meeting.

Safety Information Management Platform (e.g., ISN Software Corporation, Veriforce, etc.) – Third party systems that allow contracting companies to provide evidence of meeting pre-qualification criteria set by hiring companies, typically with some form of verification and scoring provided by the platform to facilitate contractor pre-qualification. A contractor’s safety performance metrics are typically a required and scored element and as such will affect their status with hiring companies when bidding on projects.

Responsibilities

Health and Safety Professionals

- Provide support and assistance (training if needed) in developing and implementing leading indicators and the tracking thereof,
- Perform routine audits to ensure consistency and quality of the data being inputted and/or collected in support of the organizations leading indicators,
- Review program routinely and identify successes and/or improvement opportunities and report those to organizational and program leaders. Consider lagging indicators when measuring overall effectiveness of leading indicators program.

Organizational Leaders

- Participate in the development and implementation of a leading indicator program,
- Support and enforce the leading indicator program(s) and hold supervisors accountable for their contributions to the program,
- Review program and product(s) of said program to ensure continuous improvement as an organization.

Transmission Pipeline Operators and Supply Chain Personnel

- Support leading indicators and the role they play in gauging a company’s potential performance,
- Utilize leading indicators balanced with lagging indicators as part of bid evaluation to measure performance and performance capabilities of contractors and service providers.

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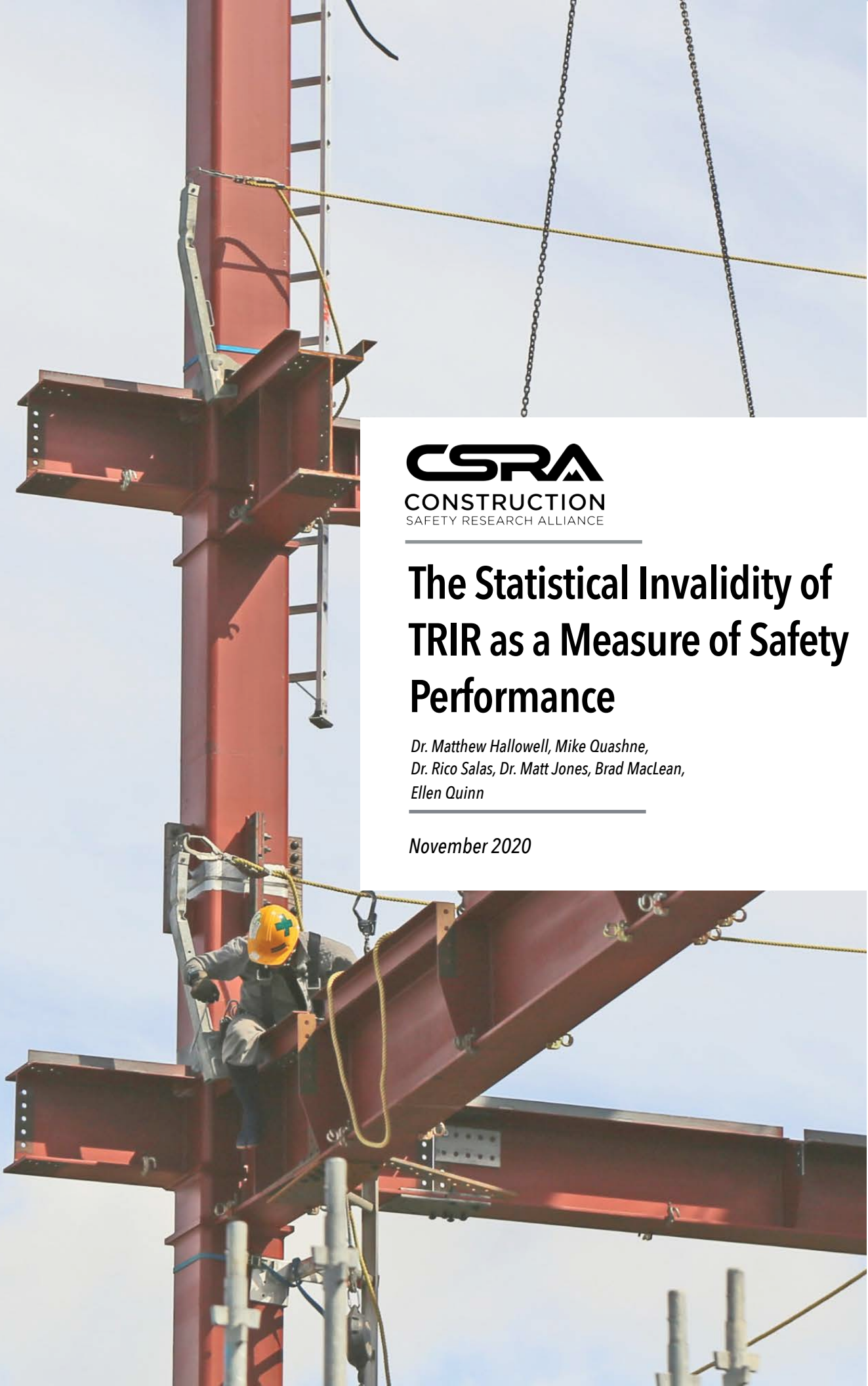
*APPENDIX A: THE STATISTICAL INVALIDITY OF TRIR
AS A MEASURE OF SAFETY PERFORMANCE*



The Statistical Invalidity of TRIR as a Measure of Safety Performance

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Key Take-Aways

Parametric and non-parametric statistical analysis data revealed that:

01.

There is no discernible association between Total Recordable Incident Rate (TRIR) and fatalities;

02.

The occurrence of recordable injuries is almost entirely random;

03.

TRIR is not precise and should not be communicated to multiple decimal points of precision; and

04.

In nearly every practical circumstance, it is statistically invalid to use TRIR to compare companies, business units, projects, or teams.

17 YEARS OF

DATA &



TRILLION WORKER HOURS



Introduction

“ *Given the way that it's used, to what extent is TRIR statistically valid?* ”

Total recordable incident rate (TRIR) has been used as the primary measure of safety performance for nearly 50 years. Simply, TRIR is the rate at which a company experiences an OSHA-recordable incident, scaled per 200,000 worker-hours. TRIR is based upon a standard definition of a “recordable” incident that was created and institutionalized in the recordkeeping requirements of the Occupational Safety and Health Act of 1970 (US Bureau of Labor Statistics 2019). According to the general criteria, an incident is recordable if it results in work-related injury or illness involving loss of consciousness or requiring medical treatment beyond first aid, days away from work, restricted work, or transfer to another job (US Department of Labor 2010). Since organizations conform to this same definition, the TRIR metric has been used to compare industries, sectors, companies, and even projects.

TRIR is used in many ways to measure safety performance, from the worksite to the board room. For example, organizations use TRIR to report results, benchmark against peers, prequalify and select contractors, evaluate the performance of managers, and track the impact of safety initiatives (Lofquist 2010; Manuele 2008; Wilbanks 2019). TRIR is also a primary safety metric of concern among executives because it may impact worker's compensation insurance premiums, influence public image, and be scrutinized by potential customers or investors (Karakhan et al. 2018; Lingard et al. 2017; Lofquist 2010; Ritchie 2013; Salas 2020; Truitt 2012). Although other lagging measures like the Days Away; Restricted; Transferred (DART) rates are also considered, no safety metric is as ubiquitous as TRIR.

Despite the pervasive use of TRIR, its limitations are being recognized. For example, some argue that TRIR is a poor reflection of safety performance because it does not account for the actual or potential severity of an incident (Toellner 2001). For example, a four-stitch cut to the finger is counted in the same way as a fatality, and a near miss with the potential to be fatal is not in the TRIR metric at all. Others point out that TRIR is reactive in nature as it only counts incidents and does not consider the underlying safety program (Lingard et al. 2017; Lofquist 2010; Salas and Hallowell 2016).

More recently, some have begun to question the statistical validity of TRIR, suggesting that recordable injuries happen so infrequently that the metric is not stable or reliable. Since TRIR is typically reported over relatively short time frames (i.e., months, quarters, or years), the number of recordable injuries in each period can be exceedingly small. Therefore, it is suspected that the confidence interval of typical reporting periods is so wide that it renders the metric useless. This potential limitation is implicitly recognized by those who criticize TRIR as unfairly biased against small companies.

To better understand the validity of TRIR as a performance metric, this study attempted to answer the basic question: *Given the way that it's used, to what extent is TRIR statistically valid?*

More specifically, we aimed to test whether TRIR is statistically stable, precise, predictive, and indicative of high-severity events. The answer will help clarify if TRIR should be used to make important business decisions like comparing two contractors, evaluating the safety performance of managers, or concluding that a new safety intervention is effective.

Background

A statistical analysis of any variable requires its decomposition into underlying components. Since TRIR is a rate, the metric is comprised of two variables: **the number of events and time**. Here, events are injuries and illnesses that conform to OSHA's definition of recordability. Time, on the other hand, is expressed as worker exposure hours. Because expressing TRIR as the number of incidents per worker-hour would yield an excessively small fraction, TRIR is scaled per 200,000 worker-hours. Since 200,000 worker-hours equates to approximately 100 employees working full time for one year, TRIR also reflects the percentage of workers who suffer a recordable incident in a year.

To compute a Total Recordable Incident Rate (TRIR) an organization applies Equation 1 for a specific period. For example, a company that accounts for 3 recordable incidents over 350,000 worker-hours in a month would have a TRIR of 1.71 per 200,000 worker-hours for that month.

Equation 1:

$$\text{TRIR} = \frac{\text{Number of Recordable Incidents} \times 200,000}{\text{Number of Worker-Hours}}$$

TRIR is typically reported as a single number. Statistically, this means that the company takes the single TRIR value to represent safety performance over the period as if it was the only possible outcome. This number is also often reported to one or more decimal points of precision, where subtle differences in TRIR are assumed to be meaningful (e.g., the difference between 1.2 and 1.6 from one month to the next). Although TRIR is used in this manner, the underlying assumptions have never been validated.

In addition, TRIR is often used as a dependent variable by academic researchers. TRIR has been applied frequently as an objective, empirical metric of safety performance and is often conceptualized as an ideal response variable. In fact, the authors of this paper have used TRIR on multiple occasions as a dependent variable when identifying which safety practices are more effective than others (Hallowell 2010; Hallowell and Gambatese 2009); validating safety leading indicators as predictive (Alruqi and Hallowell 2019; Hallowell et al. 2013; Hinze et al. 2013; Lingard et al. 2017; Salas and Hallowell 2016) and measuring intrinsic relationships between safety and other performance metrics like productivity and quality (Wanberg et al. 2013).



Example Cases

Case examples were created to illustrate the potential limitations of using TRIR as a comparative metric. The hypothetical cases were designed to vary greatly in the number of recordable injuries, the number of worker-hours accumulated, and the resulting TRIR. Case A represents a new contractor that has a recordable incident early in their company history. In contrast, Case B is a medium-sized company with fewer than 500 employees that accumulates just less than 1 million worker-hours in a year. Finally, Company C is a large company that amasses millions of worker-hours in a year.

Company A is an extreme example that underscores the limitation of reporting TRIR over very short timeframes or for small businesses. On the surface, the TRIR of 200 for Company A could be judged as over 50 times worse than average TRIR in the construction industry (US Department

of Labor 2016). However, the short timeframe makes it difficult to support this judgment. It also drives the general question: *how many worker-hours of exposure are needed before TRIR becomes statistically meaningful?*

Companies B and C offer interesting contrast as both accumulate relatively large numbers of worker-hours. Again, on the surface, it may appear that Company C is nearly twice as good as Company B. However, it is still unclear if Company B is *statistically* different from Company C given that injuries do not appear to occur at some regular, predictable interval.

Later in this paper, these three case companies are used to illustrate proper interpretation of TRIR and the implications of the results.

Company A

Has a recordable incident in the first 1,000 worker-hours that they are in business. At this point, their TRIR is 200 per 200,000 worker-hours.

Company B

Has 7 recordable incidents over 980,000 worker-hours in a given year. They report their yearly TRIR as 1.4 per 200,000 worker-hours.

Company C

Has 24 recordable incidents over 6,000,000 worker-hours in a given year. They report their yearly TRIR as 0.8 per 200,000 worker-hours.



Analytical Approach

This study was performed via a collaboration among senior leaders of ten construction companies and four academic researchers. The collaboration resulted in direct access to over 3 trillion worker-hours of internally reported incident data, which were analyzed by the academics using a variety of diagnostic and predictive analytics.

Both parametric and non-parametric analyses were used to study TRIR. A parametric statistical analysis is one that makes logical assumptions about the defining properties of the distributions (i.e., the metric follows a binomial distribution).

Parametric Approach

A parametric analysis starts by identifying the underlying distribution that governs the phenomenon to remove a layer of abstraction and create representative statistical equations. Most common metrics conform to well-known mathematical distributions like Normal, Binomial, or Poisson. When fitting a distribution, it is important to examine the assumptions about the metric to ensure that the chosen distribution is valid. Once a distribution is known, a mathematical function (equation) can be produced that allows us to interpret the precision of a given TRIR, or answer questions like: how much exposure time is required to produce a precise measure of TRIR? For simplicity, we use the term precision to refer to the width of the confidence intervals, where a wide interval is considered to be less precise than a narrow interval.

The parametric analysis revealed very important insight into how TRIR should be communicated. At present, most

TRIR as a Distribution

Two values are needed to compute TRIR: incidents and time. Incidents are discrete events; they happen, or they do not, and there is no such thing as a fractional or negative incident. Time, however, is a continuous value and there are infinite possibilities. To work with time as a variable it is often defined in ranges like days, hours, or minutes. If we look at each worker-hour (the base unit used in TRIR) as a discrete event and an incident as a binary possibility, this yields what is known as a Bernoulli trial.

Non-parametric statistical analyses make no assumptions about the underlying probability distributions, and instead estimate their distributions solely from the data. Both are important for statistical modeling because they help to answer different questions. For example, parametric analyses help us to interpret the precision of TRIR by considering confidence intervals and the non-parametric analyses help us to test whether past TRIR is predictive of future TRIR. Recognizing the significant implications of these results, both approaches were taken to gain a full understanding of when, if ever, TRIR can be used as a comparative or predictive metric.

organizations report TRIR as a single number, often to multiple decimal points (e.g., 1.84). However, as will be shown, TRIR is subject to random variation and should not be communicated as a single number. For example, with the same underlying safety system, an organization would not expect the exact same number of recordable injuries every reporting period. Rather, it may be equally likely that long periods may exist between incidents or that incidents occur in clusters. Additionally, although TRIR is widely reported as a concrete measurement, it is actually a sample taken over a discrete period of time (e.g., one month or one year). To make statements about the possible outcomes of a safety management system, it is important to understand TRIR as a distribution of potential values rather than a single point estimate.

A Bernoulli Trial is Built Upon 3 Assumptions:

Assumption 1 - Each trial results in one of two possible outcomes (occurrence or non-occurrence). Incidents satisfy this assumption because they either occur or do not in one worker-hour. Although it is possible to have more than one recordable incident in a worker-hour, it is so rare as to be mathematically negligible.

Assumption 2 - The probability (p) of an injury remains constant from one worker-hour to the next. It is assumed that a worker is equally likely to be injured in each worker-hour. Although certain situations have a higher probability of injury than others, over enough time exposure each worker-hour can be represented as approximately the same.

Assumption 3 - The trials (worker-hour) are independent. Independence in a dataset means that there is not a well-established connection in the outcomes among trials (worker-hours). For TRIR, there are no known patterns in occurrence, especially when the data are considered in a very high number of trials (e.g., hundreds of thousands of worker-hours). Although there is an argument to be made that an incident in one worker-hour makes an incident in the next more or less likely, independence remains a reasonable assumption.

Computing Confidence Intervals

Now that TRIR is understood to be logically represented as a series of Bernoulli trials, the distribution that best represents the context must be identified. Because recordable incidents can only occur or not occur, the distribution of TRIR must be discrete. In other words, the number of incidents observed over any time period must be a whole number. Although the binomial distribution represents the distribution of potential outcomes from a sample of Bernoulli trials, the Poisson distribution is an even more accurate representation of TRIR.

A Poisson distribution can be thought of as a unique case of the binomial distribution where the probability of occurrence is **very small**. The Poisson distribution is reasonable to use when there are at least 20 trials and the probability of occurrence is less than or equal to 5% (Prins 2012). In the case of TRIR at a

basic unit level (incidents and worker-hours), both are true because incidents are rare and TRIR is typically measured over at least thousands of worker-hours. Another key benefit of the Poisson distribution is that it expresses the probability of a given number of events occurring in a fixed interval of time. This means that the Poisson distribution can be scaled to virtually any time range.

When a value is observed from a distribution of possible observations, the result should be communicated as a confidence interval. A confidence interval is the range of values that is likely to contain the true value with some degree of confidence. The level of confidence is expressed as a probability that the true value lies between an upper and lower interval. For example, TRIR could be expressed as a value that is contained in a range between values X and Y with 95% confidence. This can also be practically interpreted as a 5% probability that a long-term TRIR would be outside this range. Confidence intervals are computed using equations that best represent the underlying distribution. For a Poisson distribution, the Wilson confidence interval is the most appropriate approximation (Wallis 2013). The upper and lower bounds of the Wilson confidence interval are represented by Equation 2 below (Wallis 2013). Although there are other approximations of Poisson confidence intervals that are more accurate (e.g., Garwood 1936; Ulm 1990); the Wilson confidence interval is simple to compute with a basic calculator and also provides an approximation within 1% of the more computationally demanding methods. For example, the 'exact' method from Ulm (1990) requires a statistical package to analyze and produces results that are practically indistinguishable from the Wilson Interval shown in Equation 2.

$$\text{Equation 2: } \frac{\hat{P} + \frac{z^2}{2n}}{1 + \frac{z^2}{n}} \pm \frac{z}{1 + \frac{z^2}{n}} \sqrt{\frac{\hat{P}(1-\hat{P})}{n} + \frac{z^2}{4n^2}}$$

Where, p is the number of actual events (incidents) divided by the number of trials (worker-hours) and z is the critical value of a standard normal distribution corresponding to the target confidence interval (e.g., $\alpha = 0.05$ for a 95% confidence interval). In this analysis a significance level (α) of 0.05 was always selected so the corresponding z is 1.96.

The Wilson confidence interval allows one to judge the precision of an observed TRIR using only two pieces of information: the number of incidents and the number of worker-hours in the sample. Once this information is known, the confidence interval can be approximated using Equation 2. Multiplying the endpoints by 200,000 shows the range in terms of TRIR as it is normally reported.

An example provides some clarity for the layperson. If a theoretical company had 1 recordable injury in 200,000 worker-hours ($n=200,000$, $p=1/200,000$), we can calculate the 95% confidence interval using Equation 2 as 0.18 to 5.66 injuries per 200,000 worker-hours. Theoretically, this corresponds to the range of results that the company's safety system is designed to produce that month. A TRIR below 0.18 would be interpreted as unusually low and a TRIR above 5.66 as unusually high. Therefore, reporting a TRIR of 1.00 per 200,000 is not appropriate or meaningful. Rather, the TRIR should be reported as an interval

of 0.18 to 5.66 with the most likely true value of 1.00. We can also ask the complementary question: Assuming the company's true injury rate is 1 per 200,000 worker-hours, how many injuries are likely to occur over future periods of 200,000 worker-hours if the safety system remains the same? Figure 1 shows the range of potential results and their probabilities.

As an extension of the above example, if the same company experienced 2 injuries in the next 200,000 worker-hours, the 95% interval would then be 0.55 to 7.29 per 200,000 worker-hours. The company might be concerned that they doubled their injuries from the previous interval from 1.00 to 2.00 per 200,000 worker-hours. However, a test for significance shows that there is no statistical difference between the months even though the number of injuries doubled. This result means that the difference in the count of injuries alone does not reveal anything significant about the difference in the safety system between the two periods.

Probability of Experiencing N Incidents in 200,000 Worker-Hours

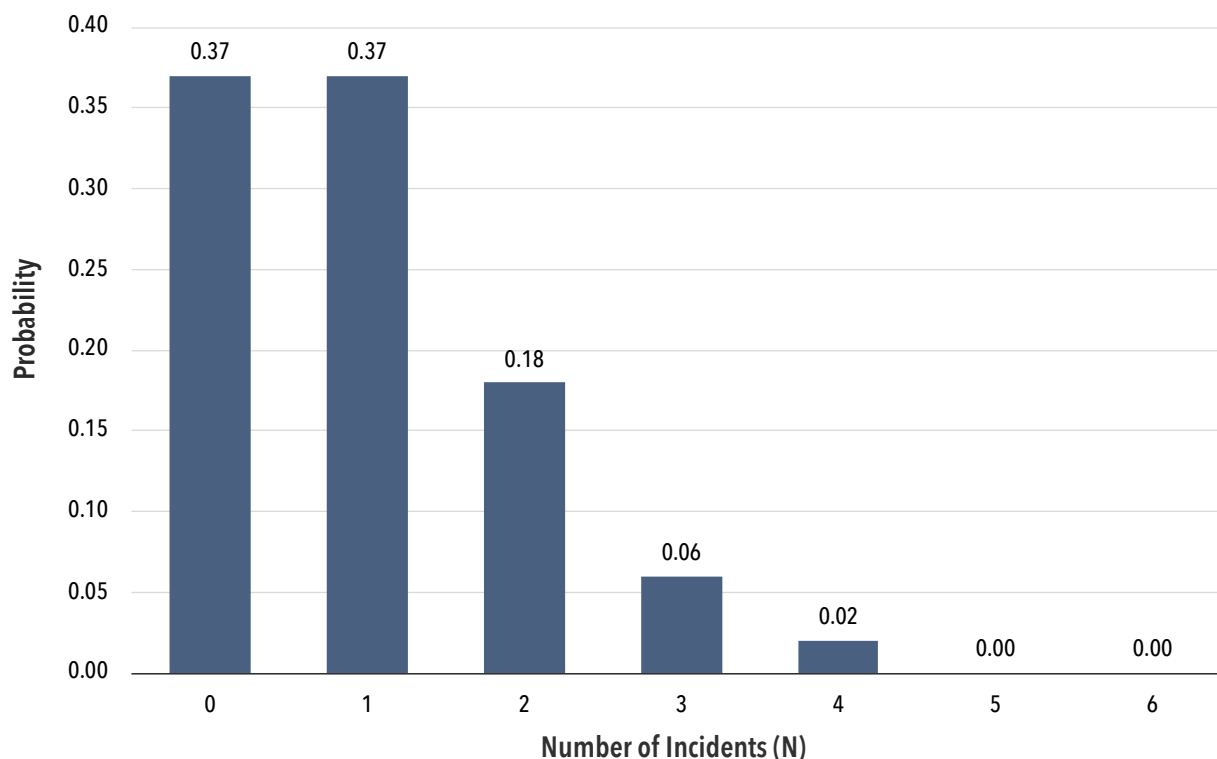


Figure 1 - Probability of experiencing N incidents in the next 200,000 worker-hours assuming a true TRIR of 1 recordable injury in 200,000 worker-hours.

Analysis of Case Examples

Using the three case examples from the background (Companies A, B, and C), we can explore how reporting TRIR as a confidence interval vastly changes its interpretation and meaning. For example, the TRIR of company A, which had a TRIR of 200 resulting from one recordable injury in 1,000 worker-hours, would be correctly reported as 35 to 1,128 with 95% confidence. This statistically confirms the logical interpretation that this new small company does not have enough exposure time to return a meaningful TRIR. The comparison of Companies B and C is also interesting. Since both companies reported their TRIR over many worker-hours, it may seem appropriate to recognize their difference in TRIR as meaningful. However, as shown in Figure 2, the distribution of Company C fits entirely within the distribution of Company B indicating that the two injury records are statistically indistinguishable. That said, another important conclusion can be made: the TRIR for Company C can be stated with a much higher precision (smaller interval) than Company B. Therefore, there is distinct advantage to having a greater number of worker-hours accumulated. However, it still remains unclear whether the historical TRIR has any bearing on future TRIR, which was the primary subject of the non-parametric empirical analysis.

Company A

Has a recordable incident in the first 1,000 worker-hours that they are in business.

TRIR range: 35.31 to 1,125.51 per 200,000 worker-hours.

Company B

Has 7 recordable incidents over 980,000 worker-hours in a given year.

TRIR range: 0.69 to 2.95 per 200,000 worker-hours.

Company C

Has 24 recordable incidents over 6,000,000 worker-hours in a given year.

TRIR range: 0.54 to 1.19 per 200,000 worker-hours.

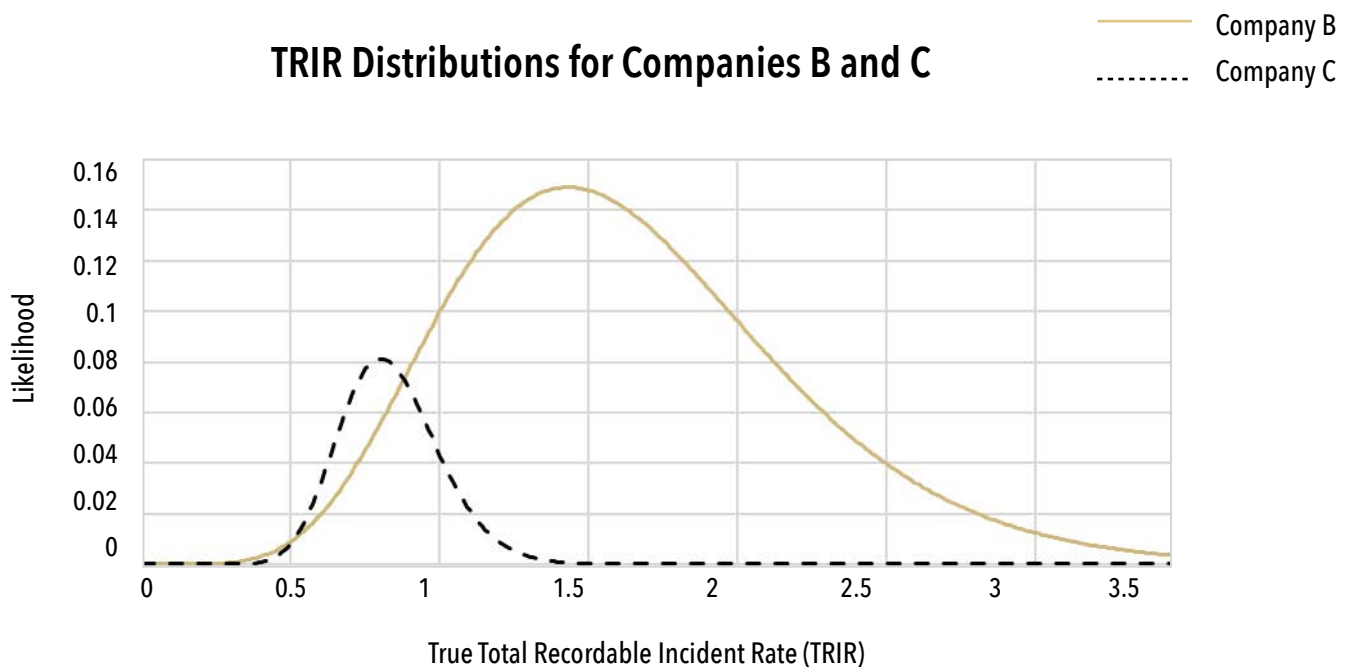


Figure 2 - Likelihood of the true injury rates for Companies B and C (per 200,000 hours), based on their observed histories.

To assist practitioners with the interpretation of TRIR as a range, Tables 1 and 2 were created. Table 1 shows the relationship between precision (width of the confidence interval), time (worker-hours), and TRIR. Simply, it shows how many worker-hours are needed to achieve a given precision level for a variety of TRIR scenarios. The number of hours needed for a given precision can be approximated by Equation 3 below, which is based upon the Wilson binomial formula (Krishnamoorthy and Peng 2007).



Equation 3:

$$n \cong \frac{z_a^2 \left[(Pq - 2d^2) + \sqrt{(Pq - 2d^2)^2 - d^2(4d^2 - 1)} \right]}{2d^2}$$

$$d = \frac{\text{Desired TRIR Precision}}{200,000 * 2}$$

Where n is the required number of worker-hours to achieve precision d given a probability of injury in each hour p, and q=1-p.

Table 1 reveals some potentially surprising results. For example, if an organization wishes to report a TRIR of 1.00 with a precision of 0.1 (e.g., 0.95 to 1.05 per 200,000 worker-hours), about 300 million worker-hours of exposure time is required. In other words, unless the TRIR of 1.0 is derived from 300 million worker-hours of exposure time, it should not be reported to even one decimal point. Furthermore, reporting two meaningful decimal places for TRIR requires approximately 30 billion worker-hours of data. The required number of worker-hours is so high because recordable injuries occur, on average, so infrequently that they do not produce statistical stability. This raises questions about reporting TRIR to two decimal points and making important business decisions with this level of granularity.

To further illustrate how TRIR should be interpreted, Table 2 shows the 95% confidence interval for a series of scenarios with varying TRIR and number of worker-hours. For example, Table 2 shows that if an organization measured their TRIR to be 1.0 over a period of 1,000,000 worker-hours (i.e., 5 recordable injuries occurred over the span of 1,000,000 worker-hours), the correct interpretation is that the safety system is designed to produce a TRIR between 0.43 and 2.34. Note that in Table 2 some scenarios are not possible because they would not correspond to a whole number of incidents; however, they are included to maintain continuity.



Non-Parametric Approach

To complement the parametric analysis and to add a degree of validation, an empirical analysis was performed with injury data provided by 10 construction organizations that are members of the Construction Safety Research Alliance (CSRA). The partner organizations represented infrastructure, power generation and delivery, oil and gas, industrial and energy, and commercial building sectors. The partners provided monthly counts of recordable injuries, fatalities, and worker-hours for a 15-year period. In total, the dataset included 3.26 trillion worker-hours of data. The empirical analysis of these data is summarized below, and the analytical approach is explained in fine detail in Salas (2020).

Random & Unpredictable Nature of TRIR

To assess the significance of TRIR, the data for each organization were fit to a generalized linear model (GLM) using different distribution functions to determine the best model (i.e., the one with the lowest Akaike Information Criterion). The best fit model was then subjected to 100 repeated sampling and 10-fold cross-validation to measure the strength, stability, and response of the model to the observed data. Then, a Monte Carlo Simulation was used to evaluate how much of the final result is due to random variation. Holding the data generating process constant, the Monte Carlo Simulation tested how different estimators fare in trying to uncover underlying parameters. Put simply, this method involved using the historical TRIR data for each organization to create a predictive equation and then testing how well that equation correctly estimated future TRIR.

The results indicated that TRIR is 96-98% random. This means that the best model was only able to predict the observed TRIR in 2-4% of the trials. Since safety is a chaotic system due to the interfaces between people, culture, policies, regulations, equipment and other external factors (e.g. economy, weather, natural events, etc.), this is not a surprising finding. However, it does have very important implications. First, it provides empirical evidence to support the logical assumptions made in the parametric analysis. Second, the fact that TRIR is random in nature provides further evidence that it must be reported as a

range (i.e., confidence interval) and absolutely should not be expressed as a single number.

In addition to measuring the significance, the models were also tested to assess the extent to which historical TRIR predicts future TRIR. The results showed that at least 100 months of data were required to achieve reasonable predictive power because of the high degree of random variation. Since TRIR is generally used to make comparisons or decisions on the order of months or years, this finding indicates that for all practical purposes, TRIR is not predictive. For example, a client that hires a contractor with a TRIR of 0.75 cannot reasonably expect that the contractor will achieve that same performance on their upcoming project.

Lack of Relationship Between TRIR & Fatalities

Effect measurements revealed that variation in TRIR has no association with fatalities. That is, trends in TRIR do not associate statistically with fatality occurrence. Instead, fatalities appear to follow different patterns, suggesting that they occur for different reasons. This finding challenges the long-standing assumption, derived from the Heinrich safety pyramid, that injuries of different severity levels exist at fixed ratios and have the same underlying causes (Heinrich 1959). It also debunks the notion that reducing TRIR is a surrogate for mitigating the risk of high-impact events.



Table 1. Relationships among Precision (width of confidence interval), TRIR, and Exposure Time (worker-hours)

Precision	TRIR	Worker-Hours	Precision	TRIR	Worker-Hours	Precision	TRIR	Worker-Hours
0.1	0.20	62,409,083	0.25	0.20	10,715,491	0.5	0.20	3,197,046
0.1	0.40	123,404,751	0.25	0.40	20,137,222	0.5	0.40	5,357,737
0.1	0.60	184,709,031	0.25	0.60	29,819,030	0.5	0.60	7,682,889
0.1	0.80	246,092,232	0.25	0.80	39,575,018	0.5	0.80	10,068,588
0.1	1.00	307,507,116	0.25	1.00	49,361,749	0.5	1.00	12,481,762
0.1	1.25	384,297,072	0.25	1.25	61,616,226	0.5	1.25	15,517,884
0.1	1.50	461,099,608	0.25	1.50	73,883,277	0.5	1.50	18,566,029
0.1	1.75	537,909,256	0.25	1.75	86,157,534	0.5	1.75	21,621,176
0.1	2.00	614,723,280	0.25	2.00	98,436,299	0.5	2.00	24,680,748
0.1	3.00	922,000,301	0.25	3.00	147,573,796	0.5	3.00	36,941,358

Table 2. 95% Confidence Intervals for a Series of TRIR Scenarios

	Total Recordable Incident Rate								
	0.1	0.2	0.5	1.0	1.5	2.0	3.0	4.0	5.0
100K	0.00 - 7.68	0.00 - 7.68	0.00 - 7.68	0.00 - 7.68	0.00 - 7.68	0.35 - 11.33	0.35 - 11.33	1.10 - 14.59	1.10 - 14.59
250K	0.00 - 3.07	0.00 - 3.07	0.00 - 3.07	0.14 - 4.53	0.14 - 4.53	0.44 - 5.83	0.82 - 7.06	1.71 - 9.36	2.20 - 10.47
500K	0.00 - 1.54	0.00 - 1.54	0.07 - 2.27	0.22 - 2.92	0.41 - 3.53	0.85 - 4.68	1.36 - 5.78	2.17 - 7.36	2.75 - 8.39
1M	0.00 - 0.77	0.04 - 1.13	0.11 - 1.46	0.43 - 2.34	0.68 - 2.89	1.09 - 3.68	1.82 - 4.95	2.59 - 6.18	3.39 - 7.38
2.5M	0.01 - 0.45	0.04 - 0.58	0.22 - 1.05	0.55 - 1.68	0.91 - 2.28	1.35 - 2.95	2.15 - 4.08	3.03 - 5.27	3.87 - 6.36
5M	0.02 - 0.29	0.09 - 0.47	0.27 - 0.84	0.68 - 1.48	1.07 - 2.04	1.52 - 2.64	2.39 - 3.76	3.29 - 4.86	4.20 - 5.96
10M	0.04 - 0.23	0.11 - 0.37	0.34 - 0.74	0.76 - 1.32	1.20 - 1.88	1.64 - 2.43	2.56 - 3.52	3.48 - 4.59	4.42 - 5.66
20M	0.05 - 0.18	0.13 - 0.31	0.38 - 0.66	0.82 - 1.22	1.28 - 1.76	1.74 - 2.30	2.68 - 3.36	3.63 - 4.41	4.58 - 5.46
50M	0.07 - 0.15	0.15 - 0.26	0.42 - 0.60	0.88 - 1.13	1.36 - 1.66	1.83 - 2.18	2.79 - 3.22	3.76 - 4.26	4.73 - 5.28

Key Findings

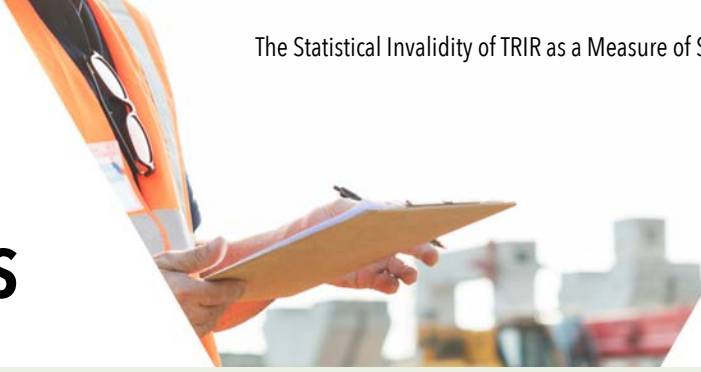


This study challenges conventional wisdom of safety measurement with an empirical analysis of 3.26 trillion worker-hours of TRIR data and a statistical demonstration of proof. The results reveal very strong evidence that TRIR is almost entirely random and is not indicative of future performance unless millions of worker-hours are amassed. The specific conclusions that follow logically and empirically are as follows:

1. **TRIR is not associated with fatalities.** The effect measurements revealed that there is no discernible association between fatalities and TRIR. Recordable injuries and fatalities follow different patterns and occur for different reasons. Thus, TRIR trends are not a proxy for high-impact incidents. Hence, it can be inferred that safety interventions, including policies, regulations and management systems, associated with the improvement in TRIR performance may not necessarily prevent fatalities.
2. **TRIR is almost entirely random.** Empirical analysis revealed that changes in TRIR are due to 96-98% random variation. This is logically confirmed by the fact that recordable injuries do not occur in predictable patterns or regular intervals. This is likely because safety is a complex phenomenon that is impacted by many factors.
3. **TRIR cannot be represented as a single point estimate.** Since TRIR is almost entirely random, a single number does not represent the true state of safety performance. Instead, TRIR is best expressed as a confidence interval and studied over extended periods of time. For example, a yearly TRIR value of 1.29 is statically meaningless for almost every organization. This finding was initially explored in the parametric analysis and was empirically validated in the non-parametric analysis.
4. **TRIR is not precise and should not be communicated to multiple decimal points.** Unless hundreds of millions of worker-hours are amassed, the confidence bands are so wide that TRIR cannot be accurately reported to even one decimal point. The implication is that the TRIR for almost all companies is virtually meaningless because they do not accumulate enough worker-hours.
5. **If an organization is using TRIR for performance evaluations, they are likely rewarding nothing more than random variation.** Because of the random nature of TRIR, it is unclear if a change in performance (positive or negative) is due to an underlying change in the safety system or if the organization is simply observing random variation.
6. **TRIR is predictive only over very long periods of time.** Previous researchers have postulated that TRIR can be used predictor of performance when taken over very long time periods (Alruqi and Hallowell 2019; Lingard et al. 2017; Salas and Hallowell 2016; Wilbanks 2019). The empirical results of this study confirmed that TRIR is only predictive when over 100 months of TRIR data are accumulated.

The results of this study may not be surprising to some professionals who have made these postulations for years. However, this is the first scientific evidence that explains why TRIR is not a valid comparative measure of safety performance.

Conclusion & Recommendations



The conclusions of this research may disrupt how the profession approaches safety measurement and reporting. Therefore, along with the senior executives from our industry partners, we offer the following practical interpretation of the results.

- 1. TRIR should not be used as a proxy for serious injuries and fatalities.** For years, many practitioners have used declining trends in TRIR to indicate the mitigation of fatality risk. However, the lack of statistical association between TRIR and fatalities suggests that the assumption holds no scientific merit. Practitioners should consider creating and testing targeted measurement, learning, and prevention efforts for serious injuries and fatalities.
- 2. TRIR should not be used to track internal performance or compare companies, business units, projects, or teams.** Since the average company requires tens of millions of worker-hours to return a confidence interval with one decimal point of precision, organizations should be very careful making *any* comparisons using TRIR. For example, most companies do not even have enough worker-hours to detect statistically significant changes in TRIR from one year to the next. Therefore, we challenge practices where TRIR is used to compare companies, projects, or teams. At best, TRIR is only useful for comparing industries or sectors of the US economy over long

periods of time. For the same reason, TRIR should not be used as the primary safety metric when incentivizing organizational performance or comparing or prequalifying contractors.

- 3. The safety profession must change how it communicates TRIR.** TRIR is almost always communicated as a precise number as if it was the only possible outcome (Stricoff 2000). Since recordable injuries are so infrequent and are a product of so much random variation, a single precise number is meaningless. Instead, TRIR should be accompanied by the range of potential outcomes that the safety system could have reasonably produced. The implication is that small companies would report large confidence intervals (high uncertainty) and large companies would report smaller confidence intervals (lower uncertainty). However, almost no company would be able to appropriately report TRIR to the level of precision most commonly used today.
- 4. Companies should not place much emphasis on short term changes in TRIR.** It is tempting to track TRIR over time to identify when performance is improving or degrading. However, as observed in the empirical analysis, changes that occur from month-to-month are mostly random and do not necessarily reflect any actual change in the safety system.

5. TRIR should not be used to measure the impact of safety interventions.

Managers are often compelled to show reductions in TRIR resulting from safety initiatives and investments. However, controlled experiments and longitudinal data are needed to establish causal inference between safety interventions and TRIR trends. This renders TRIR entirely inadequate for attributing change because most companies drastically shift their management approaches, safety programs, and even their business models over the long timeframes needed to produce a precise and stable TRIR.



6. New approaches to safety measurement are needed.

In addition to statistical invalidity, the use of TRIR also does not describe *why* the performance – good or bad – was achieved and what can be done to improve. This leaves organizations wondering, ‘Are we truly good, or simply lucky?’ or worse, ‘Are we truly bad, or do we simply need to log more worker-hours?’ The academic and professional community should consider alternative measures of safety performance that assess the actual safety system at high frequency. Increasing the number of reliable measurements could drastically improve the stability, precision, and predictive nature of safety metrics. To be comparative, however, these metrics must be standardized and consistently reported.

Since TRIR has remained the most pervasive measure of safety for nearly fifty years, this study underscores the need to scientifically test even the most basic assumptions of the safety profession. In the spirit of scientific inquiry, we recommend that other researchers propose alternative hypotheses about TRIR, conduct independent tests, and challenge the assumptions made in this paper. Although we stand by our conclusions, we recognize that other perspectives may generate different models and results.

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