PREDICTING CONSTRUCTION SAFETY PERFORMANCE

By

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ABSTRACT

Wael Muqhim Alruqi (PhD., Department of Civil, Architectural, and Environmental Engineering)

Predicting Construction Safety Performance

Dissertation directed by Associate Professor Dr. Matthew Ryan Hallowell

Researchers and leading industry practitioners have turned to proactive safety metrics, such as safety leading indicators and safety climate, as predictors of future safety performance. Current academic research shows that the relationships between safety leading indicators and safety lagging indicators remain inconsistent, as well as the relationships between the dimensions of safety climate and safety performance. In addition, prior studies have measured the predictive capacity of these constructs separately even though they are logically associated with one another. Standardizing the measurement of proactive safety metrics and understanding how they relate to one another may facilitate consistency among the indicators or dimensions that define the two metrics, and such an understand may be helpful when pursuing efficient, multi-dimensional, and unified techniques for safety monitoring and prediction.

This dissertation therefore aims to (1) empirically validate the relationship between safety leading indicators and safety performance, (2) empirically validate the relationship between the dimensions of construction safety climate and safety performance, and (3) develop a hypothetical exploratory model based on the theoretical differences between safety leading indicators and safety climate and empirically investigate using the structural equation modeling technique with data collected in the field.

The first meta-analysis of construction safety leading indicators and safety climate dimensions is used to quantify the extent to which safety leading indicators and the dimensions of safety climate predict safety performance. The results of the two meta-analyses offer a set of common safety leading indicators and safety climate dimensions that positively correlate with safety performance.

Data collected from a survey of 106 construction workers at nine construction job sites in the US were used to build the structural equation model to investigate the association between safety leading indicators and safety climate. The results show a positive relationship between safety leading indicators and safety climate.

This dissertation is the first work that standardizes, defines, and measures these relationships. Future work might expand the hypothetical exploratory model to include other construction safety predictors (e.g., precursor analysis) and empirically validate the relationships among them to advance the accuracy of construction safety prediction.

In memory of my father, Muqhim H. Alruqi (may Allah have mercy on him and forgive him).

To my mother Meznah Al-Otaibi, my wife and my kids, my brothers, and my sister with love and eternal appreciation.

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CHAPTER 1: INTRODUCTION

1.1 Background and Motivation

Despite significant safety intervention strategies, the number of injuries in the construction industry continually increases. According to the U.S. Bureau of Labor Statistics (2016), the number of injuries in the construction industry in 2016 was 991 compared to 937 in 2015. In addition, they rank the construction industry as the highest in which risk of injury resides in comparison to other industries. For decades, the construction industry relied on lagging indicators to measure safety performance (e.g., recordable injury rate). Lagging indicators were measured after incidents and accidents took place (Hinze et al. 2013). This lack of future information about safety performance is a major limitation that made the industries toward the use of proactive indicators as methods to provide future predictors for safety performance.

The information that the proactive safety metrics provided can be used to track safety performance (Alexander et al. 2017; Guo et al. 2016), minimize jobsite risk, and support continuous improvement (Hallowell et al. 2013; Janicak 2009). Safety leading indicators and safety climate are two common proactive methods used in current literature to monitor safety performance.

A safety leading indicator is described as a "measure of safety activity that could lead to predicting the future of that activity" (Hallowell et al. 2013). Prior research has shown the importance of leading indicators in predicting future injuries. Salas and Hallowell (2016), for example, showed that "near-miss reporting, stop work authority, upper management engagement in safety activities, worker involvement, owner involvement, safety auditing and observation, and safety risk assessment" are valid leading indicators for predicting future safety performance. Rajendran (2012), on the other hand, identified two leading indicators (pre-task plans and worker safety behavior) that are useful in predicting future injury. The measurement of the leading indicators is still low in the industry compared with other safety prediction techniques, such as safety climate. Researchers are still developing new methods for identifying and defining safety leading indicators.

Guo and Yiu (2015) for example, developed a framework to identify leading indicators. There are four steps in this framework: “conceptualization, operationalization, indicator generation, and validation and revision” (Guo and Yiu 2015). 32 leading indicators were generated based on this framework. These included the “number of sites visited by an owner or safety representative, written safety plans, supervisory support, stop work authority, and frequency of pre-task safety meetings” (Guo and Yiu 2015). The identification of safety leading indicators and the relationships between them and safety lagging indicators are still inconsistent. Defining, measuring, and standardizing construction safety leading indicators might help researchers and the industry collect and measure reliable safety leading indicators.

Safety climate, on the other hand, is one of the most highly recognized proactive safety measures in current safety literature. Safety climate is described as “individual perceptions of policies, procedures, and practices relating to safety in the workplace” (Neal and Griffin 2006). In other words, safety climate measure the opinions of individuals about safety aspects in their organizations (Schwatka et al. 2016). Surveys are commonly used to capture individual perceptions regarding safety. These questionnaires include multiple topics, such as “management commitment to safety,” “worker involvement,” and “supervisory safety role.”

Safety climate is highly researched in current safety literature. Numerous authors have determined a positive correlation between safety climate and worksite injuries (Arcury et al. 2015;

Hon et al. 2014a; Lingard et al. 2010b; McCabe et al. 2016). These studies correlate different types of safety climate dimensions with worksite injuries. Several safety climate dimensions are explored in current literature. In fact, there are no common dimensions to define safety climate in current construction safety climate literature (Flin et al. 2000; Schwatka et al. 2016). Research on identifying and defining a common set of construction safety climate dimensions might help standardize the assessment of construction safety climate.

Previous findings construed the importance of proactive safety measures in preventing injuries. The research on proactive safety indicators (e.g., safety climate and safety leading indicators) is relatively recent, and more research is needed to clarify the equivocality in various aspects. These include the definition, categorization, and measurement of candidate indicators for proactive measurement. More important is an investigation of the relationship between these proactive safety indicators and safety performance.

1.2 Current needs for additional research and dissertation aims

In light of existing literature, there is strong evidence that shows that lagging indicators are not efficient in preventing and predicting future incidents. In fact, current literature supports the movement to proactive safety measures (Hallowell et al. 2013; Hinze et al. 2013; Zhou et al. 2015). However, there are several gaps in the current body of knowledge regarding the measures of safety leading indicators, and safety climate.

The first limitation in current literature among these proactive measures is the lack of a common set of indicators or dimensions that defines the two predictors. Among several published studies, the selection of safety leading indicators is still questionable, and there is need to identify specific leading indicators. In fact, how these indicators relate to or predict performance is unkown. Safety leading indicators have become widely accepted as a valuable safety metric in developed organizations. However, aside from the fact that no common safety-leading indicator exists yet, the use of passive and active leading indicators terms in current literature is inconsistent. Researchers have described active indicators as passive indicators and vice versa. Standardizing and distinguishing between active and passive indicators is important to the industry to justify and target resource expenditures using persuasive scientific evidence.

This also applies to the safety safety climate literature. The topic of construction safety climate have been extensively explored in the current literature. Yet, the industry remains far from agreement on the common dimensions that define a safety climate (Flin et al. 2000; Schwatka et al. 2016) or how these dimensions relate to or predict performance. Evidence for this demonstrates a lack of consistency among contemporary researchers in terms of the dimensions selected and measured in their safety climate studies. Inconsistencies in the literature called for identifying a common set of safety climate dimensions , and empirical analysis of the relationships between climate dimensions and safety perfromance. The investigation and identification of common safety climate dimensions is important towards the standardization of safety climate measures in the construction industry. This holds true, as there is a need for the collection of consistent and reliable data for future safety climate measures by both researchers and practitioners.

The second major limitation in the current body of knowledge is that safety leading indicators and safety climate dimensions are independently investigated. These predictors are discrete. Safety leading indicators directly measure the safety system activities, while safety climate measures individual perceptions regarding these activities. I propose a hypothesis based on the differences between safety leading indicators and safety climate to see if increases in safety management activities leads to increases in safety perception within the workplace. Incorporating both proactive safety measures might advance the management safety system in the workplace, where leading indicators measure the activities of that management's safety system, and safety climate measure the quality (i.e., perception) of these activities. If this hypothesis hold true, then researchers and industry practitioners might use both measures to advance the worksite management's safety system to proactively control and monitor safety performance.

In summary, the overall goal of this dissertation as showing in figure 1 were:

(1) Empirically validate the relationship between safety leading indicators and safety performance

(2) Empirically validate the relationship between the dimensions of construction safety climate and safety performance

(3) Develop a hypothetical exploratory model based on the theoretical differences between safety leading indicators and safety climate and empirically investigate the relationship between them using the structural equation modeling technique (SEM) with data collected in the field.

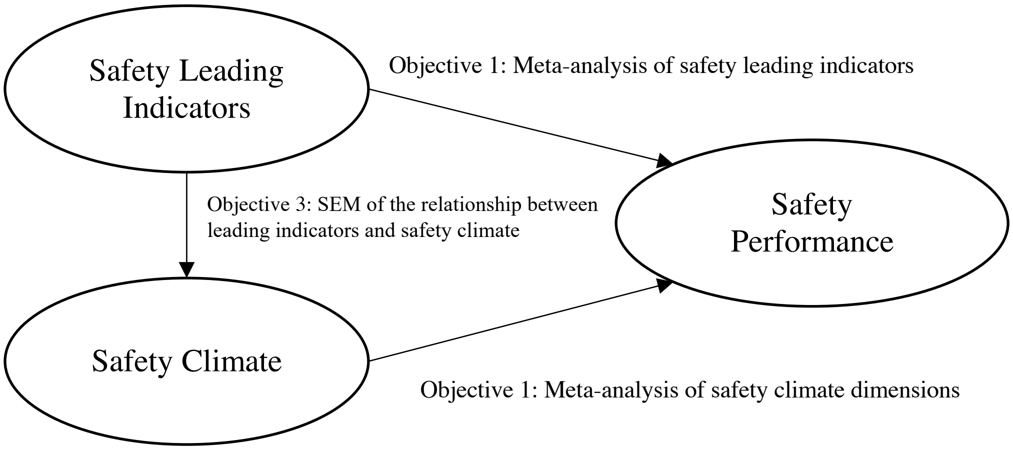

Figure 1: Dissertation overall goals

This document is organized into five chapters. The first chapter is the introduction, which consists of background, motivation, point of departure, dissertation organization, and overall research goals. Chapter 2, 3, and 4 follow a format of journal research papers. Each chapter includes abstract, introduction, methodology, results, and conclusion. Chapter 5 of this dissertation is the conclusion, which included a summary of the contributions to knowledge achieved by these studies, overall limitations, and suggestions for future research. Table 1 presents the objectives, and hypothesis for each paper in this dissertation.

1.3 Dissertation content and contribution

The first paper presented in this document can be found in chapter 2 under the title "Critical Success Factors for Construction Safety: Review and Meta-Analysis of Safety Leading Indicators". The paper addresses the need for a comprehensive review that clear the inconstancy of the leading indicators definition, categorization and measurement of candidate indicators. In addition, a statistical meta-analysis was performed to compute the effect sizes and significance for all identified indicators in all peer-reviewed published artic. This paper offers a method to distinguishing between lactive and passive leading indicators. Moreover, a set of common active and passive leading indicators were provided based on the analysis of meta-analysis. The findings discussed in this paper provides validation of the common leading indicators, which might help toward the standardization of the measure of safety leading indicators. This paper has been published at the *Journal of Construction Engineering and Management*.

The second paper presented in this dissertation can be found in chapter 3 under the title: "Safety Climate Dimensions and Their Relationship to Construction Safety Performance: A Meta-Analytic Review". This paper addresses the need for identify and summarize dimensions of construction safety climate. This paper reviews a questionnaire used to measure a construction safety climate and establishes a consistent definition for each identified safety climate dimension. Also, this paper addresses the relationship between safety climate dimensions and worksite injury by using meta-analysis procedure. This analysis leads to set of common construction safety climate dimensions that helps researchers and practitioners to collect consistent and reliable safety climate data. This paper has been published at the *Journal of Safety Science.*

The third paper presented in this document can be found in chapter 4. The point departure of this paper is built upon a comprehensive review in the first and second paper. Chapter 4 contributes to distinguishing between safety leading indicators and safety climate dimensions, test the realtionshi between safety leading scores and safety cliamte dimensions scores. The finding of this study can be used by industry practitioners to establish a clear and crisp measure of both metrics in the work site.

Table 1: Dissertation Format, questions, and objectives

Paper	Research questions	Research objectives	Scholarly activities
Paper 1 (Chapter 2)	- What is the predictive validity of active and passive safety leading indicators?	- Review of safety leading indicator research - Defines a clear method for distinguishing between active and passive indicators. - Compute the relative effect sizes both indicators	1. Alruqi W. and Hallowell, M.R "Critical success factors for construction safety: Review and meta- analysis of leading indicators." *Journal of construction engineering and management*. (Published)
Paper 2 (Chapter 3)	- How common safety climate dimensions predict construction safety performance?	- Review questionnaires used to measure construction safety climate dimensions. - Identify the salient dimensions of safety climate for construction. - Establish a consistent definition of each safety climate dimension. - Quantify the extent to which each safety climate dimensions predicts construction safety performance.	1. Alruqi, W. and Hallowell, M.R. "Dimensions of construction safety climate." Proceedings of the 2017 *Construction Research Congress, Vancouver*, Canada, May 31-June 3, 2017. 2. Alruqi W. and Hallowell, M.R "Safety Climate Dimensions and Their Relationship to Construction Safety Performance: A Meta-Analytic Review." *Safety science* (Published)
Paper 3 (Chapter 4)	- What is the relationship between leading safety indicators and dimensions of safety climate	- Provide clear differences between safety leading indictors and safety climate dimensions - Test the relationship between leading safety indicators and dimensions of safety climate	- In progress for publication

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CHAPTER 2: CRITICAL SUCCESS FACTORS FOR CONSTRUCTION SAFETY: REVIEW AND META-ANALYSIS OF SAFETY LEADING INDICATORS

2.1 Abstract:

Safety leading indicators are measures of the safety management system that correlate with injury rates. Literature on the topic is dispersed and equivocal in the definition, categorization and measurement of candidate indicators, which makes validation and replication difficult. This study includes a comprehensive review of safety leading indicator research, offers a distinction between leading indicators and other methods of safety prediction, and defines a clear method for distinguishing between active and passive indicators. By applying these definitions and leveraging empirical data, a statistical meta-analysis was performed to compute the relative effect sizes and significance for all salient indicators. Although active leading indicator research is rare and relatively recent, the meta-analysis indicates that inspections and pre-task safety meetings correlate strongly with near-term project safety performance. Passive leading indicator research is relatively common and has been conducted for several decades. The results of the meta-analysis indicate that implementing safety recordkeeping; safety resource; staffing for safety; owner involvement; safety training/orientation; personal protective equipment; safety incentives program; and safety inspections and observation each improves long-term safety performance. The findings validate suspected leading indicators and serve as a first step towards standardization. Practitioners may use the findings to justify and target resource expenditures using pervasive scientific evidence.

2.2 Introduction

In recent years, there has been growing awareness that lagging safety indicators (e.g., recordable injury rates) have limited use in the prevention of injuries. Although important for tracking performance and benchmarking, there is no direct evidence that prior safety performance predicts future performance (Hinze et al. 2013b). Further, there is no evidence that lagging indicators reflect the strength of an organization's safety system. Alternatively, recent research has shown that some safety leading indicators are predictive (Salas et al. 2016), provide early warnings of potential hazards (Guo and Yiu 2015), and can be used as levers to improve future performance (Lingard et al. 2017). Not surprisingly, there is a growing body of literature that supports a professional transition from lagging to leading indicators.

Construction safety leading indicators is a relatively new research domain. Nevertheless, over 20 studies have been published in the area in the past 5 years and the National Institute of Occupational Safety and Health (2016) has promoted it as an industry best practice. Early studies have documented industry programs and tested the efficacy of candidate indicators by measuring and analyzing their relationships to safety outcomes. Invariably, these studies have aimed to identify the best predictors or controls of future performance. However, the literature is dispersed and there is no consensus on the relative efficacy of individual indicators. In fact, even the definition and use of the term *safety leading indicator* is equivocal. This study aims to formalize this research domain by performing a comprehensive literature review and statistical meta-analysis of all empirical studies. Such analysis will reveal patterns and divergence of findings across studies and enable future researcher to build upon a solid and congruent foundation of knowledge. Additionally, a set of operational definitions are offered, which can enable consistency and enhanced internal validity of future inquiries.

At present, safety leading indicator programs are established in an ad hoc fashion based upon intuition and judgment (Hinze et al. 2013b). Formalization and aggregation of the research findings will enable practitioners to strategically select indicators, especially when initiating a program and when resources are constrained. Additionally, a single resource that statistically aggregates previous scientific study will make the body of research feasible to consume.

2.3 Background: Indicating future safety performance

There are a variety of methods that can be used to indicate aspects of future safety performance. These include safety climate, safety risk analysis, and safety leading indicators. Safety leading indicators are expressly described as predictive measures of the safety system. The other methods and are often implied to indicate future performance. These three safety measurement constructs are described, compared, and contrasted to show the position of safety leading indicators in a broader context. Further, this review aims to show that there are no crisp delineations between safety leading indicators and other measures of the strength of the safety system. Thus, some previous work that was not published with explicit reference to safety leading indicators may be highly relevant in a statistical meta-analysis.

2.2.1 Safety climate

One of the most prolific research areas in safety is safety climate. In the context of prediction, most authors explain that the measure of safety climate is an indirect measure of the strength of the safety system that indicates future performance. Some authors also claim that safety climate can be an indicator of safety culture, which is thought by many to be the nebulous underlying driver of high-performance safety. According to Neal and Griffin (2006, pp. 946–947), safety climate encompasses, “individual perceptions of policies, procedures, and practices relating to safety in the workplace.” In other words, safety climate reflects individuals’ opinions of their organization’s safety management efforts (Schwatka et al. (2016). Surveys are often used to measure safety climate and include a variety of climate dimensions, such as “management commitment to safety”, “safety rules and procedure”, “safety training”, “worker involvement”, and “risk-taking behavior”. Together, survey scores of each dimension comprise the overall safety climate score of an organization and these composite scores often indicate performance.

The association between safety climate and safety performance was observed in past studies. Researchers found that a positive safety climate is associated with fewer accidents and injuries. For example, McCabe et al. (2016) conducted longitudinal safety climate study and concluded that safety climate accounted of 20% of the variance in injury rate. Further, (Lingard et al. 2012) found that supervisors’ perceptions mediated the relationship between organizational safety climate and injury rate. In general, much of the literature was supports the role of safety climate in improving the safety performance in the construction industry (Chen et al. 2013; Goldenhar et al. 2003; Lingard et al. 2012; Panuwatwanich et al. 2016).

One may distinguish safety climate and safety leading indicators with one major criterion. Although both measure the strength of the safety system, climate is based upon perceptions of generalities (e.g., “management commitment to safety”) and leading indicator are empirical measures of specific safety activities (e.g., frequency of pre-job safety meetings). Despite the similarities between climate and leading indicators, literature related the two constructs have been almost completely isolated. In fact, there is no research that explores co-variance, interaction, or composite predictions of these two areas. However, Lingard et al (2011) implicitly treated safety climate scores as a leading indicator when diagnosing health and safety performance. The study found aggregating these safety measures captures the dynamics of safety performance on the site.

2.2.2 Safety risk analysis

Risk analysis is a method used in many fields, where past data are used to indicate the future liabilities. Specifically, data are used to make probabilistic estimates for a specific time or exposure that are based on past trends. The same general methodology is applied to construction safety risk analysis, where past injury records are used to indicate the likelihood and severity of injury for a specific work period (Hallowell and Gambatese 2009), work package (Tixier et al. 2017), or project (Zhang et al. 2014). At present, most safety risk analyses are focused on the dangers that are defined primarily based upon the attributes of the work (e.g., means and methods of construction, environmental conditions, and task) (Tixier et al. 2017). Regardless of methodology, all safety risk analysis studies operate under the assumption that previous trends will remain relatively stable in the short-term such that the magnitude of previous risks reflect the magnitude of near-term risks. For example, if lubricating materials is noted as a key risk for formwork construction in the past 2 years, this task may be anticipated as a key risk for the next year (Hallowell and Gambatese 2009).

Risk analysis is typically purported to be *anything* that is formally analyzed to predict the likelihood and magnitude of future injuries. That is, if measures of safety climate or safety leading indicators are analyzed for the purposes of indirectly indicating the likelihood and severity of future injuries, the method could be considered a risk analysis. However, since climate and leading indicators are typically used to reflect the strength of the safety system rather than the danger associated with specific work attributes, these metrics are rarely explained as risk factors. Nevertheless, there are blurry delineations among safety risk analysis, safety climate, and leading indicators and the true differences are merely theoretical and ideological.

Although safety leading indicators and risk factors could theoretically be used interchangeably depending on the epistemological positioning, patterns in the current literature offers little confusion. All safety risk analysis studies involve quantification for specific work or project characteristics. For example, (Fung et al. 2010) quantify safety risk for contrsuction trades (e.g., welding), Hallowell and Gambatse (2009) quantify safety risk for construction tasks and environments (e.g., ascending and descending a ladder), and Tixier et al. (2017) defines safety risk based upon fundamental attributes (e.g., uneven work surface). Other researchers such Mitropoulos and Namboodiri (2010), and Rosa et al. (2015) quantified risk based on project activities (e.g., roofing activity).

The sum of the dangers associated with a work package is referred to by Hallowell and Gambatese (2010) as *demand*. Alternatively, all safety leading indicator studies discuss the quantity or quality of safety management activities implemented to prevent injuries. Hallowell and Gambatese (2010) refer to the sum-total of preventative efforts as *capacity*. According to this theory, one could differentiate safety leading indicators as measuring capacity only and not concerning the physical characteristics that make work dangerous.

2.2.3 Safety Leading Indicators

Unlike safety climate and risk analysis, leading indicators directly and empirically measure the strength of the safety management system and how it improves future performance. Typically, the proposition made by a researcher is that the leading indicator measure taken now predict general safety performance (e.g., recordable injury rates for a project). Hinze et al. (2013) described leading indicators as a group of selected measures that can provide insight safety process effectiveness. In addition, leading indicators are described as supporting proactive responses because actions can be taken to control the system before an injury propagates.

Leading indicators can be measured at different time periods. For example, an organization could measure daily management activities, weekly safety meeting frequency, or monthly safety audit scores (Hallowell et al. 2013). These proactive metrics should be valid and reliable measures that cover all relevant safety aspects, have positive effects in reducing injury, quantitatively measure and monitor data, and have less impact on both time and cost of a construction project (Biggs et al. 2010; Guo and Yiu 2015; Hale 2009; Hallowell et al. 2013; Leveson 2015).

Recent studies have addressed various aspects of leading indicators in the construction industry; for example, identifying proactive safety metrics (Guo and Yiu 2015; Hallowell et al. 2013), measuring and controlling these indicators (Hallowell et al. 2013), investigating their relationship to worksite injury (Rajendran 2012; Salas and Hallowell 2016), and measuring how they relate and cycle over time (Lingard et al. 2017)

As shown in Table 2, there are a plethora of possible indicators identified in early research on the topic. For example, through expert panel and case studies, Hallowell et al. (2013) identified 13 proactive safety indicators that improve safety performance. These indicators include near miss reporting, safety observation, auditing program, pre-task safety meeting, housekeeping program, and worker involvement. Later, in a study of 261 contractors, Salas and Hallowell (2016) found evidence that empirically supported the following as predictive: near-miss reporting, stop work authority, upper management engagement in safety activities, worker involvement, owner involvement, safety auditing and observation, and safety risk assessment. To provide practical recommendations for the formation of a leading indicator program, Guo and Yiu (2015) presented a model for developing leading indicators based on four major steps: define the system and analysis level (*conceptualization*), include only measurable constructs (*operationalization*), develop leading indicators (*indicator generation*), and validate selected leading indicators (*validation and revision*). This process was then applied to a hypothetical construction project, and 32 leading indicators were generated. These included the number of sites visited by an owner or safety representative, written safety plan, supervisory support, stop work authority, and frequency of pre-task safety meeting. Clearly, both the process to create and the leading indicators themselves vary widely. Thus, aggregation and standardization of this body of literature is needed.

Perhaps most importantly, the definition and categorization of safety leading indicators is equivocal and nebulous. This has led to serious confusion in the literature in what is a leading indicator and what is not, active versus passive indicators, and the role of near misses. The following section provides clarity in the epistemological positioning of safety leading indicators to standardize the definitions using logical and empirical evidence.

Table 2: Examples, descriptions, and sources of construction safety leading indicators

Leading indicator	Description	Example item	Selected Reference (s)
Upper management involvement	The degree of upper management commitment to safety aspects of worker safety and health.	Safety support includes safety funding; training; engagement in safety meeting.	Hallowell and Gambatese (2009); Choudhry et al. (2008); Salas and Hallowell (2016)
Training/orientation	The degree of providing training and orientation of job site hazards for skilled and unskilled workers.	Jobsite orientation sessions; in-house safety training	Hallowell and Gambatese (2009); Hinze and Wilson (2000)
Pre-task safety meeting	The frequency of pre-task safety planning that conducted by both foramen and workers as daily tasks to ensure day-to-day activities performed safely.	Safety pre-task plan; formal safety meetings with project supervisor	Hallowell et al. (2013); Rajendran (2012); Jaselskis et al. (1996)
Safety inspections/ observation	The frequency of safety inspection/observation to identify hazards or safety violation to ensure worker safety and health.	Safety officer makes specific job site safety walkthrough; safety auditing	Hallowell and Gambatese (2009); Hinze and Raboud (1988); Salas and Hallowell (2016)
Hazard and accident analysis	The frequency of safety hazard and accidents analysis reported and reviewed for construction process.	Near-miss reporting; project risk assessment; accident investigation	(Cheng et al. 2015; Hinze et al. 2013a); Salas and Hallowell (2016)
Owner involvement	The degree of owner involving in the safety aspect.	Owner safety walkthroughs; review safety plans; attending safety meeting	Salas and Hallowell (2016); Hinze et al. (2013); Hinze and Raboud (1988)
Safety record	The degree of reporting and maintaining accident records, and safety performance record	Accident reporting; first-aid log is maintained	Hinze et al. (2013a); Cheng et al. (2015)
Worker involvement	The degree of worker involvement in safety aspects, such as safety decisions and feedback to top management.	Workers involved in safety policy, perception surveys, and safety feedback	Hinze et al. (2013a)
Safety resource	The effort of safety committee (e.g., supervisory, owner safety representative, and project leaders) of providing requires safety resources.	Providing medical facilities in worksite	Hinze et al. (2013a)
Staffing for safety	The number of certified safety representatives in the worksite.	The percentage of workers to safety professionals	Jaselskis et al. (1996); Hinze et al. (2013a)
Written safety plan	A complete and comprehensive safety plan that guides project safety.	Written safety plan includes safety goals; objectives, and procedures	Hallowell and Gambatese (2009)
PPE	The provision of the requirement personal protective equipment (PPE) for all workers.	PPE program; providing worker with safety clothes and shoes	Aksorn and Hadikusumo (2008); Choudhry et al. (2008); Sawacha et al. (1999)
Substance abuse	The frequency of random drug and alcohol tests to prevent substance abuse of the worker.	Drug and alcohol testing	Lingard et al. (2017); Hinze and Gambatese (2003)
Incentives	The safety promotions and praise for workers with positive safe work behavior.	Safety incentive programs; assessment of craft worker penalties	Hallowell et al. (2013); Hinze and Gambatese (2003); Jaselskis et al. (1996)

2.4 Distinguishing between passive and active safety leading indicators

Leading indicators are classified as active and passive indicators, and both have been used to predict safety performance (Hinze et al. 2013). The following section highlights the differences between active and passive leading indicators and reviews 27 studies published between 1986-2016.

2.4.1 Differences between active and passive leading indicators

Passive leading indicators are typically implemented before work begins and remain relatively static once a project has begun (Hinze et al. 2013). Measures of these indicators are also generally dichotomous in that the organization implements them or does not. Examples of passive leading indicators include a steel-toed boots policy, a design for safety review in the design phase, and contract provisions that require subcontractor compliance with a site-specific safety policy or program (Hinze et al. 2013a; Hinze et al. 2013). These activities are not likely to change once a project begins and can be noted as implemented or not implemented before construction. The common data entry for these indicators is a binary ‘yes/no’ response.

In contrast, active leading can be readily changed during the construction phase (Hallowell et al. 2013; Hinze et al. 2013). These indicators are generally continuous in that they occur at a frequency or are measures of quality of implementation. Examples of active leading indicators include the frequency of job site safety meetings, quality of pre-job safety meetings, rate of involvement of upper management in safety walk-throughs, and safety audit scores. Each of these indicators can be modified during construction if goals are not met. For example, the organization can increase the frequency or quality of safety meetings, increase involvement of upper management, and seek to improve safety audit scores.

Use of these terms is inconsistent in the literature. Often, authors describe active indicators as passive and vice versa. Typically, inconsistencies exist in the ways that the indicators are discussed. For example, authors may consider safety meetings an active indicator. However, the distinction between active and passive for safety meetings depends on how the indicator is measured. For example, if the researchers ask whether the organization implemented pre-job safety meetings, the indicator will be passive (i.e., the data were collected as dichotomous). Alternatively, if the frequency or quality of safety meetings was monitored and controlled over time, this indicator would be active. That is, many indicators could be both active or passive and the true distinction between active and passive depends on the way that the data are collected (i.e., the data form).

Figure 2 provides a flowchart to assist future researchers with the correct indicator distinction. This chart was applied in the present study to make consistent, operationalized definitions and distinctions in the meta-analysis. This which was critical for consistency in an area of literature where the distinction is often erroneous or unclear.

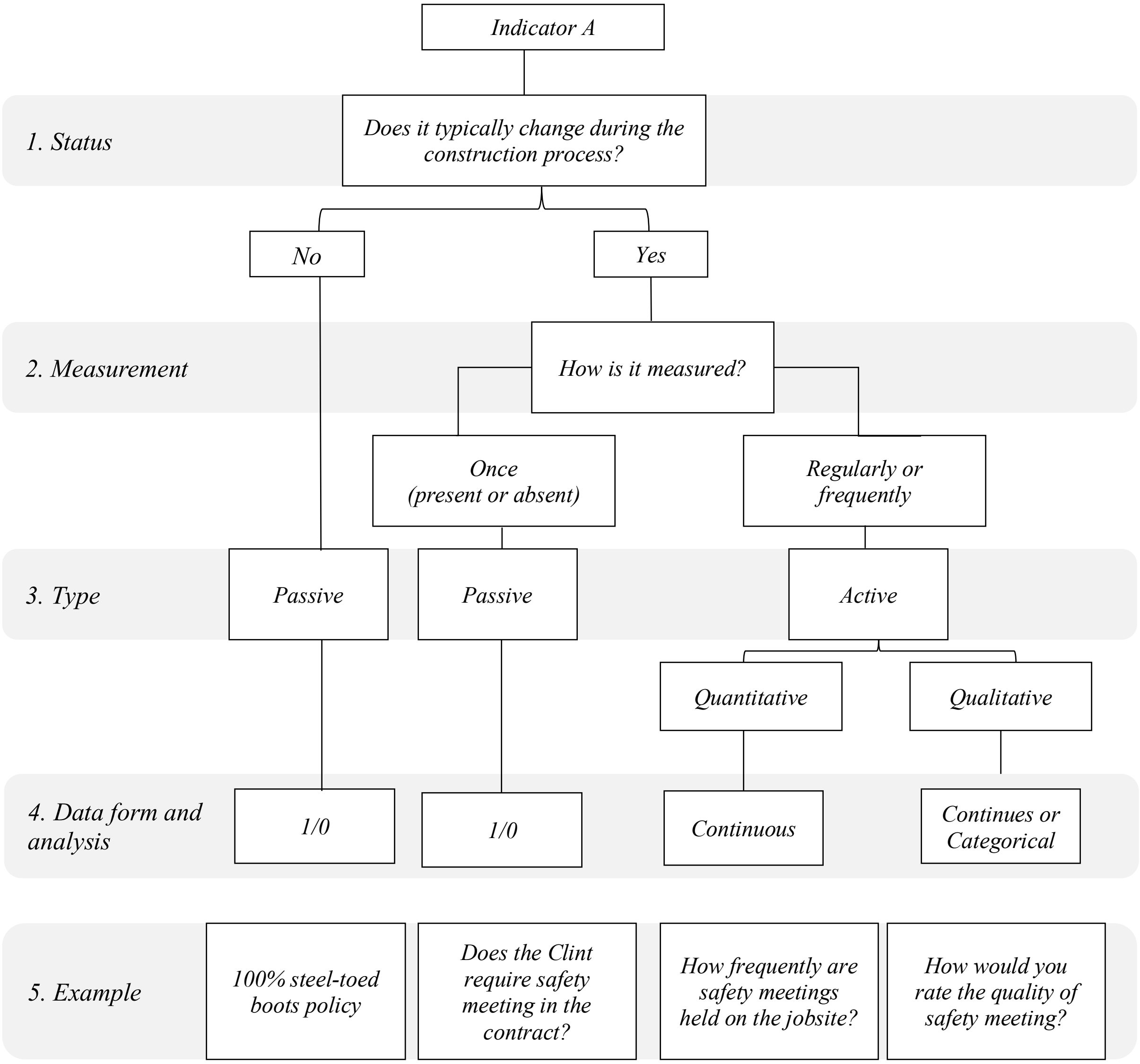

Figure 2: Flowchart that enables the distinction between active and passive safety leading indicators

2.4.2 Examples of passive leading indicators

Per the definition in Figure 2, 22 of the 27 extant studies investigated passive indicators (See Appendix B for complete list of all studies included in the review). Interestingly, there is a significant body of knowledge that examined how safety strategies impact safety performance. Although not explicitly labeled as leading indicator research, these studies include data and perspectives that are completely aligned with the definitions in this paper. Thus, they are included in this review.

Among the indicators studied, the most common are safety training and orientation, incentives, and safety inspections. To illustrate examples of how some passive safety leading indicators are assessed and the extent that they predict performance is reviewed. The most prominent passive safety leading indicator is safety training, appearing in the majority of studies on the topic (Aksorn and Hadikusumo 2008; Alarcón et al. 2016; Cheng et al. 2012; Goh and Chua 2013; Hinze and Gambatese 2003; Hinze et al. 2013a; Jaselskis et al. 1996; Lai et al. 2011). The proposition is that having a safety training program on a project leads reduces the frequency of injuries (Hallowell and Gambatese 2009). Research unequivocally connected enhancements in training with improvements in performance. Safety training was typically assessed by questions such as, “Is health and safety training provided to the employees of subcontractors?” (Choudhry and Zahoor 2016; Hassanein and Hanna 2007).

Similarly, the relationship between safety incentives programs and injury rate was included in nearly 80% of studies. However, the connection to performance was less conclusive (Alarcón et al. 2016; Hinze and Gambatese 2003; Idoro 2008; Jaselskis et al. 1996). In fact, the existence of safety incentive programs in some specialty contractors had no effect on company safety performance (Hinze and Gambatese 2003) and others found that safety incentive programs *increase* injury rates (Hinze et al. 2013). An example of a question assessing this indicator is, “Do workers receive an incentive or reward for not being injured?” (Hallowell et al. 2013).

As a final example, safety inspection/observation appeared in 11 studies (50%). This indicator includes site safety auditing, formal safety inspection, and worker behavior observation. Studies showed moderately strong evidence of a reduction in injury rates (Hinze and

Gambatese 2003; Hinze and Raboud 1988; Jaselskis et al. 1996). This indicator is typically assessed with questions like, "Does the job supervisor or safety officer make specific jobsite safety tours?" (Hinze and Raboud (1988)

2.4.3 Active leading indicators

The measurement of active leading indicators is comparatively rare, which is likely because these studies require significant resources and access to large volume of sensitive company data. An interesting difference between active and passive indicators is the way that they are measured. Rather than yes or no questions measured once to indicate overall project performance, active indicators are measured at a regular frequency (e.g., monthly) to indicate future performance on the same project (e.g., with a three-month delay).

Of the 27 studies identified, only five measured active leading indicators as they are defined here (Appendix B). Hazard reporting and accident analysis, safety inspection and observation, and pre-task safety meeting were the most common. The strongest predictors of future performance were safety inspection and observation and pre-task safety meetings (Rajendran 2012; Salas and Hallowell 2016). For example, Salas and Hallowell (2016) measured the frequency of contractor internal safety audits using a data reported in the client's standardized safety management system software. The results predicted recordable injury rates three months later for the same project. This is a representative example of the data collection and analysis process.

2.5 Research Approach

A meta-analysis method used to assess the predictive validity of both active and passive construction safety leading indicators. Meta-analysis used a statistical approach to combine quantitative research findings from multiple empirical studies. This approach leads to combined effect sizes from different studies to increase power and capture the true effect (Card 2011;

Schmidt and Hunter 2004) by: reviewing literature, coding studies, standardizing effect sizes, and calculating the combined effect size.

2.5.1 **Comprehensive literature search**

The overall goal of the comprehensive literature search was to locate all published studies on the topic and to compute and aggregate effect size for each salient variable (Card 2011). The authors searched for studies using search engines offered by the American Society of Civil Engineering, Web of Since, Engineering Village, and Google Scholar. Additionally, a variety of individual and combined keywords were used, such as "safety management system," "safety program," "construction-safety practices," "safety performance," "safety strategies", "safety leading indicators," and "proactive indicators." Studies were included if they: (1) investigated the relationship between either active or passive safety leading indicators (e.g., construction safety practices) and accidents or injury; (2) reported the effect size (e.g., correlation values) or enough information to compute the effect size; (3) sampled data from the construction industry; and (4) were peer-reviewed. It is also important to note that primary author was contacted via email if more information on a study was needed. Once the author responded with required information, the study was included in the meta-analysis.

2.5.2 Coding study characteristics and effect sizes

Studies that met the inclusion criteria were coded into a database using the following categories: author, publication date, measurement characteristics (i.e., active or passive safety leading indicators), and outcome characteristics (e.g. recordable injury rate). Table 10 shows the coding and characterization of included studies.

The second step of the coding process was extracting the effect size from individual studies (e.g., correlation values) or statistics information (e.g., z-value) to compute the effect size. When a study reported a correlation value between individual leading indicators and injury rate, the correlation value was used directly as the index of effect size (Card 2011). Leading indicators identified from different studies were assigned to specific categories, as shown in Table 3. Distinctions between active and passive leading indicators were based on distinctions presented in Figure 2. When more than one leading indicator from a study was assigned to a category, the overall correlation value was calculated by using the composite score correlation formula given by Schmidt and Hunter (2004, pp. 430-439), as shown in Equation 1:

$$r_{xy} = \frac{\sum r_{xyi}}{\sqrt{n + n(n-1)\bar{r}_{yi\,yi}}} \tag{1}$$

Where r_{xyi} is the sum of correlations, n is the sample size (i.e., number of correlations), and $\bar{r}_{yi\,yi}$ is average correlation among these indicators.

For example, Salas and Hallowell (2016) provided the correlation of the following five leading indicators with injury rates (e.g., grouped into safety inspection and observation category): safety observation (r = 0.32); client audits (r = 0.15); contractor safety audits (r =0 .22); subcontractor safety audits (r = 0.12) and corrective action items (r = 0.26). The sum of these correlations is 1.09, and the average correlation among these indicators ($\bar{r}_{yi\,yi}$) is 0.129. Thus, the composite score correlation then calculated as follows: (1.09)/sqrt(5+5(5-1)*0.129 = 0.4.

Table 4 shows a practical example of applying the following equations and procedures for the relationship between pre-task safety meeting and injury rates. The correlation values were transferred to Fisher's (Z_r) to avoid the assumption of skewness linked to the distribution of sample r (Card 2011) by using Fisher's transformation of r equation, shown in Equation 2:

$$Z_r = 1/2ln\left(\frac{1+r}{1-r}\right) \tag{2}$$

Where Z_r represents Fisher's transformation of *r*, and r is the correlation coefficient. The standard error of Fisher's test then calculated by using Equation 3:

$$SE_{Zr} = \left(\frac{1}{\sqrt{N-3}}\right) \tag{3}$$

Where SE_{Zr} represents the standard error of Z_r, and *N* the sample size for the individual study.

Schmidt and Hunter (2004) identified 11 artifacts that the meta-analyst can use to correct collected effect sizes, including correction of error of measurement in individual studies, range variation, and dichotomization of a continuous variable. To make these corrections, more information was required for each primary study, such as reliability coefficients to correct the measurement error artifacts. When the artifact information was reported in some of the included studies, Schmidt and Hunter (2004) suggested the *distributions of artifacts* method of using available information from some of the included studies. However, the studies included in this meta-analysis lacked the required statistical information to correct the effect sizes so no correction was applied.

In the forthcoming analysis, the details of the analytical procedure are described in detail and two examples are provided from Salas and Hallowell (2016) and Rajendran (2012). These data are provided so that future researchers can replicate and validate the method and so that the safety community has a clear guide on the use of meta-analysis.

Table 3: Characteristics of empirical studies included in the meta-analysis

			Indicator category								
Study (date)	N	Indicator type	Safety inspection/observation	Pre-task	Training/orientation	Incentive	Safety resources	Staffing for safety	Safety record	PPE	Owner involvement
Salas and Hallowell (2016)	191	Active	×	×							
Alarcón et al. (2016)	1,180	Passive			×	×					
Hinze et al. (2013a)	28	Passive			×		×	×	×	×	×
Rajendran (2012)[a]	684; 1,417	Active	×	×							
Idoro (2008)	43	Passive	×			×	×			×	
Hinze and Gambatese (2003)	46	Passive	×		×	×					
Jaselskis et al. (1996)	69	Passive	×	×		×		×			
Hinze and Raboud (1988)	14	Passive	×	×				×	*x*		×

Note: [a]This study reported two different sample sizes for each leading indicator

Table 4:Effect size calculation results for the relationship between pre-task safety meeting and toinjury

Citation	N	r	Z_r	SE_{zr}
(Salas and Hallowell 2016)	191	0.38	0.40	0.07
(Rajendran 2012)	684	0.51	0.56	0.04

Note: N= sample size; r= correlation value reported in each study; Z_r = Fisher's transformation of *r; and* SE_{zr} = standard error of Fisher's test

2.5.3 Standardization

Many studies reported different statistics to represent effect size. In cases where the statistic varied among studies, the data were standardized to one comparable statistic. For example, when a study reported the result of z statistical significance test, Equation 4 was used to compute the effect size *r:*

$$r = \sqrt{\frac{Z^2}{N}} \tag{4}$$

Where *r* represents the effect size, *z* is the *z*-score, and *N* is the sample size.

In addition, when a study reported only the statistical significance of *t*-tests or chi-square tests (e.g., Jaselskis et al. (1996) study), this method was used to transfer those reported statistical significance values to effect size *r* (Card, 2011, pp. 101-102). Once the corresponding z-score of that statistical significance is found, Equation 4 was used to transfer that z-score to effect size *r*.

2.5.4 Computation of overall effect size

The effect sizes from individual studies were aggregated to obtain the overall effect size for both active and passive leading indicators using a random-effect model. In this, the main assumption is that the effect sizes from each primary study vary across studies (Borenstein et al. 2009). Table 5 illustrates the calculation procedures of the overall effect size. Each study was weighted by the inverse of the standard error of the effect size to ensure that more accurate individual study effect sizes have a greater impact on overall effect size than the less accurate (Card 2011). Equation 5 shows the formula to calculate the weighted values for each study:

$$w_i = \left(\frac{1}{SE_i{}^2}\right) \tag{5}$$

Where w_i is the weight for study *i*, and SE_i is the standard error of the effect size estimate for study i.

Once each study was weighted, the result was used to estimate weighted mean effect size. Equation 6 illustrates the generic equation to calculate the weighted mean effect size referred to by Card (2011):

$$\overline{ES} = \frac{\sum(w_i Es_i)}{\sum(w_i)} \tag{6}$$

Where $\overline{ES}$ represents the weighted average effect size, Es_i is effect size, and w_i is the weight for each individual study calculated using Equation 5.

The next step was to evaluate heterogeneity among studies. The heterogeneity test can help determine whether all included studies in the meta-analysis were measuring the same effect (Higgins et al. 2003). Equation 7 illustrates how to calculate the heterogeneity among included studies using the Q test (Card 2011):

$$Q = \sum (w_i \, ES^2{}_i) - \frac{(\sum(w_i ES_i))^2}{\sum w_i} \tag{7}$$

Where Q represents the heterogeneity statistic, w_i the weight of study i, and ES_i the effect size estimate for such a study.

Applying this equation to the example illustrated in Table 5, a value of 3.81 was obtained. The result obtained from the Q test can be used to evaluate the random variance associated with true differences among different studies by using Equation 8:

$$\tau^2 = \frac{Q - (k - 1)}{(\sum w_i) - \frac{(\sum w_i{}^2)}{(\sum w_i)}} \tag{8}$$

Where τ^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.

Because this study used a random-effect model, a new weighted calculation was needed. Equation 9 was used to calculate the weighted values for individual studies in the random-effect model by using the results from Equations 3 and 8:

$$w_i = \left(\frac{1}{\tau^2 + SE_i{}^2}\right) \tag{9}$$

Where w_i is the weight for study i, τ^2 is the random variance of heterogeneity, and SE_i is the standard error of the effect size estimate for study i.

Table 5:Fixed and random effect calculation procedure and results for the relationship between pre-task safety meeting and injury

Citation	Fixed Effect Model				Random Effect Model			
	w_i	w_i (%)	$w_i * Z_r$	$(w_i * Z_r^2)$	${w_i}^2$	w_r	w_r (%)	$w_iEs_i(w_r * Z_r)$
(Salas and Hallowell 2016)	188	21.63%	74.77	29.74	35,344	67.2074	42.57%	26.7300
(Rajendran 2012)	681	78.37%	380.46	212.56	463,761	90.6734	57.4%	50.6577
Total	869	100	455.23	242.29	499,105	157.8	100	77.38

Note: w_i = study weight (fixed effect model), w_r = study weight (random effect model).

Calculating the overall effect size (Z_r) for the example in Table 5 by using equation 6, a value of 0. 49 was obtained. However, Card (2011) suggested transferring this value back to *r* because the Z_r is less frequently used and may be increase the difficulty of interpreting results. Equation 10 shows the mathematical process to transfer Z_r back to *r:*

$$r = \left(\frac{e^{2z_r} - 1}{e^{2z_r} + 1}\right) \tag{10}$$

By applying the Equation 10 to the value we obtained from the previous step (Z_r = 0.49), we found an *r* was 0.45.

It is important to note that this procedure was used to conduct two distinct meta-analyses, one for active and another for passive safety leading indicators. The data were not aggregated across groups because of the differences in the construct being measured, data form, and implications as indicated in Figure 2.

2.6 Meta-analysis results

The results of this meta-analysis revealed that the effect sizes of the relationship between leading indicators and injury varied widely, as shown in Tables 6 and 7. Nine construction safety leading indicators were included in this analysis. As shown in Table 6, the effect sizes of the relationships between *safety inspection and observation* and injury ($r = 0.51$, *95% CI* = 0.30 to 0.67) between *pre-task safety meeting* and injury was also large ($r = 0.45$, *95% CI* = 0.32 to 0.57) were very large.

For the nine passive leading indicators, eight were significant ($p < 0.05$) as shown in Table 7. Specifically, the relationship between injury rate and *safety record* ($r = 0.56$, *95% CI* = 0.20 to 0.79) and *safety resources* ($r = 0.48$, *95% CI* = 0.28 to 0.65) had large effect sizes. *Staffing for safety* ($r = 0.44$, *95%CI* = 0.12 to 0.68), *owner involvement* ($r = 0.45$, *95%CI* = 0.16 to 0.67), *training and orientation* ($r = 0.42$, *95% CI* = 0.10 to 0.66), *personal protective equipment* ($r = 0.40$, *95%* = 0.17 to 0.58), and *incentives programs* ($r = 0.30$, *95%* = 0.15 to 0.43) were all moderate. Finally, the effect size of *safety inspections and observation* was low ($r = 0.27$, *95%* = 0.12 to 0.41) and *pre-task meetings* was not significant ($p = 0.103$).

An interesting finding was that pre-task safety meetings showed to be a significant predictor of future performance when measured regularly and treated like an active leading indicator. However, considering pre-task safety meetings as a passive indicator (i.e., does the organization have meetings or not) is not predictive. This underscored the need to understand the most effective use of each indicator and the importance of a formal distinction and meta-analysis offered in this paper.

Table 6: Correlation of active construction safety leading indicators and injury rate

Active indicators	*K*	*N*	*r*	*95% CI (LL,*	*UL)*	*P-value*
Safety inspections and observation	2	1,608	0.51	0.30	0.67	0.000
Pre-task safety meeting	2	875	0.45	0.32	0.57	0.000

Note*: K: number of study; N*= sample size*; r*= effect size; and *95% CI*= confidence interval (lower-upper) around r

Table 7:Correlation of passive construction safety leading indicators and injury rate

Passive indicators	*K*	*N*	*r*	*95% CI (LL,*	*UL)*	*P-value*
Safety record	2	42	0.56	0.20	0.79	0.005
Safety resource	2	71	0.48	0.28	0.65	0.000
Owner involvement	2	42	0.45	0.16	0.67	0.003
Staffing for safety	3	111	0.44	0.12	0.68	0.013
Training/orientation	2	1,254	0.42	0.10	0.66	0.016
PPE	2	71	0.40	0.17	0.58	0.001
Incentives	3	1,338	0.30	0.15	0.43	0.000
Safety inspections and observation	4	168	0.27	0.12	0.41	0.001
Pre-task safety meeting	2	83	0.40	-0.07	0.72	0.103

Note*: K: number of study; N*= sample size*; r*= effect size; and *95% CI*= confidence interval (lower-upper) around r

2.7 Conclusion and discussions

This paper offers three primary contributions: (1) a clear definition and distinction of safety leading indicators from other predictive safety techniques; (2) a practical method for distinguishing active and passive indicators; and (3) the first meta-analysis of safety leading indicators. The objective of the meta-analysis was to determine a set of common indicators and measure the extent to which they predict injury rates across multiple studies and samples. This addresses a current gap in the literature where the epistemological positions are highly variable and findings remained preliminary and have yet to be validated. This study identified nine common leading indicators that are significantly correlated with worksite injuries: safety record; safety resource; staffing for safety; owner involvement; safety training/orientation; personal protective equipment; safety incentives program; safety inspections and observation; and pre-task safety meeting. The source studies included diverse types of construction projects (e.g., rail, highway, oil and gas, and buildings), geographies (e.g., USA, Australia, and Canada), and companies. Thus, for the first time, this study revealed that these indicators are valid and generalizable across geographies, industry sectors, company types, and safety cultures.

Regarding active safety leading indicators, *safety inspection and observation* had the large effect size ($r = 0.51$). This finding is explained qualitatively by Toole (2002) who found that proper inspection and worker observation targets unsafe behaviors, poor skills and safety knowledge, and errors that are the root cause of many injuries. In practice, Hallowell et al. (2013) suggested that an average number of safety observations conducted by a trained observer per 200,000 work-hours should be considered as the standard method of measuring this indicator.

Additionally, this study found a large effect size of the relationship between *pre-task safety meeting* and injury ($r = 0.45$). A wide variety of literature propose that safety meetings and their corresponding job hazard analyses are the foundation of an effective safety program (Hinze and Wilson (2000). Hallowell et al. (2013) suggested that the frequency of pre-task plans conducted at the job site should be used to measure this indicator. Interestingly, in a later study, Albert et al. (2013) developed and tested a new method of assessing, tracking, and improving the quality of these meetings. Although the present study includes only quantitative approaches to indicator measurement, this new research suggests that qualitative indicators may also be effective.

Regarding passive safety leading indicators, this meta-analysis study revealed that eight passive safety leading indicators predict safety performance, ranging from strong to weak predictive power: (1) safety record; (2) safety resource; (3) staffing for safety; (4) owner involvement; (5) safety training/orientation; (6) personal protective equipment; (7) safety incentives program; and (8) safety inspections and observation. These include safety management activities like recordkeeping that many consider to be standard practice. In this way, some of the passive indicators may be used to distinguish standard practice from divergent organizations. Active indicators, on the other hand can be used to distinguish even among high-performance organizations because frequency and quality of implementation can vary widely.

Nevertheless, not all passive indicators would measure divergence. For example, safety resources (e.g., the availability of medical facilities in the job site) showed the second strongest correlation with performance (r = 0.48) and is not necessarily standard practice. Organizations may use these findings to justify additional resource expenditure based upon scientific findings. More importantly, pre-task safety meeting indicator was found to be not significant when it is measured as passive leading indicators.

The practices that are moderately predictive (see Table 14) are considered by most previous researchers to be harmonious and interactive in the creation of a comprehensive safety program (Hallowell and Calhoun 2011). The commitment and involvement of clients in safety activities, for example, can effectively reduce injuries and ensure effective implementation of personal protective equipment, staffing, training, and incentives (Huang and Hinze 2006; Hallowell and Calhoun 2011).

The findings of this study are important for both researchers and practitioners to create and validate common leading indicators of safety performance for the construction industry and serves as a first step towards standardizing leading indicators for the construction industry. Researchers and practitioners are encouraged to contribute to the debate and suggest other epistemological positions or to apply the rules for distinguishing leading indicators from other predictive safety methods and for distinguishing among the two primary types of safety indicators. Consistency among perspectives and methodologies would enable scientific discourse that is presently lacking.

2.7.1 Study Limitations

Empirical studies in the construction safety leading indicator are rare, and access to a large volume of empirical data was one of the major limitations of this meta-analysis study. Specifically, studies reporting active leading indicators were very rare. Only six in the current literature reported active leading indicators, and only two qualified for inclusion in this meta-analysis. Of the 13 common leading indicators identified in this study (Table 9), only nine were included in this meta-analysis due to insufficient reported sample sizes. Researchers may see this as an opportunity to expand upon this work as the field matures. More empirical investigation of the relationship of active safety leading indicators should be considered.

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CHAPTER 3: SAFETY CLIMATE DIMENSIONS AND THEIR RELATIONSHIP TO CONSTRUCTION SAFETY PERFORMANCE: A META-ANALYTIC REVIEW

3.1 Abstract

This study investigated the empirical relationship between measures of construction safety climate dimensions and safety performance. A comprehensive review of existing literature of construction safety climate was conducted to: (1) review the questionnaires used to measure safety climate dimensions in the construction industry; (2) identify the salient dimensions of safety climate; and (3) establish a consistent definition of each safety climate dimension. Then, a statistical meta-analysis of the empirical relationship between construction safety climate dimensions and safety performance was performed. 107 studies were reviewed, and 11 studies were included in the meta-analysis. The review indicated that 14 construction safety climate dimensions were commonly used to assess safety climate. Of the 14 dimensions, five—supervisor's safety role (*$r=0.30$, 95% CI= 0.07 to 0.50),* management commitment to safety (*$r=0.27$, 95% CI=0.23 to 0.31)*, safety rules and procedures (*$r= 0.25$, 95% CI= 0.12 to 0.37)*, individual responsibility to health and safety (*$r=0.23$, 95% CI= 0.17 to 0.31*, and training (*$r= 0.10$, 95% CI= 0.03 to 0.17)*—were identified as commonly used predictors of injury rates. The results can be used by researchers and practitioners in this burgeoning field to standardize the assessment of safety climate and to validate the use of safety climate as a predictor of safety performance.

3.2 Introduction

Researchers have begun to implement a variety of methods of predicting construction safety performance including safety risk analysis, leading indicators, precursor analysis, and safety climate. Among these, safety climate, defined as "individual perceptions of policies, procedures, and practices relating to safety in the workplace" (Neal and Griffin 2006, pp. 946–947) is the most widely researched. Recent studies have focused on developing new safety climate measurements ((Kines et al. 2011; Mohamed 2002; Zhang et al. 2015). However, safety climate assessment remains inconsistent across studies (Schwatka et al. 2016). Glendon and Litherland (2001) argued that organizations present different roles and requirements for safety, thus safety climate dimensions might differ by organization. Nevertheless, some dimensions are universally recognized, such as management commitment to safety (Beus et al. 2010; Flin et al. 2000; Schwatka et al. 2016). Thus, the extent to which they consistently predict safety performance is of interest.

Recently, researchers have begun to explore the predictive nature of safety climate. In fact, a positive correlation between safety climate and safety performance has been found by many studies, as indicated by an inverse relationship between positive assessments of safety climate and injury rates (Chen et al. 2013; Goldenhar et al. 2003; Lingard et al. 2011; Hon et al. 2014a; Lingard et al. 2012; McCabe et al. 2016; Panuwatwanich et al. 2016). Unfortunately, these studies do not use a single safety climate survey, which makes evaluating consistency in results difficult. However, a formal statistical meta-analysis can enable comparison and aggregation cross studies and reveal patterns across multiple samples.

No meta-analysis has yet been conducted specifically on safety climate in the construction industry. The construction industry reflects unique and complicated characteristics, and project site conditions that differentiate it from other industries. However, out of all the published meta-analysis and literature review studies, only two reviewed safety culture and climate in the construction industry (Choudhry et al. 2007; Schwatka et al. 2016). For example, Schwatka et al. (2016) qualitatively summarized the literature of safety climate studies between 1980 and 2014.

Despite the many construction safety climate studies published recently, a gap exists in safety climate dimension literature from 2014 to present

The main purpose of this study was to: (1) review questionnaires used to measure construction safety climate dimensions; (2) identify the salient dimensions of safety climate for construction; (3) establish a consistent definition of each safety climate dimension; and (4) quantify the extent to which each safety climate dimensions predicts construction safety performance. To achieve this last objective, a meta-analysis was performed using all peer-reviewed articles published in English from 2000 to 2016.

3.3 Literature review

The objective of the literature search was to collect and code all safety climate studies that included empirical data published between 2000 and 2016. The search was performed using a wide variety of individual or combined keywords. These key words were "construction," "safety climate," "safety culture," "safety attitude," "safety performance," and "construction safety." These keywords were searched in the following recognized databases and indexing tools: Google Scholar, Web of Science; Engineering Village; PubMed; PsychInfo; and the American Society of Civil Engineering. The following is a summary of the history and salient trends in safety climate in the construction industry.

3.3.1 Safety climate in the construction industry

In the initial years following the introduction of the safety climate concept (Zohar 1980), the construction research community showed faint interest with only a few studies published between the years 1980-2000. In the first construction-specific study, Dedobbeleer and Béland (1991) examined the concept of safety climate among construction workers using the Brown and Holmes (1986) three-factor model developed for American manufacturing and production companies. Despite the slow start, the publication rate of construction safety climate studies has accelerated in recent years as illustrated in Figure 3. In a comprehensive literature review, 107 articles on construction safety climate were published from 2000 to 2016 and approximately 60% were published in the last 5 years. The topics of these studies varied widely, with some focusing on worker perceptions based on work type (Glendon and Litherland 2001; Cigularov et al. 2010; Hon et al. 2014b) and others developing construction climate surveys (Mohamad 2002; Kines et al. 2011) or investigating the relationship between safety climate and performance (e.g. Chen et al. 2013; Goldenhar et al. 2003; Lingard et al. 2011; Hon et al. 2014a; Lingard et al. 2012; McCabe et al. 2016; Panuwatwanich et al. 2016). As the volume of research increases in this domain, it is important to strive for consistency, which enables scientific rigor through replication and validation.

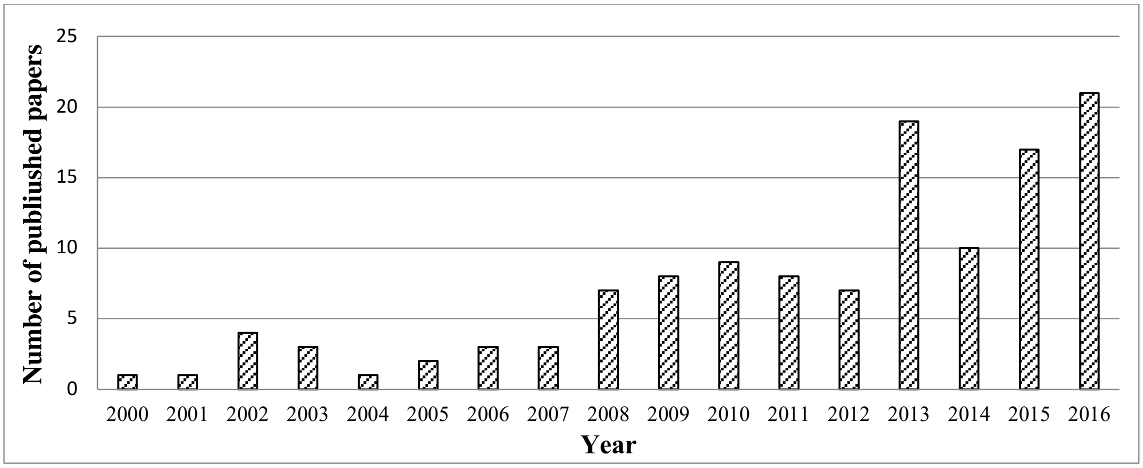

Figure 3: Construction safety climate studies published between 2000 to 2016

3.3.2 Measuring safety climate

Researchers have measured safety climate through the use of a diverse and inconsistent set of questionnaires. The questionnaires, in general, were designed to reflect the definition of safety climate (Mohamed 2002). Commonly, the outputs of these surveys are aggregated scores measuring worker perceptions of safety. In an early study by Zohar (1980), eight safety climate dimensions were introduced: (1) "management commitment to safety; (2) safety training; (3) level of work risk; (4) status of safety officer; (5) work pace; (6) safety committee status; (7) effects of safe conduct on promotion; and (8) effects of safe conduct on social status". The final product was a questionnaire with 40 total items related to the eight dimensions. The questionnaire was tested with a sample from industrial organizations and was shown to be a valid tool for quantifying worker perceptions of safety. In total, the following six climate surveys have been adapted and adopted for use in the construction industry:

1. The 10-item questionnaire developed by Dedobbeleer and Béland (1991), which was based on Brown and Holmes' (1986) original 10-dimension survey.
2. The 16-item organizational safety climate questionnaire developed by Zohar and Luria (2005).
3. The 10-item group-level safety climate questionnaire developed by Zohar (2000). Several authors have combined these last two questionnaires to measure both organization and group safety climate (Cooke et al. 2013; Gao et al. 2016; Lingard et al. 2012; Soraperra et al. 2015).
4. The Climate Survey Tool (CST), developed by the UK Health and Safety Executive (Davies et al. 2001). The CST, originally included 71 items that measured ten safety climate dimensions, such as "organizational commitment and communication, line management commitment, supervisor roles, and workmate influence". The CST is the most popular safety climate questionnaire, and many other researchers have used parts of the CST along with other safety climate tools (Choudhry et al. 2009; Lingard et al. 2011; Lingard et al. 2012).
5. A 10-dimension survey created by Mohamed (2002).

6. The Safety Climate Index Survey (SCI) of the Occupational Safety and Health Council of Hong Kong (OSHC, 2008). The SCI includes 38 questions related to different safety dimensions (Hon et al. 2014b). Various authors across a variety of sectors and work types tested the SCI (He et al. 2016; Hon et al. 2014a; Hon and Liu 2016).

While several recent studies have focused on construction industry safety climate, these studies are inconsistent regarding climate dimensions and levels of analysis (Table 8).

Table 8: Safety climate questionnaires developed for the construction industry

Author (year)	Dimensions (original names)	Description
Li et al. (2016)	Workers' self-perception of safety Worker involvement in safety Co-workers' interaction Safety environment Safety management involvement Safety Personnel support	Designed to capture the perceptions of workers at team level. The survey consists of 23 items, and was tested based on Chinese construction workers.
Zhang et al. (2015)	Organizational safety response Supervisor's safety response Co-workers' safety response Individual safety response	A multilevel safety climate measurement tool designed based on the agent's view (e.g. "client, principal contractor, supervisor, co-workers, and individual workers") Zhang et al (2015)
Kines et al. (2011)	Management safety priority, commitment and competence Management safety empowerment Management safety justice Workers' safety commitment Workers' safety priority and risk non-acceptance Safety communication, learning, and trust in co-workers' safety competence Workers' trust in the efficacy of safety systems	Developed specifically for the Nordic countries. The survey consists of 50 items, and tested with different samples from different industries including construction industry.
Mohamed (2002)	Management commitment to safety Communication Safety role and procedure Supportive environment Supervisory environment Worker involvement Risk-taking behavior Appraisal of work hazard Work pressure Competence	Designed with 70 safety climate statements that capture the perceptions of worker. It was tested with Australian construction workers.
Dedobbeleer and Béland (1991)	Management's attitude toward safety Management's attitude toward workers' safety Foreman's behavior Safety instructions	Constructed 9 items of safety climate, and tested on US construction worker.

	Safety meetings
	Perceived control
	Perception of risk-taking
	Perceived likelihood of Injuries

3.3.3 Common safety climate dimensions in current literature

As discussed, safety climate is invariably measured through multiple dimensions within one survey, such as management's prioritization of safety, worker safety training and involvement, and safety roles by first-line leaders. Thus, safety climate assessment presents a multi-factor structure (Guldenmund (2000). The results across dimensions are aggregated to represent the level of safety climate in an organization. In general, there is an agreement on quantitatively measuring the safety perceptions of workers (Wu et al. 2015). However, the core dimensions of safety climate remain contested among researchers, and a commonly accepted set of climate dimensions remains elusive. For example, Guldenmund (2000), Flin et al. (2000), and Schwatka et al. (2016) performed three reviews of safety climate dimensions and they all present a different set of common dimensions. After examining construction safety climate literature from the year 2000 to 2016, 14 common construction safety climate dimensions were found across 107 studies as illustrated in Figure 4 (see appendix A) . Table 9 presents a description for the top 8 safety climate dimensions. Each of these dimensions and their use in safety climate surveys are briefly reviewed below.

Management commitment to safety is the most common dimension found in the literature, present in 63 studies (59%). This dimension is used by several researchers to quantitatively measure how effectively top management prioritizes safety in an organization (Flin et al. (2000) because researchers believe that it is a strong predictor of work-related injuries (Beus et al. 2010). However, the items defining management commitment to safety differ greatly across studies. For example, Mohamed (2002) used seven items to measure management commitment to safety (e.g., "*Management clearly considers safety to be equally as important as production)"* and Tholén et al. (2013) used sixteen.

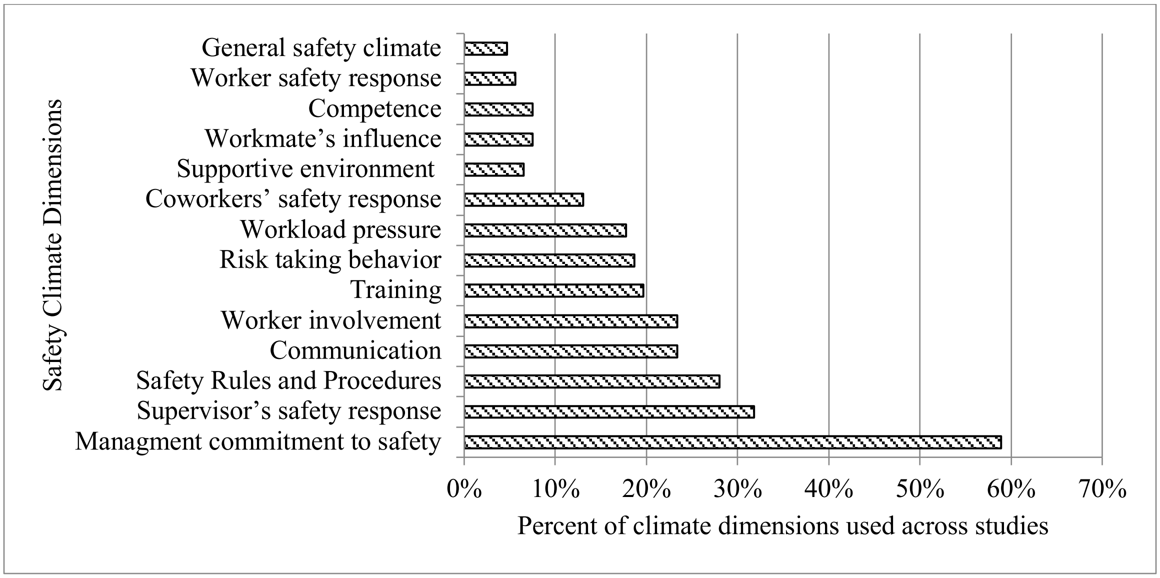

Figure 4: Percentage of safety climate dimensions used across studies (N = 107)

Supervisory safety response was used by 34 studies (32%). This dimensions measures the behavior of direct supervisors regarding safety procedures implementation. Zohar (2000) argued that supervisors play a major role in organizational safety as the party mainly responsible for executing the policies and procedures of the organization. To measure supervisor influence, Zohar (2000) constructed a 10-item group safety climate survey that measures workers' perceptions of two types of supervisory practice: (1) "*action* (e.g., *My supervisor says a good word whenever he sees a job done according to the safety rules, and My supervisor pays less attention to safety problems);* and (2) *expectation* (e.g., *Whenever pressure builds up, my supervisor wants us to work faster, rather than by the rules*)". Although most studies that used supervisory safety response adopted the 10-item survey, other studies adopted different items from climate surveys developed by (Zohar and Luria 2005) and (Mohamed 2002). (Zohar and Luria 2005) questionnaire covered three types of supervisory behavior: "(1) *active practices* (e.g., *Makes sure we receive all the* *equipment needed to do the job safe*), (2) *proactive practices* (e.g., *Reminds workers who need reminders to work safely*), and (3) *declarative practices* (e.g., *Spends time helping us learn to see problems before they arise*)". On the other hand, Mohamed (2002) used items such as monitoring and controlling safety behaviors.

Thirty studies (28%) included a dimension related to rules and procedures, which measured worker perceptions of safety management system. This dimension includes factors such as the degree of understanding of safety rules and procedures, the availability of written safety information, the degree of belief that safety rules and producers will prevent worker injuries, and the rules concerning personal protective equipment. These items were adopted from a variety of questionnaires, including the CST (Davies et al. 2001), SCI (OSHC 2008), and the survey developed by (Mohamed 2002). Overall, the number of items used to assess this dimension varied across studies; however, most questions were similar. For example, when measuring clarity of rules and procedures at the jobsite, Hon et al. (2014b) used the item "*Some health and safety rules or procedures are difficult to follow"*, the CST tool used "*The written safety rules and instructions are too complicated (for people) to follow"* (Davies et al. 2001), and Mohamed (2002) used "*Current safety rules and procedures are so complicated that some workers do not pay much attention to them"*. This consistency enables a strong meta-analysis because the underlying construct being measured by each study are the same.

The dimension of communication was used by 25 studies (23%) and refers to formal and informal safety communication at all levels of an organization. The items used to assess this dimension were inconsistent across studies. For example, Mohamed (2002) and Patel and Jha (2016) used seven items, but Wu et al. (2016) used only two items and Probst et al. (2008) used eight items. Example statements in this dimension include, "*the upper management clearly* *communicates safety issues to all levels within the organiztion* and *the upper management listens to and acts upon feedbacks from the onsite staff"* (Mohamed's 2002).

Worker involvement was also used by 25 studies (23%), and refers to the degree to which workers receive encouragement from the upper management to participate in safety procedures. The number and type of items used to assess this dimension also varies across studies. Fang et al. (2015) and Wu et al. (2016) used the following four items to measure workers' self-reported involvement in the following facets: accident reporting (e.g., "*everyone actively reports safety accidents and potentially hazardous situations")*, safety planning participation (e.g., "*everyone is willing to participate in safety planning if being asked"*), safety analysis (e.g., *"everyone contributes to job safety analysis"*), and sharing safety concern (e.g., *"everyone aims to achieve high levels of safety performance"*). Although Prasad and Reghunath (2010), Zhou et al. (2008), and Hon et al. (2012) all used three questions, the questions were all different.

Training was used by twenty-one studies (20%). Questions used to assess this dimension were shaped by different organizational practices such as safety regulation training, safety program training (e.g., hazard recognition, using protective equipment, etc.), sufficient time and funds for training, and worker access to safety training and information. Wu et al. (2016) used four items to measure safety regulation, including rule training (i.e., "*I fully understand current and relevant safety legislation"*) and safety program training (*i.e., "I am capable of identifying potential hazardous situations, I am capable of using relevant protective equipment and tools,* and *I receive adequate training to perform my job safely and coach others"*). Marin et al. (2015) and Shin et al. (2015) also used four items to assess training similar to but worded differently than Wu et al. (2016). Marin et al. (2015) took a different approach by incorporating potential language barriers for Hispanic workers in the US (e.g., "*workers who do not speak English have difficulty* *understanding safety rules on construction sites"*). Shin et al. (2015) also took a different approach by measuring the propriety of training workers, safety training topics, the amount of training receive, and the access of safety training program and information. When performing a meta-analysis, we are only able to include types of questions related to the training on rules, regulations, and safety programs because they are common across all studies.

Risk-taking behavior was included in 20 studies (19%) to measure worker's awareness of the risk level associated with required work activities. Patel and Jha (2016) used seven items to assess this dimension, Fang et al. (2006) used nine items, and Teo and Feng (2011) used four items. In general, the questions used to assess risk-taking behavior included personal risk taking, perceived likelihood of injury, and the importance of following safety rule and procedure. Even though there is a general agreement about the overall goal of assessing this dimension, the questions used to assess this dimension differed. Some questions only considered the level of personal risk, such as in Mohamed (2002) study (e.g., "*I am sure that it is only a matter of time before I am involved in an accident* and *I am aware that safety is the number one priority in my mind while working"*). Other studies assessed the level of risk at both individual and collective levels, such as Fung et al. (2005) questionnaire (e.g., "*Some of the workforces pay little attention to safety; Some people have a poor understanding of the risks associated with their work"*).

Finally, workload pressure was included in 20 studies (19%) as well. Generally, these questions assess the extent to which workers feel pressure to work quickly. Again, the items used to assess this dimension were inconstant across studies. For example, McCabe et al. (2016) adopted one item from Glendon and Litherland (2001) that measures the degree to which workers feel pressure to work quickly. Alternatively, Teo and Feng (2011) included four items that measure the workload pressure (e.g., "*workers always work under a great deal of tension,* and *workers are not given enough time to get the job done safely"*).

Table 9: Common safety climate dimensions used across studies

Dimension	Description
Management commitment to safety	Refers to how effective top management members are in ensuring that safety is a priority in their organization.
Supervisory safety response	Refers to how responsible first-line leaders are regarding the implementation of organizational safety procedures during day-to-day activities.
Safety rules and procedures	Refers to the degree to which workers believe and follow their organization's safety rules and procedures to prevent accidents/incidents
Communication	Refers to how members of both top management and front line workers communicate health and safety issues, and how openly managers receive feedback from workers about their safety and health concerns.
Worker involvement	Refers to the degree to which workers receive encouragement from the upper management to participate in safety procedures and the extent to which they are invited to be a part of policy creation
Training	Refers to the amount of safety education and instruction that workers receive during their work
Risk-taking behavior	Refers to the degree of risk that workers are willing to take to complete tasks while violating safety regulations in the organization
Workload pressure	Refers to the amount of work that lead workers to perform work unsafely

3.4 Meta-analysis of relationship between safety climate dimensions and injuries

Previous research has found that a positive safety climate leads to safer worker behavior, which also leads to fewer accidents and injuries (Christian et al. 2009; Clarke 2006; Neal and Griffin 2006). In a meta-analysis of general industry, Clarke (2010) linked safety climate and work attitude to safety outcomes. In the construction industry, several studies have investigated the link between safety climate and injuries (Abbe et al. 2011; Goldenhar et al. 2003; Hoffmeister et al. 2014; Hon et al. 2014a; Panuwatwanich et al. 2016; Probst et al. 2008; Siu et al. 2004; Soraperra et al. 2015). However, no meta-analysis has been performed. Most of these studies found that aggregate safety climate was correlated with injury rates but the correlations and specific questions differed (Panuwatwanich et al. 2016). Therefore, it is vital to determine the true effect of safety climate dimensions on safety performance, thus allowing for a more rigorous implementation of safety climate analysis.

3.4.1 Methods

The meta-analysis approach was used to assess the predictive validity of the most common construction safety climate dimensions. Meta-analysis is the primary tool for compounding research findings and can provide quantitative results regarding the magnitude and direction of relationships between variables (effect size) (Lipsey and Wilson 2001). Safety climate dimensions are modeled as independent variables (Table 9) and workplace accidents and injuries as dependent variables. The methods utilized in this study were based on the explanations provided by Schmidt and Hunter (2004) and (Card 2011), and followed four steps: (1) conduct literature search, (2) code individual study characteristics and effect sizes, (3) standardize effect sizes, and (4) calculate the overall effect size. As noted, we ensure that only studies with similar definitions and questions were aggregated to ensure internal validity.

3.4.2 Inclusion of studies for meta-analysis

After conducting the comprehensive literature review, studies eligible for a formal meta-analysis were identified. A study was eligible for inclusion in this meta-analysis if (1) investigated the relationship between safety climate dimensions and accidents or injury; (2) reported either an effect size or enough information to compute an effect size; (3) collected data from a sample of construction industry workers; and (4) was published in English. The initial literature search showed that injuries, the dependent variable in this meta-analysis, was measured by either a self-reported survey or empirical data (injury rate). Both types of data were included in this study and a separate meta-analysis procedure was conducted for each safety climate dimension and injury data type.

3.4.3 Coding

Coding the data for meta-analysis was performed in two steps. First, individual study characteristics were coded into a database. These characteristics included: study, author, publication date, sample size, measurement characteristics (e.g., safety climate dimensions), analysis level (e.g., individual, group, or organizational level), outcome characteristics (e.g., self-reported injury or recordable injury rate). Table 4 illustrates the coding scheme for studies included in this meta-analysis.

After entering all descriptive data, the second step of the coding process was extracting or calculating the effect size for individual studies. Effect sizes were extracted directly from individual studies when reported (i.e., the correlation value, *r*). A composite score correlation formula given by Schmidt and Hunter (2004, pp. 430-439) was used to compute the overall correlation value of safety climate dimension when a study reported the correlation between questionnaire items and injuries (e.g., those items were assigned to safety climate dimension based on previous study by the same author, and the single correlation of each item under that dimension were used to calculate the composite) or measured the same dimension for two different groups (e.g., principle contractor, sub-contractor). Once effect sizes were coded from individual studies, the reliability of the extracted effect sizes were corrected. The average reliability estimate for climate dimensions and self-reported injuries was used (Table10) when a study did not provide a reliability measure, such as Cronbach's alpha. This approach has been used in several meta-analyses (Christian et al. 2009; Clarke 2006). The standard error, which represents the margin of error for effect size estimates, was also adjusted because it would increase with additional estimation of effect size correction (Card 2011). It is important to note that no attempt was made to correct the recordable injury rate because no reliability value was reported for this variable.

Table 11 illustrates a practical example of calculating the effect size for one dimension (e.g. relationship between management commitment to safety and self-reported injury) using the following explained process. This example is provided for clarity and to enable replication of the analysis by others. The correlation coefficient was the most reported effect size statistic across the identified studies. Fisher's transformations was used to avoid the skewness of the distribution of sample *r*, and the standard error was then calculated (Card 2012). The equation used to transform the correlation coefficient (*r*) Fisher's (Z_r) is shown in Equation 1:

$$Z_r = 1/2ln\left(\frac{1+r}{1-r}\right) \tag{1}$$

Where Zr represents Fisher's transformation of *r*, and *r* is the correlation coefficient. The standard error of the Fisher's (Z_r) can be calculated using Equation 2:

$$SE_{Zr} = \left(\frac{1}{\sqrt{N-3}}\right) \tag{2}$$

Where SE_{Zr} is the standard error of Z_r, and *n* the sample size for each primary study.

However*,* *r* is more frequently used than Z_r, and thus the statistics were transformed back to (*r*) when reporting the final meta-analysis results (Card 2011). The inverse Fisher transformation is shown in Equation 3:

$$r = \left(\frac{e^{2z_r} - 1}{e^{2z_r} + 1}\right) \tag{3}$$

Where (r) represents the correlation value, and (Zr) represents Fisher's transformation value of (r).

Table 10: Studies included in the safty climate Meta-analysis

Author (data)	N	Level of analysis	Independent Variables	Dependent Variables
Goldenhar et al. (2003)	408	Individual-level	Management' s commitment to safety Training	Self-reported Injury
Cigularov et al. (2010)	235	Individual-level	Communication	Self-reported
Hoffmeister et al. (2014)	1,548	Individual-level	Supervisory safety climate	Self-reported
Hon et al. (2014a)	396	Individual-level	Management' s commitment to safety Safety rules & procedures Individual responsibility	Self-reported Injury
Hon et al. (2014b)	809	Multiple -levels	Management' s commitment to safety Safety rules & procedures Individual responsibility	Self-reported Injury
Lingard et al. (2012)	400	Group-level	Management' s commitment to safety Supervisors safety role Coworkers safety response	Injury rate
Lingard et al. (2011a)	236^a	Group-level	Coworkers safety response	Injury rate
Lingard et al. (2010a)	114	Group-level	Management' s commitment to safety Supervisors safety role	Injury rate
Lingard et al. (2010b)	307	Group-level	Supervisors safety role Coworkers safety response	Injury rate
Nkhungulu (2014)	851	Individual-level	Management' s commitment to safety Supervisors safety role Safety rules & procedures Communication Training Workload pressure	Self-reported Injury
Siu et al. (2003)	374	Individual-level	Supervisors safety role Safety rules & procedure Communication Training Workload pressure	Self-reported Injury

Note: a: The total sample size of this study was 370 comes from three construction organization. The sample of one of these organizations was excluded because there was not enough information to calculate the effect size. Only dimensions included in this meta-analysis are presented in this table.

Table 12: Mean reliability estimate for study variables

Construct	k	N	Average reliability estimate
Management's commitment to safety	6	2240	0.886
Supervisors' safety role	6	3594	0.826
Coworkers' safety response	3	943	0.85
Safety rules & procedures	3	1621	0.818
Communication	3	1460	0.808
Training	3	1633	0.827
Workload pressure	2	1225	0.833
Individual responsibility[a]	2	1198	0.67
Accidents and injuries (self-reported overall)	3	1315	0.847

Note: k = number of studies; N = total sample size

[a] *This dimension included only two studies, both conducted by the same author with the same questionnaire. The reliability measure was reported in one of them and it was used to correct the effect size in the other.*

3.4.4 Standardization

The aim of standardization was to obtain common effect sizes comparable across collected studies. The correlation coefficient (r) was the most common value reported across studies. When a study reported the Kendall's rank correlation (Hon et al. (2014b), the value of this correlation was then converted to Pearson's *r* using the formula provided by Walker (2003):

$$r = sin\ (0.5\pi\tau) \qquad (4)$$

Table 13: Effect size calculation procedure for the relationship between management commitment to safety and self-reported injury

Author (date)	N	r	r_c	Z_r	SE_{zr}	SE_{rc}
Hon et al. (2014a)	396	0.25	0.30	0.31	0.05	0.06
Goldenhar et al. (2003)	408	0.15	0.18	0.18	0.05	0.06
Hon et al.(2014b)	809	0.26	0.28	0.29	0.04	0.04
Nkhungulu (2014)	851	0.26	0.29	0.30	0.03	0.04
Sum	2,464					

Note: N= sample size, r= uncorrected effect size, r_c = corrected effect size (reliability corrected), SE_{zr} = standard error of Fisher's (Z_r), SE_{rc} = adjusted stander error

3.4.5 Computation of overall effect size

The final step in the meta-analysis was the computation of the overall effect size, which aggregated the individual effect sizes from each study to obtain an overall effect size representing the relationship between each safety climate dimension and injuries. A random-effect model was used because the effect size assumed to be different in the included studies (Borenstein, Hedges, & Rothstein, 2007). Table 13 illustrates a practical example of calculating the overall effect size for one dimension (e.g. relationship between management commitment to safety and self-reported injury) using the following explained process. First, each study was weighted by the inverse of each individual effect size standard error squared. Thus, ensuring that more accurate individual effect sizes have a greater impact in overall effect size (Card 2011). Equation 5 shows the formula to calculate the weights.

$$w_i = \left(\frac{1}{{SE_i}^2}\right) \tag{5}$$

Where the w_i is the weight for study *i*, and SE_i is the standard error of the effect size estimate for study *i.* The weighted average effect size was then calculated using the generic equation referred to by Card (2011):

$$\overline{ES} = \frac{\sum(w_i ES_i)}{\sum(w_i)} \tag{6}$$

Where w_i is the weight for study i (calculated using Equation 5), and Es_i is the effect size calculated from individual studies (Zr) as shown in Table 14.

The next step was to determine the heterogeneity of each effect size by using Equation 7:

$$Q = \sum (w_i \, ES^2{}_i) - \frac{(\sum(w_i \, ES_i))^2}{\sum w_i} \tag{7}$$

Where Q represents the heterogeneity statistic, w_i the weight of study i, and ES_i the effect size estimate for such a study. Calculating the heterogeneity test for the example illustrated in Table 14, a value of 3.23 was obtained. The heterogeneity statistic was used to estimate the random variance associated with true differences among different studies by using the Equation 8:

$$\tau^2 = \frac{Q - (k - 1)}{(\sum w_i) - \frac{(\sum w_i{}^2)}{(\sum w_i)}} \tag{8}$$

Where τ^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. Calculating the random variance for the example illustrated in Table 14, a value of 0.0002 was obtained. However, the weight given to an individual study using Equation 5 is sufficient only for the fixed-effect model and a new weighted calculation for the random effect was calculated using Equation 9:

$$w_i = \left(\frac{1}{\tau^2 + SE_i{}^2}\right) \tag{9}$$

Where the w_i is the weight for study i, τ^2 is the random variance of the heterogeneity test, and SE_i is the standard error of the effect size estimate for study i.

Table 14: Fixed and random effect calculation procedure for the relationship between management commitment to safety and self-reported injury

	Fixed Effect Model				Random Effect Model			
Author (date)	w_i	w_i (%)	$w_i * Z_r$	$(w_i * Z_r^2)$	${w_i}^2$	w_r	w_r (%)	$w_i ES_i(w_r * Z_r)$
Hon et al. (2014a)	276.67	14.04	85.01	26.12	76,547.40	264.52	14.7	81.28
Goldenhar et al. (2003)	282.37	14.33	51.28	9.31	79,730.56	269.72	15.0	48.98
Hon et al.(2014b)	725.40	36.80	207.23	59.20	526,205.16	647.44	36.0	184.95
Nkhungulu (2014)	686.54	34.83	205.87	61.73	471,338.27	616.31	34.3	184.80
Sum	1,970.98	100	549.38	156.37	1,153,821.3	1,797.9	100	500.02

Note: w_i *= study weight (fixed effect model),* w_r *= study weight (random effect model).*

Calculating the overall effect size for the example illustrated in Table 14, a value of 0. 27 was obtained. However, the above calculation procedure was replicated with each relationship between safety climate dimensions and injury data type (self-reported and recordable injury rate) at both levels (individual and group).

3.5 Meta-analysis results

Of the 107 studies reviewed, 11 met the inclusion criteria. Out of the 14 common construction safety climate dimensions identified in the construction safety climate literature, eight were analyzed with self-reported injuries or injury rate data at both levels (individual and group), and the result of this meta-analysis are shown in Table 15. Of the eight dimensions, five were significant ($P < 0.05$). The effect size of the relationship between the five dimensions and injuries (i.e., self-reported and recordable injury rate) varied between moderate and low. At individual level, the relationship between supervisor safety role and self-reported injuries had a moderate effect (*r* = 0.30, *95%* = 0.07 to 0.50) . Also, the relationship between management commitment to safety and self-reported injuries was moderate (*r* = 0.27, *95%* = 0.23 to 0.31). The effect of safety rules and procedures on injuries was moderate also (*r* = 0.25, *95%* = 0.12 to 0.37), as was individual health and safety responsibility (*r* = 0.23, *95%* = 0.17 to 0.31), and the effect of training on self-reported injuries was low (*r* = 0.10, *95%* = 0.03 to 0.17).

At group level, relationship between supervisor safety role and recorded injury rates had a moderate effect ($r = 0.26$, *95%* = 0.07 to 0.44). The effect of management commitment to safety and injury rate was low ($r = 0.13$, *95%* = 0.03 to 0.22).

Of the eight dimensions, three safety climate dimensions were found non-significant with self-reported injuries or injury rate ($p > 0.05$). These dimensions were co-worker's safety role ($p = 0.11$), communication ($p = 0.06$), and workload pressure ($p = 0.12$).

Table 15: Correlation of construction safety climate dimensions and Injuries

Relationship		*k*	*N*	Uncorrected				Corrected			
				r	*95% CI*		*P-value*	r_c	*95% CI*		*P-value*
Individual level											
Management Commitment	Self-reported Injury	4	2,464	0.25	0.19	0.29	0.000	0.27	0.23	0.31	0.000
Supervisors safety role	Self-reported Injury	3	2,773	0.25	0.06	0.43	0.005	0.30	0.07	0.50	0.006
Safety rules & procedures	Self-reported Injury	4	2,430	0.21	0.10	0.30	0.000	0.25	0.12	0.37	0.000
Communication	Self-reported Injury	3	1,460	0.29	-0.08	0.59	0.067	0.33	-0.08	0.65	0.060
Training	Self-reported Injury	3	1,701	0.08	0.03	0.14	0.001	0.10	0.03	0.17	0.002
Workload pressure	Self-reported Injury	2	1,225	0.36	-0.25	0.76	0.126	0.42	-0.29	0.83	0.125
Individual responsibility	Self-reported Injury	2	1,198	0.17	0.13	0.24	0.001	0.23	0.17	0.31	0.001
Group-Level											
Management Commitment	Injury rate	2	514	0.12	0.02	0.21	0.007	0.13	0.03	0.22	0.004
Supervisors safety role	Injury rate	3	821	0.23	0.06	0.38	0.004	0.26	0.07	0.44	0.004
Co-workers safety role	Injury rate	3	943	0.12	-0.08	0.31	0.115	0.13	-0.08	0.34	0.115

Note: k= number of studies, N= sample size, r= uncorrected effect size, r_c *= corrected effect size (reliability corrected for safety climate dimensions and self-reported injuries), 95% CI= confidence interval (lower-upper) around r*

3.6 Discussion

The results of this meta-analysis suggested that five dimensions were important factors in assessing construction safety climate and, most importantly, the association with performance: (1)

management commitment to safety; (2) supervisor safety role; (3) safety rules and producers; (4) training; and (5) individual responsibility for health and safety.

Supervisory safety role had a moderate relationship with both self-reported injuries and recorded injury rate data (r_c = 0.30 and r_c = 0.27, respectively). This is a surprising result compared to other meta-analysis studies, where supervisory safety role had weaker relationship to injuries. Christian et al. 2009 found that the effect size of the relationship between supervisory safety role and safety outcome was small (r_c= -0.15) at the organizational level, and moderate at the group level (r_c = -0.24). This novel finding may be due to the unique attributes of the construction industry. Since construction companies are generally decentralized organizations, the direct effect of first line leaders on construction safety performance is likely to be high (Lingard et al. 2012). Lingard et al. (2012) found that the role of supervisor in the construction industry mediated the relationship between the commitment of management toward safety and work group injuries. Other studies also found evidence for a strong relationship between first line leader action and behavior on effecting safety outcome (Hoffmeister et al. 2014; Siu et al. 2003). This suggests that, in the construction industry, supervisor behavior is a particularly important for decreasing worksite injuries and improving safety climate.

Management commitment to safety, the most commonly included climate dimension, showed a moderate correlation with injury outcomes, particularly self-reported injuries (r_c = 0.27). The fact that management commitment predicts injury rates is consistent with previous studies and meta-analyses (Beus et al. 2010; Christian et al. 2009; Flin et al. 2000; Schwatka et al. 2016). For example, Beus et al. (2010) found that management commitment to safety at the organizational level was the strongest predictor of injuries, among the other safety climate dimensions. The results here, however, are not as strong as is implied in prevailing climate research.

Both safety rules and procedures (r_c = 0.25) and individual responsibility (r_c = 0.23) had moderate effects on injuries. These dimensions are important because, once safety rules and procedures are instituted, management can promote worker awareness and understanding of safety policies and procedures. As organizations mature, greater commitment of workers is likely to make rules and procedures a norm rather than something to be enforced.

Finally, training had relatively weak relationship to self-reported injuries (r_c= 0.10). Individual studies in this domain found that training is poorly correlated with self-reported injuries (r = 0.05 to 0.14). However, other safety research has strongly linked poor training to injuries in root cause analyses (Burke et al. 2011). Thus, well-trained workers are generally expected to have fewer injuries (Burke et al. 2011; Chen et al. 2013; Goldenhar et al. 2003)). One explanation for the lower correlation of this dimension may be that individual experiences with safety training lead to a variety of expectations. Thus, climate scores in this dimension may be highly variable.

3.6.1 Limitations and Future Research

The major limitation of this meta-analysis study was the small number of studies that met the inclusion criteria and their sample sizes. Many studies had to be excluded due to lack of sufficient statistical information with which to calculate effect sizes. In most construction studies, safety climate was reported as an aggregated score instead of individual scores for each dimension. In the future, researchers should consider reporting the full result of the relationship of each safety climate dimensions with safety outcome to allow replication with larger sample sizes. The small sample size limitation also precluded analysis of the relationship of safety climate dimensions and injures at different safety climate levels (e.g., individual, group, organizational levels). One meta-analysis found a stronger association between group safety climate level and injuries compared to individual safety climate level (Christian et al. 2009). Thus, future research should investigate the effect of group safety climate levels on predicting injuries. Another limitation of this study was that only studies that included two or more dimensions reported effect sizes. Thus, only eight safety climate dimensions out of 14 common dimensions were analyzed in this study. Some dimensions, such as risk-taking behavior, are important dimensions in the construction industry, and might be relevant to other dimensions such as individual responsibility and safety rules and procedures. Thus, the meta-analysis should be replicated to include all 14 common safety climate dimensions in the current literature.

In the future, a way to build scientific knowledge in this domain is to adopt a consistent approach to the assessment of construction safety climate. This study suggests that five dimensions should be used to make an empirical assessment in the case that a researcher or organization seeks to use the construct to predict future safety performance.

3.7 Conclusions

This is the first meta-analysis of safety climate dimensions specific to the construction industry. The purpose of this meta-analysis was to determine a set of common construction safety climate dimensions that predict future injuries. This information is critical for those that plan to use safety climate as a predictor or proxy for safety performance. The literature search revealed great inconsistency in the inclusion of specific safety climate dimensions, which creates difficulty in comparing results across studies. The meta-analysis procedure, however, helps to systematically uncover patterns across this body of research and a singular correlation to performance for each dimension that aggregates the sample size.

Management commitment to safety, supervisory safety rules, safety rules and procedures, training, and individual responsibility of health and safety were found to be significantly correlated with worksite injuries. Among these dimensions, supervisory safety role had moderate effect on injury at both levels (e.g., individual and group level). This relationship was followed by moderate correlation between management commitment to safety and self-reported injury. Both safety rules and procedures and individual responsibility had moderate effects on injuries. Finally, training at individual level and management commitment at group level had weaker relationship with injury. Indeed, these dimensions can serve as core construction safety climate dimensions for use in future construction safety climate research.

However, the findings presented in this study mark an important first step towards standardizing safety climate measurement in the construction industry and helping researchers collect consistent and reliable data.

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CHAPTER 4: RELATIONSHIPS AMONG SAFETY LEADING INDICATORS AND SAFETY CLIMATE DIMENSIONS: STRUCTURAL EQUATION MODEL BUILT FROM FIELD DATA

1. Abstract

Managing safety proactively has consistently shown to be effective for preventing construction accidents. Safety leading indicators and safety climate are both measures that predict future safety performance and can be used to make adjustments to the safety system before injuries occur. Prior studies have on identifying and measuring the predictive capacity of these constructs separately even though they logically associate. This study takes the first step toward the empirical investigation of the relationship between safety indicators and safety climate dimensions. More specifically, a hypothetical exploratory model was designed based on the theoretical differences among them and was empirically investigated using the structural equation modelling. Data collected from a survey of 106 construction workers were used to build the structural equation model. The results showed that there is a positive relationship between safety leading indicators and safety climate. More specifically, the model indicates that there is empirical evidence that worker observation is significant predictor of management commitment to safety, safety training perception, and supervisor safety role. In additions, pre-task plan is also significant predictor to supervisory role. The results also indicate that, despite the pervasive method of self-reporting injury rates, we found the approach of self-reporting leading indicators to provide highly variable responses. Recommendations for future studies and more valid and reliable measurement techniques are provided.

2. Introduction

In recent years, there has been growing awareness that some measures of safety like measures of the quality and quantity of safety activities (i.e., leading indicators) and general perceptions of safety management (i.e., safety climate) consistently correlate with future injury rates (Alruqi and Hallowell 2019; Alruqi et al. 2018). These types of metrics are important because, as Haslam et al. (2005) found, most construction injuries could have be predicted and prevented with early intelligence. Early work of measuring the predictability of the safety climate and leading safety indictors focused on correlating these constructs with safety performance (Feng et al. 2014; Hon et al. 2014b; Lingard et al. 2012). However, to date, the relationships among safety leading indicators and safety climate have yet to be explored.

There is a wide body of literature that has defined safety climate dimensions. For example, Schwatka et al. (2016) identified several common safety climate dimensions in the construction industry, such as management commitment to safety, safety rules and procedures, and supervisors' safety roles. More recently, Alruqi et al. (2018) performed a meta-analysis of the studies that have empirically investigate the relationship between safety climate dimensions and safety performance. The strongest predictors are management commitment to safety, supervisory safety role, training, individual responsibility of safety and health, and safety rules and procedures.

Although a smaller body of literature in comparison to safety climate, researchers have begun to explore the relationship between safety leading indicators and future safety performance (e.g., Hallowell et al. 2013, Salas et al. 2016, Lingard et al. 2017). Similarly, Alruqi and Hallowell (2019) conducted a meta-analysis of these studies and found that pre-task safety plan, worker observation, owner involvement, and safety auditing best predict future injury rates. Interestingly, despite studies showing strong predictive capacity for both leading indicators and safety climate, no study has examined the theoretical or empirical relationships between these predictors. This paper presents an empirical field study that tests the relationship between safety leading indicators and the dimensions of safety climate. We consider safety leading indicators to be the independent variable as they measure safety effort and we consider safety climate dimensions to be the dependent variables because they measure perception of safety management. As such, our epistemological position is that safety leading indicators are direct and primary divers of safety performance and that climate is a mediating indicator and possible proxy of safety performance.

3. Literature review

The purpose of the following sections is to describe the constructs of safety leading indicators and safety climate. It is from this body of literature that we define the constructs for our study and establish our hypotheses and points of departure.

3.2. Leading safety indicators

Leading indicators are an emerging tool for proactively measuring attributes of the safety system, predicting future performance, and controlling safety performance. According to Hinze et al. (2013), leading indicators provide information of the effectiveness of a safety system. These indicators can be measured at different time periods, such as the measure of daily management activities and weekly safety meeting frequency (Hallowell et al. 2013).

There are two types of leading indicators: active and passive (Hinze et al. 2013). Alruqi and Hallowell (2019) distinguished these two types, defining passive as those indicators planned before the actual work begins, and researchers have assessed only their presence or absence (Alruqi and Hallowell 2019). Examples of passive leading indicators include establishing a steel-toed boots policy or developing a safety review during the design phase of a project (Hinze et al. 2013a; Hinze et al. 2013b). In contrast, active leading indicators are measures of the quantity and quality of safety management during the actual work. Examples of active leading indicators may include updating the frequency of safety meetings or safety audit scores (Hallowell et al. 2013; Hinze et al. 2013).

Most leading indicator research has investigated the predictive relationship between leading indicators and safety performance. For example, Rajendran (2012) determined that there is a correlation between pre-task safety meetings, safe work behavior, and on-site safety audits with injuries. The study found that safe worker behavior and pre-task safety meetings strongly predicted safety outcomes. Another study conducted by Salas and Hallowell (2016) examined the predictive validity of a set of proactive leading indicators and focused on safety observations, frequency of walkthroughs, and the percentage of safety auditing. The study showed the capability of these proactive metrics to predicate the total recordable incident rate and severity rate. Lingard et al. (2017) also predicted the validity of leading safety indicators and how they can become lagging indicators over time (and vice versa). All these studies used contractor owner-reported injury rates like recordable injury rates, first aid rates, and days away from work or transfer (DART) rates. The use of actual injury rates has helped propel leading indicators in industry as an empirically-validated technique rather than an academic concept.

Since there were several studies investigating the relationship between safety leading indicators and actual safety performance, Alruqi and Hallowell (2019) conducted a comprehensive meta-analysis to identify the best predictors. The study found that pre-task safety planning, owner involvement, safety auditing programs, and worker observation were all very strong and consistent predictors.

3.1. Safety climate

Extensive research has been undertaken to measure safety climate and define dimensions. According to Neal and Griffin (2006, pp. 946–947), safety climate is "individual perception of policies, procedures, and practices relating to safety in the workplace." Researchers use questionnaires as primary tools to measure individual perceptions (Alruqi et al. 2018) and the safety climate level in an organization is a composite score of numerous dimensions. Several efforts have been made to identify the most common safety climate dimensions in literature (Flin et al. 2000; Mohamed 2002; Schwatka et al. 2016). They have consistently shown management commitment to safety, safety rules and procedures , and supervisory role to be the primary dimensions that appear in most studies.

The predictive validity of safety climate been a popular topic of research in recent research (Feng et al. 2014; Lingard et al. 2012; Lingard et al. 2010a; Lingard et al. 2011a; McCabe et al. 2016; Panuwatwanich et al. 2016; Soraperra et al. 2015). Recently, Alruqi et al. (2018) meta-analyzed empirical research that had explored the relationship between safety climate dimensions and performance and found that the following 5 dimensions are positively correlated with: (1) management commitment to safety; (2) supervisor safety role; (3) safety rules and procedures; (4) training; and (5) individual responsibility for health and safety.

When measuring safety climate, all researchers have used perception surveys of the construction workforce, and most solicit responses on a Likert scale. When collecting safety performance (outcome) data, two approaches have been used: (1) actual injury rates from projects or organization reported in safety management systems and (2) self-reported injury rates collected from the workforce. The majority of studies used self-reported injury rates because actual injury rates can be difficult to collect as they require long time periods of reporting to produce stable and representative values and they are often subject to confidentiality restrictions.

4. Distinguishing between safety leading indicators and safety climate

Some researchers causally use the term safety leading indicators and safety climate interchangeable or, most commonly, considering safety climate as a leading indicator. However, there are marked differences between the two constructs and notable deviation of what they are measuring and how they may be used to improve safety performance. The major similarity between these indicators is their capability of predicting future safety performance.

The major difference between safety leading indicators and safety climate is that safety leading indicators measure the quantity and quality of safety efforts implemented to prevent and manage injuries. In other words, safety leading indicators measure what an organization does to keep its workers safe. These measures typically measure the frequency of specific activities with the data taking the form of counts of instances when the safety management activity was performed. These data are usually reported by workers or managers and captured in a safety data management system. These counts are converted to a frequency when divided by a specific exposure time like months, quarters, or years. For example, the rate at which safety observations are conducted may represent a leading indicator.

Alternatively, safety climate is a measure of worker's perceptions of the safety system and the organization's priority. Most often, the data are collected from a subjective survey where participants are asked to rate the extent to which they agree with statements about the safety system (e.g., "management clearly communicate safety issues to all levels within the organization") on a Likert scale (Muhammad 2002). Typically, the responses from many employees are aggregated to represent the general themes in how safety is perceived in the organization (Neal and Griffin 2006).

As such, climate is a subjective, relative measure of how actual safety management compares against the average employee's expectations.

In this study, we impose an important distinction when categorizing metrics. Leading indicators measure how often an activity is performed (e.g., frequency of management safety audits) or the result of that activity (e.g., safety audit scores measuring % of jobs in compliance with company policies). Alternatively, safety climate dimensions measures worker perception of the quality of an aspect of organizational safety (e.g., management support and commitment to safety). When studying the relationship between these two constructs, we are considering how the safety activities performed relate to employee perceptions of safety.

5. Point of departure

Previous research has explored safety leading indicators and safety climate independently. Meta-analyses of the many empirical studies have shown that both constructs predict future safety performance. However, no study has explored the theoretical or empirical relationships among these constructs. Simply, it is unknown if and to what extent measures of the activities that an organization performs to prevent injuries relate to the general safety perceptions of employees. Thus, we aimed to answer the following question:

How do safety leading indicators relate to the safety climate's dimensions?

Such information is important as researchers and organizations seek to build predictive models for safety. Theoretically, if an association exists, the metrics can be used in concert to jointly predict the safety performance and to provide more holistic insight into the system's safety. Based on the result of the measurement model in figure 5, the model will be revised to measure the relationship between significant leading indicators and safety climate dimensions.

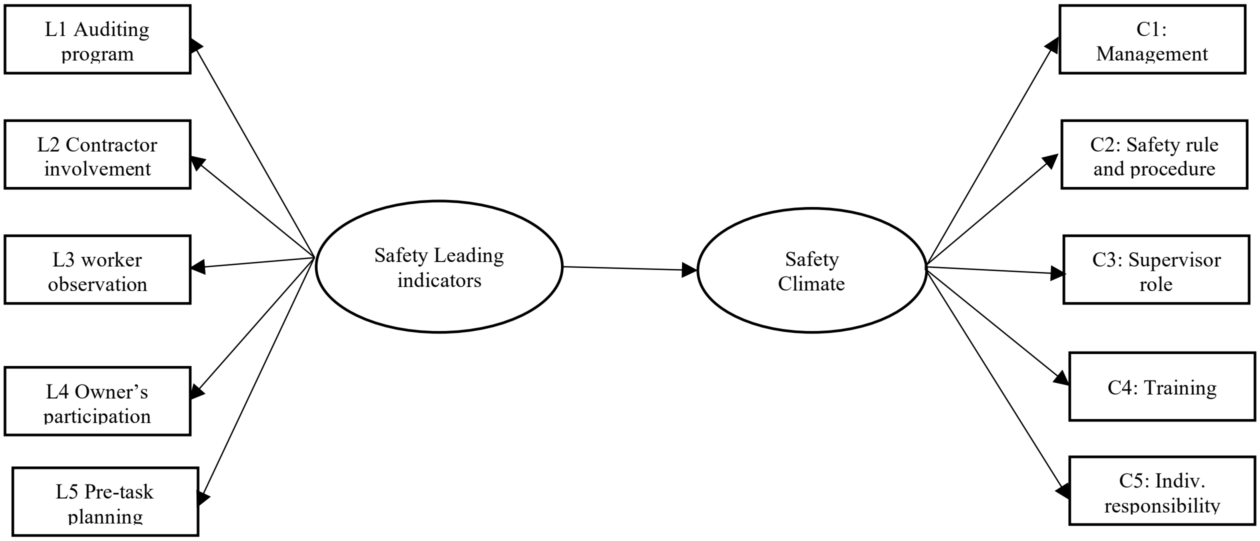

Figure 5: Study hypothetical model

6. Research Method

6.1. Study survey instrument

A questionnaire survey of construction workers from nine construction job sites in the United States was used to collect data for this study. The questionnaire was administered on site during the normal work hours. Prior to visiting sites, the survey instrument was approved by an institutional review board (IRB) panel to ensure protection of human subjects per University guidelines. The relevant portion of the survey instrument included questions about participant demographics, safety leading indicators, and safety climate. The survey was translated to Spanish to increase the participant rate. The Hispanic construction labor force accounts for about 47.6% of the total construction labor in the US(Bureau of Labor Statistics 2018). The authors used the following steps to validate the survey translation: (1) a linguistics expert translated the English version to Spanish and (2) two Civil Engineering experts who speak both languages reviewed the translated version.

The survey instrument was administered in three parts. The first collected demographic information including age, years of experience, job title, and trade. The second included questions about the following four safety climate dimensions that were validated as consistently predictive from the meta-analysis performed by Alruqi et al. (2018): (1) management commitment to safety; (2) supervisory safety response; (3) safety rules and procedures; (4) training; (5) and individual responsibility for safety and health. The third section asked questions about the following five leading indicators identified as consistently predictive from a meta-analysis from Alruqi and Hallowell (2019): (1) pre-task safety planning; (2) owner involvement; (3) worker observation; (4) safety auditing program; and (5) contractor participation.

Measuring safety leading indicators

Most researchers have measured safety leading indicators from data reported in safety management systems. Invariably, these data are records of times that specific activities were performed and, sometimes for elements like safety audits, the scores derived from those activities. Collecting such data requires access to client or contractor data that typically spans many work crews and long time periods (e.g., months and hundreds of thousands of worker-hours of exposure). Unfortunately, we did not have access to such a database for multiple contractors. Therefore, we approached the method of measuring leading indicators differently, using reported values from the workers (Table 16). We desired self-reported leading indicators because reasons (1) the data could be collected at the same time and in the same instrument as safety climate data; (2) work crews should be able to accurately report leading indicators like the frequency with which they hold pre-job safety planning meetings; and (3) to allow for common unit of analysis (i.e., individual level). This approach also allowed us to measure and report the extent to which self-reported leading indicators are consistently reported among members of the same crew, which helps to understand if the method is valid and should be applied in future studies.

Table 16: Safety leading indicators and their corresponding questions

Leading indicators	Code	Statement
Auditing program	L1	1. How many times per month does leadership conduct a safety inspection or audit?
Contractor participation	L2	1. In what percentage of daily safety meetings does contractor leadership participate? 2. In what percentage of safety orientations does contractor leadership participate? 3. In what percentage of safety audits does a contractor representative participate?
Worker observation	L3	1. How many times per month does leadership conduct worker observations?
Owner’s participation	L4	1. How many times per month does an owner’s representative conduct safety walkthroughs? 2. How many times per month does an owner’s representative participate in orientation sessions? 3. How many times per month does an owner’s representative participate in daily pre-job meetings?
Pre-task planning	L5	For what percentage of tasks are pre-task plans conducted?

Measuring safety climate

The portion of the questionnaire focusing on safety climate included multiple questions for each dimension per typical convention (Table 17). As is typical, participants were asked to indicate the degree to which they agreed with the statement using a Likert scale (from 1 = “strongly disagree” to 5 = “strongly agree”). All the questions inquired about the participant’s perceptions of the safety system, rather than inquiring about factual information. The 16 questions for climate represented the most popular questions asked in literature to define these dimensions (Griffin and Neal 2000; Mohamed 2002; Zhang et al. 2015; Zohar 2000).

Table 17: Safety climate factors and their corresponding questions

Safety Climate Dimension	Code	Statement	Source
Management commitment to safety	C1	1. “Management continues to bring safety information to on-site employees’ attention” 2. “Management operates an open-door policy on safety issues” 3. “Management encourages feedback from on-site employees regarding safety issues”	Mohamed (2002)
Safety rules and procedures	C2	1. “Current safety rules and procedures are made available to protect us from accidents” 2. “Current safety rules and procedures are so complicated that some workers do not pay much attention to them” 3. “Current safety rules and procedures require us to report any safety violations by a fellow worker”	Mohamed (2002)
Supervisory safety role	C3	1. “My supervisor seriously considers any worker's suggestions for improving safety” 2. “My supervisor gets annoyed with any worker ignoring safety rules, even minor rules” 3. “Whenever pressure builds up, my supervisor wants us to work faster, rather than by the rules” 4. “As long as work remains on schedule, my supervisor doesn't care how this has been achieved”	Zohar (2000)
Training	C4	1. “Safety issues are given a high priority in training programs” 2. “Workplace health and safety training covers the types of situations that employees encounter in their job” 3. “Employees receive comprehensive training in workplace health and safety issues”	Griffin and Neal (2000)
Individual responsibility for safety and health	C5	1. “I use all the necessary safety equipment to do my job” 2. “I use the correct safety procedures for carrying out my job” 3. “I ensure the highest levels of safety when I carry out my job”	Griffin and Neal (2000)

6.2. Data collection and participant profile

The data collection took place from September 2018 to March 2019. Of the 117 questionnaires administrated in the nine construction jobsites, 106 were included in the final analysis due to incomplete questionnaires or those removed due to suspicious response patterns.

These nine construction projects were varied in terms type and location. The sample consisted of different constructions trades: framers (12.3%), operators (2.8%), iron workers (15.1%), laborers (17.9%), carpenters (7.5%), plumbers (2.8%), cleaners (0.9%), bricklayers (0.9%), electricians (23.6%), pipe fitters (2.8%), and not specified (7.5%). Most of the participants were male (97.2%), and the range of the years of experience was 1 to 36. Moreover, respondents' work experience ranged from five months to 35 years of experience.

6.3. Analytical approach

Structural equation modeling (SEM) was chosen to test the primary hypothesis that safety leading indicators correlate positively with dimensions of safety climate. Compared to other multivariate analyses such as multiple regression, SEM accounts for latent variables and allows several dependent variables to be evaluated in the model at the same time (Hair et al. 2016). More importantly, SEM allows for evaluating all variables in the model simultaneously. Two primary structural equation modeling methods exist in the current literature: covariance-based structural equation modeling (CB-SEM) and partial least squares structural equation modeling (PLS-SEM) (Hair et al. 2016; Henseler et al. 2014). CB-SEM is covariance based analysis, and PLS-SEM is based on variance analysis (Hair et al. 2016). The comparison between the two methods is still a developing topic in the current literature; however, several researchers have shown different characteristics that distinguish the two methods. Hair et al. (2016) noted that CB-SEM is a methods typically used to confirm or test theory. Additionally, the modeling approach is a covariance-based analysis that treats the latent variables as a "common factor," the method is built on the assumption of normally-distributed data, and the models require relatively large sample sizes to be fit. Alternatively, SB-SEM is typically used for exploratory and predictive research rather than confirmatory research (Kline 2016; Hair et al. 2016). The modeling approach does not have a distributional assumption and the models can be fit with smaller sample sizes. The advantages of PLS-SEM mentioned made it appropriate for this study.

6.3. Sample size requirement

The sample size for the PLS-SEM model is still debated in the current literature. Hair et al. (2016) found that the sample size should be at least 10 times the maximum number of expected relationships to the latent variable in the model (Hair et al. 2016, p. 24). Applying this rule to this study, where the highest number of arrows pointing to latent variables was 2, the minim sample size of this study would be 20 workers. Another standard approach of sample size estimation relies on Cohen's (1992, as cited in Hair et al. 2016) power analysis for multiple regressions. According to this method, the sample size required for this study would be 72 workers to detect R^2 with 80% statistical power. Fortunately, our final sample size of 106 workers exceeded this goal.

6.4. PLS-SEM procedure

The PLS-SEM approach consists of two models: the structural model and the measurement model. The structural model (also referred to as the inner model in PLS-SEM) explains the relationships among latent variables, and the measurement model (also referred to as the outer model in PLS-SEM) explains the relationships between each construct and its measured variables. In PLS-Sem, the latent variables scores, and path coefficients are estimated through the following seven-step procedure (Hair et al. 2016; Henseler et al. 2012): "(1) specifying the structural model; (2) specifying the measurement models; (3) collecting and examining data; (4) estimating the PLS path model; (5) assessing the measurement model results; (6) assessing the structural model results; and (7) reporting and interpreting results." The explanation of these steps and the PLS-SEM algorithm are based on the explanation of Lohmöller (1983), Sarstedt et al. (2017), Hair et al. (2016), and Henseler et al. (2012).

Specifying the structural model: The structural model in PLS-SEM describes the relationships among constructs in the model (i.e., latent variables). In this study, for example, the structure model is the path between each leading safety indicator and safety climate as shown in Figure 4. In this step, the order of these variables in the model and their relationships is identified through theory, logic, or researcher experience. The variables in the left side of the model (i.e., leading safety indicators) are exogenous variables and the variables on the right side of the model (i.e., safety climate) are endogenous variables. Simply, the leading indicators were considered independent variables and the safety climate were dependent variables.

Specifying the measurement model: The measurement model represents the relationship between each construct and its indicators. In this study, the measurement model refers to the items used to measure safety leading safety indicator (i.e., pre-task plan, safety auditing) and safety climate (i.e., management commitment to safety, supervisory role).

Data collection and examination: After the administration of the survey, Hair et al. (2016) suggested examining the data following four issues: missing data, suspicious responses, outliers, and data distribution. The data were examined using the above criteria. As expected the data were not normally distributed, further justifying the selection of PLS-SEM as the analytical technique.

Estimating the PLS path model: The PLS-SEM model estimation is based on two main stages: latent variable score estimation and path and loading estimation (Henseler et al. 2012). The first stage is an iterative estimation and consists of four steps as shown in Figure 6.

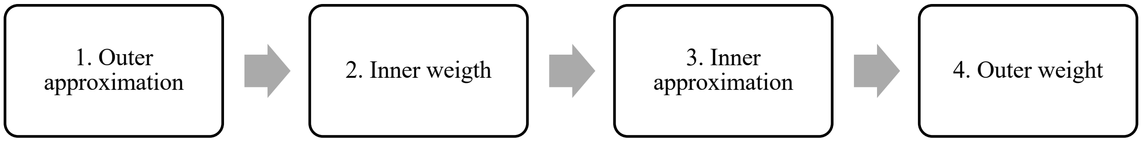

Figure 6: Steps for estimating latent variable scores

Estimating the outer approximation: The first step is estimating the outer proxies by initialization of the weight. All weights in the initialization step were 1. Then, each outer proxy of the latent variables was estimated as the weighted sum (Henseler et al. 2012). Equation (1) represents the process of estimating the outer approximation (Lohmöller 1983):

$$Y_{jn} = \sum_{kj} \widetilde{W}_{kj} y_{k_j n} \tag{1}$$

where Y_{jn} is the outer approximation score for latent variables, w_{kj} is a weight coefficient, and $y_{k_j n}$ is the observed variable.

Estimating the inner weight: Estimating the inner weight (i.e., path coefficient) provides information on the strength of the relationship for the outer latent variables proxies. Three different weighting schemes can be used to estimate the inner weight: centroid, factorial, and path weighting (Henseler et al. 2012). The path weighting scheme is most common because it predicts the latent variables and can be applied for all different types of modeling (Henseler et al. 2012). Equation 2 shows the procedure for estimating the inner weight (i.e.,V_{ji}) as the covariance between (Y_j) (i.e., dependent latent variable) and (Y_i) (i.e., independent latent variable) by using the initialization weight in the previous step. The zero in Equation 2 represent the absence of connection between latent variables (Lohmöller 1983).

$$V_{ji} = \begin{cases} cov\ (Y_j\ , Y_i) \\ \quad 0 \end{cases} \tag{2}$$

Inner approximation: The latent variable proxies in this step are calculated as the inside approximation, and it is computed by using the “weighted sum of the adjacent variables” as shown in Equation 3:

$$\tilde{Y}_j = \sum\nolimits_i v_{ji} \, Y_i \tag{3}$$

Outer weight: The outer weight estimation shows the strength of the relationship between “each latent variable in the model and its corresponding indicator” (Sarstedt et al. 2017). It is important to note that the estimation of the outer weight depends on the measurement model type (i.e., reflective or formative). We used a reflective measurement model. To estimate the outer weight for this reflective model, the covariance for each construct and its indicator were calculated. In other words, the outer weight is computed as the covariance of the latent variable proxies that result from the inner approximation in step 3. Equation 4 shows the mathematical expression to calculate the outer weight for the reflective measurement model:

$$\tilde{Y}_{jn} = \sum\nolimits_{kj} \widetilde{W}_{kj} y_{k_j n} + d_{jn} \tag{4}$$

where Y_{jn} is the inner approximation score for latent variables (i.e., step 3), w_{kj} is the outer weight, $y_{k_j n}$ is raw data for indicator k of a latent variable j and observation n, and d represents the error term.

The first stage of estimating the latent variable scores is an iterative estimation that required repeating the above-explained steps until the model converged (i.e., the outer weight changes between to iterations get very small).

The final output from step 4 is the final latent variable scores, and these results are used to estimate the relationship in the structural model through the use of ordinary least squares regressions (i.e., phase 2) (Henseler et al. 2012). The output from phase 2 is the final estimation of the outer loading, outer weight, and path coefficient (Lohmöller 1983).

6.5. Unit of analysis and data form

Data was analyzed in this study at an individual level for both safety leading indicators and safety climate. Table 17 shows the leading indicators, the safety climate dimensions, and their averaged items for the analysis. The climate dimensions included in this table represent the average of the questions used to measure the dimension. The leading indicators in this table represent the average of the questions used to measure the indicators that were assessed with more than one question, as shown in table 18 (i.e., contractor involvement and owner participation).

Table 18: Averaged survey items for the analysis

Latent variable	Indicators/Dimension	Code	Averaged items
Safety leading indicators	Auditing program	L1	Single item
	Contractor participation	L2	L2-1, L2-2, L2-3
	Worker observation	L3	Single item
	Owner's participation	L4	L4-1, L4-2, L4-3
	Pre-task planning	L5	Single item
Safety Climate	Management commitment	C1	C1-1, C1-2, C1-3
	Safety rules and procedures	C2	C2-1, C2-2, C2-3
	Supervisory safety role	C3	C3-1, C3-2, C3-3, C3-4
	Training	C4	C4-1, C4-2, C4-3
	Individual responsibility	C5	C5-1, C5-2, C5-3

7. Model result

The study model was analyzed with the PLS-SEM method using SmartPLS 3 (Ringle 2015). Table 18 shows summary statistics and bivariate correlation among the indicators used to measure safety climate and leading safety indicators.

Table 18**:** Mean, standard deviation, and correlation of safety leading indicators and climate dimensions

	Mean	SD	L1	L2	L3	L4	L5	C1	C2	C3	C4
L1 Auditing program	7.72	10.03									
L2 Contractor involvement	0.72	0.31	0.12								
L3 Worker observation	12.92	12.04	0.46	0.19							
L4 Owner's participation	5.99	7.24	0.31	0.17	0.16						
L5 Pre-task planning	0.81	0.30	0.05	0.43	0.11	0.28					
C1: Management commitment	4.56	0.52	0.07	0.05	0.21	0.15	0.02				
C2: Safety rule and procedure	4.01	0.73	0.05	0.15	0.14	0.18	0.17	0.50			
C3: Supervisor role	4.11	0.66	0.19	0.21	0.33	0.05	0.28	0.34	0.37		
C4: Training	4.15	0.86	0.03	0.15	0.20	0.09	0.17	0.57	0.56	0.44	
C5: Indiv. Responsibility	4.55	0.51	0.05	0.11	0.09	0.00	0.15	0.32	0.35	0.42	0.36

There are two steps to interpret the PLS-SEM model result: (1) measurement model evaluation to determine the reliability and validity of the measurement items and (2) structural model evaluation to determine the strengths and significance of the relationships among latent variables. The results of the two model evaluations are presented below.

7.1. Measurement model evaluation

The evaluation of the measurement model consists of examining the following three metrics: internal consistency, convergent validity, and discriminant validity. The internal consistency is a measure to assess the agreement of the different indicators used to measure the same construct. The traditional approach of measuring internal consistency is Cronbach's alpha (i.e., the intercorrelation of the observed indicators). Hair et al. (2016) stated that Cronbach's alpha is affected by the number of items, and in some cases results underestimate the true internal consistency. A composite reliability is the alternative approach to measuring the internal consistency, and it considers the outer loading of the measurement model to estimate the internal consistency as shown in the following equation:

$$P_c = \frac{(\sum_{i=1}^{M} l_i)^2}{(\sum_{i=1}^{M} l_i)^2 + \sum_{i=1}^{M} var\ (e_i)} \tag{5}$$

where *pc* is the composite reliability for latent variable, l_i is the standardized out loading, and $var\ (e_i)$ is the variance of the measurement error, which is equal to 1- l_i (Hair et al. 2016).

The composite reliability value range of 0.6 to 0.7 is an acceptable composite reliability for the construct.

The convergent validity refers to the positive relationship between each construct (e.g., safety climate) and its respective indicators. The convergent validity can be assessed by examining the outer model load and the average variance extracted (AVE). The outer loading should be 0.7 or higher but not exceed 0.95 (Hair et al. 2016). Outer loading with values between 0.4 and 0.7 require more examination of how the reliability and validity will be affected by removing the indicator related to this construct. An item is considered for removal if it only can improve the validity of the construct, otherwise it is retained. In addition, an outer load below 0.4 should be considered for removal. The AVE is another metric for measuring the convergent vitality, which defines the average square of outer loading associated with each construct. AVE with a value of 0.5 is acceptable, and it indicates that, “on average, more variance remains in the error of the items than the variance explained by the construct.” (Hair et al. 2016). The finale metric to evaluate the measurement model is the discriminant validity. Discriminant validity is defined as the degree to which a construct is different from another construct in the model. This distinction can be tested by examining the cross-loading of the items. The outer loading for associated construct (e.g., management commitment and safety climate construct) should be higher than all its loading on other constructs (e.g., leading indicators).

However, the above-explained requirement must be met to increase the reliability and validity of the measurement model. The evaluation of the structure model is heavily dependent on the reliability and validity of the measurement model. It's important to note that this process allows researchers to consider removing or retaining some of the indicators that are included in the initial model testing (Figure 4). Table 19 shows the result of internal consistency and convergent validity for this model.

Table 19: Reliability and validity estimate for model constructs

Construct	Composite Reliability	Average Variance Extracted (AVE)
Safety Leading indicators	0.714	0.557
Safety climate	0.846	0.525
C1: Management commitment	0.82	0.60
C2: Safety rule and procedure	0.86	0.75
C3: Supervisor role	0.87	0.76
C4: Training	0.90	0.75
C5: Indiv. Responsibility	0.87	0.69

The results represented in Table 20 indicate that all model constructs were at a high level of internal consistency. Additionally, the result in Table 20 indicates that the measurement model met the convergent validity requirements. The cross-loading was also investigated to ensure that the discriminant validity was established. The initial model in figure 4 was revised according to the measurement model criteria explained above. Safety observation and a pre-task safety plan were the only two indicators, representing a safety leading indicator construct. The rest of the leading indicators were removed from the model due to their very low loadings (i.e., they were unreliable items), and their removal increased the reliability and validity for the leading indicators construct. Figure 6 shows the final revised model and the resulting final loading estimate. As stated earlier, safety observation and a pre-task plan are the only leading indicators with a significant loading. These two leading indicators were used to test the relationship between safety leading indicators and safety climate dimensions. Table 19 also shows the resulting internal consistency and convergent validity of the safety climate dimensions. The results from table 19 indicated that all safety climate dimensions included in this model had high internal reliability, and the measurement model met the convergent validity requirements. Safety observation and the pre-task plan were measured with a single item. As result, there were no reliability and validity estimates for these two constructs.

7.1. Structural model evaluation

The structure relationship for model in this study was assessed using the following criteria: (1) the assessment of collinearity; (2) significance and relevance; (3) coefficient of determination represented by R^2; and (4) and the effect size represented by f^2.

Collinearity

The variance inflation factor (VIF) is the common way of assessing the collinearity in the model. A VIF value above 5 indicates the presence of collinearity among constructs. However, in both models the VIF for both the inner model and outer model was below the threshold value. The highest value of VIF was 2.3 for the first item used to measure individual responsibility.

Significance and relevance

The significance of the relationship between latent variables was estimated through the resampling method (i.e., bootstrapping) to test the significance of t-value and significant alpha (i.e., 0.05). The PLS-SEM does not require the data to be normally distributed, and as a result the nonparametric estimate (i.e., bootstrapping) was used to estimate the significance of the estimated path coefficient (i.e., beta). The method allows for estimating sampling distribution by a random drawing and replacement from the original data to indicate whether the path coefficient is different from zero (Hair et al. 2016). For each subsample created in the random drawing procedure, the model parameters are estimated. The bootstrapping procedure allows for significant testing of the structural relationships in the model via the sampling distribution created from the original data (i.e., bootstrapping sampling). Table 20 and figures 7 and 8 show the path coefficients and significant values (i.e., alpha at 0.05) for all relationships in the two models.

Coefficient of determination

The coefficient of determination, R^2, is the squared multiple correlations of dependent variables in a model, ranging from 0 to 1. For example, the R^2 value for the safety climate in model A (i.e., dependent variable) was 0.13, meaning that about a 13% chance of the safety climate was predicted by the safety leading indicators. The effect size f^2 was referred to to assess the effect of R^2 when the independent variable was omitted from the model, and this omission can result in a substantive impact on the dependent variable. The effect size f^2 are calculated using the following equation:

$$f^2 = \frac{R^2_{included} - R^2_{excluded}}{1 - R^2_{included}} \qquad (6)$$

where $R^2_{included}$ and $R^2_{excluded}$ are the R^2 values of the dependent variables when targeted independent variables are included or excluded from the model.

Values of 0.02, 0.15, and 0.35 of f^2 represents small, medium, and large effects (Hair et al. 2016) Table 20 shows the assessment of the significant relationships only in the structural model result for both models.

Table 20: Structure model assessment

	Path-coefficient	R^2	f^2	P Values
Safety leading indicators → safety climate	0.37	0.13	0.15	0.00
Worker observation → Management commitment to safety	0.24	0.05	0.06	0.00
Worker observation → Training perception	0.19	0.06	0.04	0.04
Worker observation → Supervisor safety role	0.20	0.14	0.04	0.041
Pre-task → Supervisor safety role	0.30	0.14	0.10	0.00

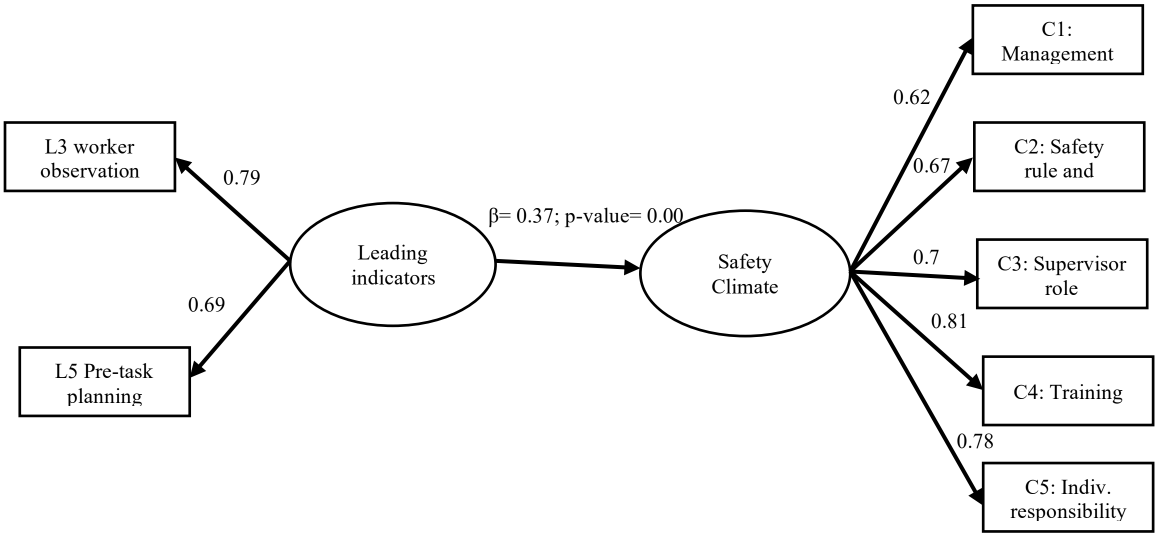

Figure 7: Revised hypothetical model

$R^2 = 0.13$

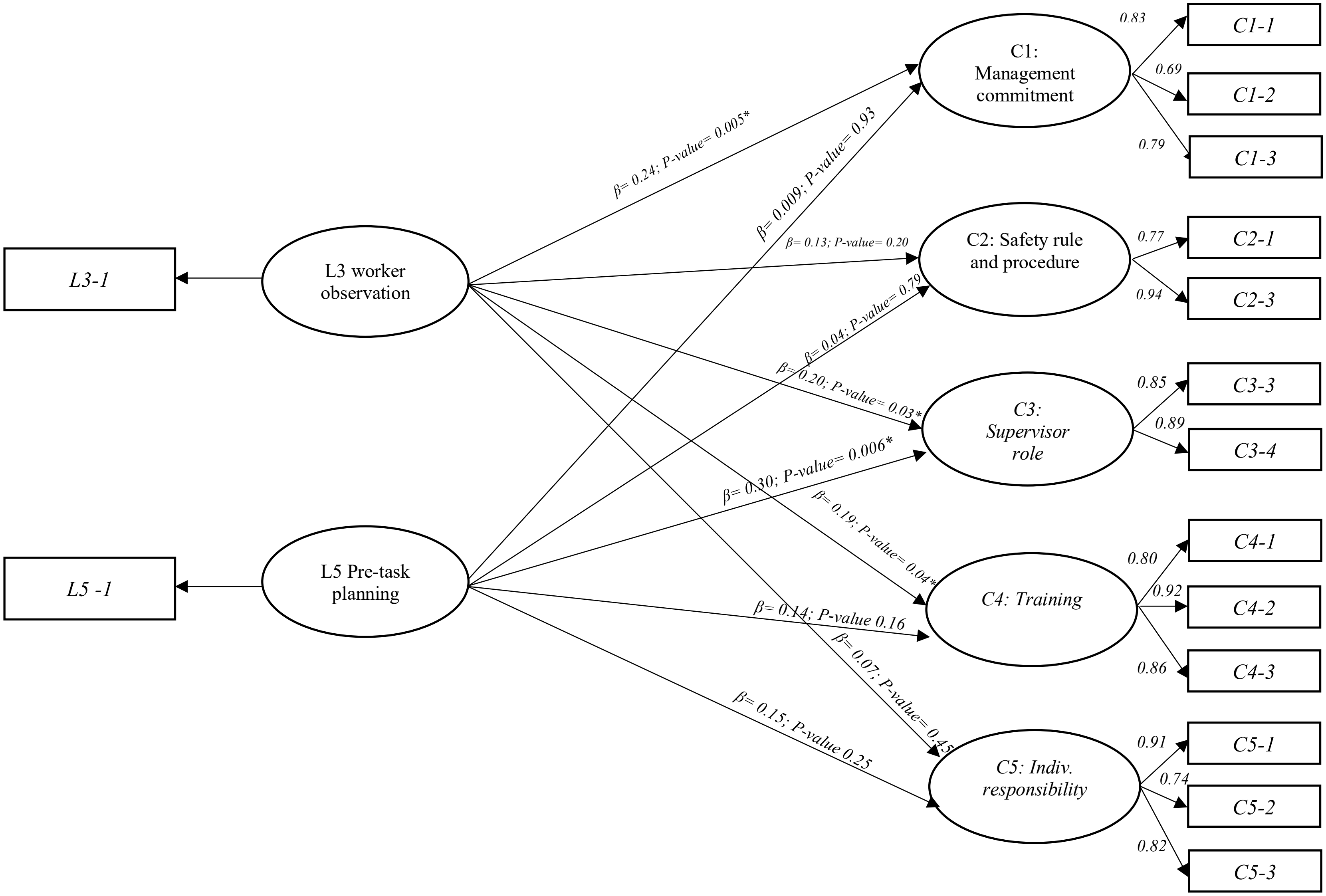

Figure 8: hypothetical model of the significant safety leading indicators relationships with safety climate dimensions

As shown in Table 20, safety leading indicators are predictors of safety climate. The results indicated that every unit increase in management safety activities (i.e., leading indicators) increases the construction workers' perception of these activities by 0.37. The results also show that worker observation and pre-task plan indicators are predictors of construction workers' perception of management's commitment to safety, of the supervisory safety role, and of training, as shown in figure 8. The results show that worker observation has a significant association with management's commitment to safety and to the supervisory safety role, where every unit increase in the worker observation program on the construction jobsite increases the perception of management's commitment to safety and to the supervisory safety role by 0.24 and 0.2, respectively. Similarly, an increase of one unit in the worker observation program increases the perception of safety training by 0.19. A pre-task plan also has a significant association with the supervisory safety role, where a one unit increase in the pre-task plan increases the awareness of a positive supervisory safety role among construction workers. The results also show that the effect size of the relationship between safety climate and leading indicators is medium (*f= 0.15).* The effect size of the relationship between a pre-task safety plan and a supervisory safety role is similar (*f= 0.10*). In addition, the effect sizes between worker observation and management's commitment to safety, the supervisory role, and safety training were small (i.e., *f*= 0.06, 0.04, and 0.04, respectively). Goodhue et al. (2012) indicted that a small sample size and a deviation from normality might be sources of the small effect sizes in PLS-SEM. The smaller effect sizes in this study might be due to the high variation in safety leading indicators, as discussed more in the study limitation.

8. Discussion and conclusion

In previous research, safety leading indicators and safety climate were individually correlated with safety performance (Lingard et al. 2017, Salas and Hallowell 2016, McCabe et al. 2016, Panuwatwanich et al. 2016). However, no studies have investigated the association between leading safety indicators and safety climate.

This study aimed to explore the relationship between leading safety indicators and safety climate. Per convention, leading safety indicators were defined as the direct measure of safety management activities (i.e., measures of safety activities performed) and safety climate was defined as the perception of individuals related to these safety activities (i.e., perceptions of system safety). Although both concepts measure very different aspects of safety, both constructs have shown to predict future injury rates. Thus, understanding how they relate to one another is helpful in pursuing an efficient, multi-dimensional, and unified techniques for safety monitoring and prediction. Further, this study elucidates the differences and complementary nature of these constructs.

The study began by making a clear distinction between the leading indicators and climate, which was important because some researchers and practitioners casually refer to them interchangeably. A hypothetical model linking the leading safety indicators to the safety climate was developed based on this distinction and the main hypothesis was that leading safety indicators positively associate with safety climate dimensions. This hypothesis was tested using a partial least structural equation model (PLS-SEM).

The results showed that the leading indicators predict safety climate. The model showed that an increase of safety activities in the construction jobsite by one unit increases the safety perception of workers by 0.37 unit. Prior safety leading indicators suggested measuring both the quantity and quality of management safety activities to insure the effectiveness of these activities to reduce future injury (Hallowell et al. 2013). Additionally, previous literature showed that leading safety indicators can become as lagging indicators when managers decreases the attention on safety management practices (i.e., pre-task plan, worker observation) as result of the decreases of site incident/injury (Lingard et al. 2017). However, the result of this study suggested that measuring worker perception can be used to evaluate and track management safety activities in the jobsite, as these activities presents and implemented in the way that can be recognized by the workforce.

The result of this study also revealed that *frequency of worker observations* predict three of the safety climate dimensions: management commitment to safety, supervisor safety role, and safety training. With every one unit increase of the number of safety observations, construction workers perception of *upper management commitment*, *safety supervision, and safety training* increases by 0.24 , 0.20, and 0.19 units, respectively. This result is important because, as Rajendran (2012) and Huang and Hinze (2006) found, safety observations are important for controlling worker behavior and correlate strongly with future safety performance. One other perspective of this finding is that worker observation programs enhance workers' feeling that they are supported by management.

Similarly, *pre-task safety meeting activities* was also found to predict the perceived importance of *supervisor safety roles*. The result showed that an increase of pre-task safety meeting by one unit increases perception of the importance of supervisor safety roles by 0.30 and This finding is confirmed by research that has consistently shown the importance of pretask safety meeting that conducted by both supervisors and construction workers (Alruqi and Hallowell 2019; Hinze and Wilson 2000).

Interestingly, the extent to which perception (climate) mediates the relationship between leading and lagging indicators remains unknown. It is possible that the positive perceptions from climate magnify the relationship between leading indicators and safety performance or that climate is simply a proxy measures for performance. It is also possible that climate measures could be used to complement leading indicators where the leading indicators measure what is performed (quantity) and climate measures how well the activities are performed (quality). If this complement were to be explored, the safety climate questions would need to be revised to better inquire about how well specific activities are performed instead of asking only about generalities.

9. Limitation and recommendation

The study model has several limitations, including a high variation among participant responses and measurement types. This high variation among responses caused the model to dictate a small effect size for the relationship between leading indicators and safety climate dimensions in some relationships investigated in this study (i.e., worker observation to safety climate dimensions) and weakened the model's predictive relevance.

. Given that safety leading indicators (e.g., the frequency of pre-job safety meetings) are typically applied consistently across a crew, we would expect the responses to be consistent within a crew. The results show that there is moderate variation in the responses, raising the question of whether self-reported leading indicators provide a stable and reliable measure. It could be argued that all leading indicator data are self-reported because someone must enter traditional data into a safety management system. Thus, it remains unknown if aggregated data reported by crew members or data entered by management is preferred. In the future, it would be interesting to measure the extent to which self-reported safety leading indicators from crew members correlate with data entries in a safety management system and the extent to which both measures predict future performance.

Additionally, all leading indicator data reported by previous researchers and in this study focus on objective and quantitative measures of performance. However, it is possible that the quality of safety activities is more important to safety prediction and injury prevention than the quantity. This underscores the need for future research into quality-based safety leading indicators. Future researchers may also explore how the quality of safety activities correlate with safety climate and safety performance. It is possible that safety climate surveys may provide an avenue to collect quality-based safety leading indicators if the questions inquire about how well specific safety activities are performed.

As researchers continue to pursue predictors of safety performance that can be used for proactive safety management, it is paramount to consider how the various predictors relate and may provide synergy. To date, predictors like safety leading indicators, climate, precursor analysis, and risk assessment are all applied in isolation. However, these constructs measure different aspects of the safety programs and, together, may provide a more holistic view of safety. This study is an important first step toward the goal of an efficient and unified model of safety prediction.

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CHAPTER 5: SUMMARY AND CONCLUSIONS

Despite the efforts of government regulators and industry researchers to reduce risk in the construction industry, the number of injuries has increased from 937 in 2015 to 991 in 2016 (U.S. Bureau of Labor Statistics, 2016). To date, safety lagging indicators have provided information about accidents only after these occur. Such indicators have taken many forms, one of which is the 'industry recordable injury rate.' However, safety prediction has recently been introduced in the construction industry domain. The aim of safety prediction is the prevention of future workplace accidents and injury.

Proactive metrics, an alternative to lagging indicators, might better predict future accidents and injury. For example, the risk of injury increases as the perceptions of safety rules decreases. In recent years, several construction proactive safety metrics have been developed, with safety climate and safety leading indicators found to significantly improve prediction of worksite injury.

Unfortunately, prior literature on workplace safety has not reached consensus on the specific indicators critical to predicting worksite injury. Furthermore, safety climate and safety leading indicators were independently modeled with safety performance. Safety climate and safety leading indicators might better be integrated into a single model for improving workplace safety in the construction industry.

An additional benefit of integrating these metrics is that they function as crosschecks for quality level when used together in a single jobsite.

In summary, the overarching objective of this dissertation is to examine the empirical relationship between the dimensions of the construction safety climate and the leading safety indicators associated with safety performance.

5.1 Contributions

The chapters of this dissertation contribute to the identification, standardization, and critical examination of the interaction among safety climate dimensions and safety leading indicators.

Chapter 2 defines and differentiates safety leading indicators from other safety predictors, establishes clear procedures for distinguishing two types of safety leading indicators (active and passive), and then empirically investigates through meta-analysis the links between active and passive leading indicators with risk of injury.

This study's finding serves as a guide for the construction industry and researchers in developing valid common construction safety leading indicators.

Chapter 3 (the initial paper in this study) focuses on requirements for identifying common construction safety climate dimensions. The inconsistencies in current literature in this regard justifies the aforementioned focus. Furthermore, Chapter 3 improves upon the current literature by offering an unambiguous definition of common safety climate dimensions and by providing a preliminary meta-analysis of construction safety climate dimensions and their relationships with injury across multiple samples. The finding of this study yields a set of common construction climate dimensions strongly predictive of worksite injury.

Chapter 4 contributes to distinguishing between safety leading indicators and safety climate dimensions, establishing a hypothetical model of the connections between safety leading indicators scores and safety climate dimensions, and employing a structural equation modeling methods for validation. The finding of this study can be used by industry practitioners to establish a clear and crisp measure of both jobsite metrics, which can then be used as a crosscheck for determining the quality of leading indicators. These findings have potential for use as a guide in modeling complex safety metrics.

This study's limitation serves as a guide for future research investigating interactions between safety climate and safety leading indicators in connection with injury when both metrics are integrated into a single model.

5.2. Limitation

The paucity of published studies is a limitation of both Chapters 2 and 3. This limitation affects the meta-analysis procedure, given that sample size in this procedure was necessarily restricted by the number of available studies from which individual effects were extracted in order to perform the overall aggregation of effect size.

The focus of Chapter 2 is to invstgated the relationship between sfety leading indactors and inury. Similarly, Chapter 3's identified common dimensions that defining construction safety climate. In both cahpters the limited number included in the analysis were the major limitation. Safety climate study for example included only eight of these dimensions in the meta-analysis out of 14 safety climate dimensions identified in current ltreture. .

The key limitation of Chapter 4 is the availability of reliable data for self-reported injury data to validate the exploratory model with injury. In additions, high variation among participant responses and measurement types. Given that safety leading indicators (e.g., the frequency of pre-job safety meetings) are typically applied consistently across a crew, we would expect the responses to be consistent within a crew. The results show that there is moderate variation in the responses, raising the question of whether self-reported leading indicators provide a stable and reliable measure. It could be argued that all leading indicator data are self-reported because someone must enter traditional data into a safety management system.

5.3. Suggestions for Future Research

This dissertation findings might better prepare future researchers in overcoming the limitations. The studies in Chapters 2 and 3 have similar limitations. In chapter 1 for example, few studies measure active leading indicators, given that safety leading indicators is a relatively recent topic of research. I recommend that the meta-analysis in this study be replicated in the future, but with more up-to-date analyses so that the construction community is provided with the most recent predictors of leading indicators.

Chapter 3 on the other hand offers a comprehensive review of the literature on construction safety climate, with 107 studies in total in the sample. Of the 107 studies under review, 11 are included in the meta-analysis. These 11 studies report statistical information concerning the relationship between climate dimensions and safety outcomes. Studies reporting the aggregation score of safety climate are excluded because the research question was specific to the empirical quantification of the relationship between safety climate dimension and safety outcome. Given the small sample size of this part of the study, generalization of results is not possible. Future studies, however, might profitably replicate the meta-analysis part of this study, with necessary updating of published literature. Another suggested extension of the current study presented in chapter 2 is the inclusion of multiple levels of analysis concerning safety climate – individual level, group level, and team level. Recent interest in developing safety climate dimensions based on such levels occurring in construction jobsites could build on the current study’s analysis. Developments in safety climate dimensions will need to take into account the comparison of such dimensions at different levels of analysis.

In Chapter 4 (the third study of this dissertation), I investigate the hypothesis that safety-leading indicators predict safety climate dimensions. This chapter is first step toward testing and combining mulitble safety predictors to detrimne the relationship among thes To date, predictors like safety leading indicators, climate, precursor analysis, and risk assessment are all applied in isolation. However, these constructs measure different aspects of the safety programs and, together, may provide a more holistic view of safety. This study is an important first step toward the goal of an efficient and unified model of safety prediction. Several safety predictors, such as a precursor analysis and a safety risk analysis, can be joined to the model in chapter 4 to advance the safety system. This joined model requires future empirical research to validate the relationships among these various safety forecasters.

5.4 Lessons Learned

There were several issues with the data collection of precursors and self-reported injuries that I was planning to incorporate with the current dissertation model. The aim of this section is to highlight these issues to help future researchers eliminate them in future work related to the measurement of these two variables. The precursor analysis protocol for this data collection is adopted from published literature. This procedure's protocol requires direct conversations with construction workers and questions that directly relate to the task/s they are performing (e.g., "what task you are performing today"). Investigators can then combine the observations collected during conversions with respondents' answers to the precursor protocol questions to judge the degree to which the precursor is present or not. Early in the data-collection process, I asked participants to write answers for the precursor protocol questions. Very few participants took the time to answer these question due to the time it took to write the answers. The first lesson learned here is to not ask participants to write their responses. Instead, recording the conversation seems to be an efficient way to collect information about precursors. In the data I collected, most respondents provided very short answers to precursor questions (e.g., Yes/No), and these answers were not helpful in judging whether the precursor present or not. Investigators must be familiar with tasks and procedures that participants perform. This knowledge will allow the investigator to ask more questions and collect more research data that can help to assign the precursor score. The second issue was related to the respondents' answers to the self-reported injury questions. The survey includes four questions related to self-reported injuries and near miss (e.g., questions about first aid, minor injuries, and injuries that required absence from work). Seventy percent of the survey participants reported no injuries for all of the questions. Even though some questions asked about minor injuries, respondents still did not want to share their injury history. Future research should consider using different questions or methods that can make participants comfortable with sharing their injury history.

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Appendices

Appendix A : Descreption of all safety climate dimentions includeed in the review study

Table C1: Discerption of each safety climate dimensions used across reviewed studies

Author (year)	**Management commitment to safety**	**Coworkers’ safety response**	**Worker safety response**	**Supervisor’ s safety response**	**Individual responsibility for health and safety**	**Management systems (Safety rules & procedures)**	**Communication**	**Training**	**Workload pressure**	**Risk taking behavior**	**Safety involvement (Worker)**	**Workmate’ s influence**
Pinion et al. (2016)	X											
Gao et al. (2016)	X	X	X	X								
He et al. (2016)	X				X	X						
McCabe et al. (2016)	X	X		X		X			X			
Patel and Jha (2016)	X			X		X	X		X	X	X	
Pousette and Törner (2016)	X											
Hon and Liu (2016)	X				X	X						
Sparer et al. (2016)	X					X				X		
Fung et al. (2016)												
Daniels et al. (2016)							X					
Wu et al. (2016)	X					X	X	X			X	
Kaskutas et al. (2016)	X			X							X	
Panuwatwanich et al. (2016)	X					X			X	X		
Guo et al. (2016)	X		X						X			
Gao et al. (2016)	X	X		X								

Table C1-1 : Continued discerption of each safety climate dimensions used across reviewed studies

Author (year)	Management commitment to safety	Coworkers' safety response	Worker safety response	Supervisor's safety response	Individual responsibility for health and safety	Management systems (Safety rules & procedures)	Communication	Training	Workload pressure	Risk taking behavior	Safety involvement (Worker)	Workmate's influence
Li et al. (2016)												
Raja et al. (2016)	X		X			X		X	X			
Jafari et al. (2015)	X					X	X	X	X		X	
Seo et al. (2015)	X			X		X	X	X				
Meliá (2015)	X	X		X						X		
Fang et al. (2015)				X							X	X
Arcury et al. (2015)	X									X		
Lipscomb et al. (2015)												
Shen et al. (2015)												
Wu et al. (2015)				X			X		X			X
Wu et al. (2015)				X		X	X	X			X	
Marin et al. (2015)								X	X			
Stoilkovska et al. (2015)	X	X										
Zhang et al. (2015)	X	X		X	X							
Soraperra et al. (2015)	X											

Table C1-2: Continued discerption of each safety climate dimensions used across reviewed studies

Author (year)	Management commitment to safety	Coworkers’ safety response	Worker safety response	Supervisor’s safety response	Individual responsibility for health and safety	Management systems (Safety rules & procedures)	Communication	Training	Workload pressure	Risk taking behavior	Safety involvement (Worker)	Workmate’s influence
Shin et al. (2015)	X			X		X	X	X				
Liao et al. (2014)	X		X	X		X		X				
Votano and Sunindijo (2014)												
Hoffmeister et al. (2014)				X			X					
Solís-Carca and Franco-Poot (2014)								X				
Okoye and Aderibigbe (2014)	X							X			X	
Hon et al. (2014b)	X			X		X		X		X	X	X
Masood et al. (2014)	X			X		X		X		X	X	X
Hon et al. (2014a)	X				X	X						
Feng et al. (2014)	X			X		X	X	X	X	X	X	
Han et al. (2014)				X				X				
Nkhungulu (2014)	X			X	X	X	X	X	X			
Tholén et al. (2013)	X						X				X	
Zou and Sunindijo (2013)												
Liao et al. (2013)	X			X					X	X	X	

Table C1-3: Continued discerption of each safety climate dimensions used across reviewed studies

Author (year)	Management commitment to safety	Coworkers’ safety response	Worker safety response	Supervisor’ s safety response	Individual responsibility for health and safety	Management systems (Safety rules & procedures)	Communication	Training	Workload pressure	Risk taking behavior	Safety involvement (Worker)	Workmate’ s influence
Sparer et al. (2013)	X					X				X		
Kanten (2013)						X	X	X	X			
Cooke et al. (2013)				X								
Silva et al. (2013)		X	X	X								
Cigularov et al. (2013a)	X								X			
Cigularov et al. (2013b)	X								X			
Gilkey et al. (2013)	X				X	X	X	X		X		
Lingard et al. (2012)	X	X		X								
Hon et al. (2012)	X			X		X		X			X	X
Arcury et al. (2012a)	X											
Okolie and Okoye (2012)	X							X			X	
Arcury et al. (2012b)	X										X	
Grzywacz et al. (2012)	X										X	
Healey and Sugden (2012)	X											
Lingard et al. (2011a)		X										

Table C1-4: Continued discerption of each safety climate dimensions used across reviewed studies

Author (year)	Management commitment to safety	Coworkers’ safety response	Worker safety response	Supervisor’s safety response	Individual responsibility for health and safety	Management systems (Safety rules & procedures)	Communication	Training	Workload pressure	Risk taking behavior	Safety involvement (Worker)	Workmate’s influence
Sparer et al. (2013)	X					X				X		
Kanten (2013)						X	X	X	X			
Cooke et al. (2013)				X								
Silva et al. (2013)		X	X	X								
Cigularov et al. (2013a)	X								X			
Cigularov et al. (2013b)	X								X			
Gilkey et al. (2013)	X				X	X	X	X		X		
Lingard et al. (2012)	X	X		X								
Hon et al. (2012)	X			X		X		X			X	X
Arcury et al. (2012a)	X											
Okolie and Okoye (2012)	X							X			X	
Arcury et al. (2012b)	X										X	
Grzywacz et al. (2012)	X										X	
Healey and Sugden (2012)	X											
Lingard et al. (2011a)		X										

Table C1-5: Continued discerption of each safety climate dimensions used across reviewed studies

Author (year)	**Management commitment to safety**	**Coworkers’ safety response**	**Worker safety response**	**Supervisor’ s safety response**	**Individual responsibility for health and safety**	**Management systems (Safety rules & procedures)**	**Communication**	**Training**	**Workload pressure**	**Risk taking behavior**	**Safety involvement (Worker)**	**Workmate’ s influence**
Sparer et al. (2013)	X					X				X		
Kanten (2013)						X	X	X	X			
Cooke et al. (2013)				X								
Silva et al. (2013)		X	X	X								
Cigularov et al. (2013a)	X								X			
Cigularov et al. (2013b)	X								X			
Gilkey et al. (2013)	X				X	X	X	X		X		
Lingard et al. (2012)	X	X		X								
Hon et al. (2012)	X			X		X		X			X	X
Arcury et al. (2012a)	X											
Okolie and Okoye (2012)	X							X			X	
Arcury et al. (2012b)	X										X	
Grzywacz et al. (2012)	X										X	
Healey and Sugden (2012)	X											
Lingard et al. (2011a)		X										

Table C1-6: Continued discerption of each safety climate dimensions used across reviewed studies

Author (year)	Management commitment to safety	Coworkers’ safety response	Worker safety response	Supervisor’ s safety response	Individual responsibility for health and safety	Management systems (Safety rules & procedures)	Communication	Training	Workload pressure	Risk taking behavior	Safety involvement (Worker)	Workmate’ s influence
Lingard et al. (2009)		X		X								
Mohamed et al. (2009)	X						X	X	X	X		
Edelson et al. (2009)	X											
Probst et al. (2008)							X					
Zhou et al. (2008)	X					X				X	X	X
Larsson et al. (2008)												
Meliá et al. (2008)	X	X	X	X								
Pousette et al. (2008)	X						X					
Chinda and Mohamed (2008)												
McCabe et al. (2008)	X	X		X					X		X	
Jorgensen et al. (2007)												
Fang et al. (2006)	X			1		X		X		X	X	X
Abudayyeh et al. (2006)	X											
Fung et al. (2005)	X			X						X		X

Table C1-7: Continued discerption of each safety climate dimensions used across reviewed studies

Author (year)	Management commitment to safety	Coworkers’ safety response	Worker safety response	Supervisor’s safety response	Individual responsibility for health and safety	Management systems (Safety rules & procedures)	Communication	Training	Workload pressure	Risk taking behavior	Safety involvement (Worker)	Workmate’s influence
Siu et al. (2004)							X					
Goldenhar et al. (2003)	X							X				
Siu et al. (2003)						X			X			
Gillen et al. (2002)	X										X	
Mohamed (2002)	X			X		X	X		X	X	X	
O'Toole (2002)	X			X							X	
Glendon and Litherland (2001)						X	X		X			
Langford et al. (2000)										X		

Appendix B: Descreption of all safety leading indicators studies includeed in the review

Table B-1 : All passive leading indicators studies included in the review

Author(date)	Hazard reporting	Safety inspections and observation	Documentation	Pre-task safety meeting	Upper management involvement	Owner involvement	Training and orientation	Substance Abuse	Incentives	PPE	Worker involvement	Safety resource	Staffing for safety	Written Safety Plan
Choudhry and Zahoor (2016)			X	X	X		X		X	X	X	X		X
Alarcón et al. (2016)	X	X			X		X		X					X
Cheng et al. (2015)	X	X	X	X			X		X				X	X
Hinze et al. (2013a)			X			X	X			X	X	X	X	
Hasan and Jha (2013)									X					
Goh and Chua (2013)	X	X		X			X		X					X
De Silva and Wimalaratne (2012)					X		X					X		
Chen and Jin (2011)				X					X					
Lai et al. (2011)					X		X		X		X			
McDonald et al. (2009)	X			X			X	X						
Aksorn and Hadikusumo (2008a)					X		X				X	X		X
Aksorn and Hadikusumo (2008b)	X	X	X				X		X					X
Idoro (2008)		X							X	X		X		
Hassanein and Hanna (2007)		X		X			X		X	X			X	

Table B-2 : Continued All passive leading indicators studies included in the review

Author(date)	Hazard reporting	Safety inspections and observation	Documentation	Pre-task safety meeting	Upper management involvement	Owner involvement	Training and orientation	Substance Abuse	Incentives	PPE	Worker involvement	Safety resource	Staffing for safety	Written Safety Plan
Razuri et al. (2007)	X			X	X	X	X	X	X				X	X
Huang and Hinze (2006)						X								
Hoonakker et al. (2005)				X			X						X	X
Teo et al. (2005)									X					
Gangwar and Goodrum (2005)									X					
Hinze and Gambatese (2003)		X					X	X	X					
Hinze (2002)									X					
Lin and Mills (2001)		X												
Sawacha et al. (1999)					X		X			X	X		X	X
Tam and Fung Iv (1998)					X		X		X				X	
Jaselskis et al. (1996)		X		X	X		X		X				X	X
Hinze and Raboud (1988)		X	X	X	X	X							X	

Table B-3 : All active safety leading indicators included in the review

Author(date)	Hazard reporting	Safety inspections and observation	Documentation	Pre-task safety meeting	Upper management involvement	Owner involvement	Training and orientation	Substance Abuse	Incentives	PPE	Worker involvement	Safety resource	Staffing for safety	Written Safety Plan
Lingard et al. (2017)	X	X		X			X	X	X					
Salas and Hallowell (2016)	X	X		X	X	X	X							
Guo et al. (2016)	X				X									X
Hallowell et al. (2013)	X	X		X	X	X					X			
Rajendran (2012)		X		X										

Appndix C : English Questionnaire

Project PIN______________________________ Date_________/______/__________________

Participant PIN____________________________

Crew PIN_______________________________

Part 1: Demographic Questionnaire:

Please answer the following demographic questions:

1.1: Personal Information:

Your age ____________________________

Your gender: Male [ ] Female [ ]

Your race/ Ethnicity:

- ☐ Asian
- ☐ Black/African American
- ☐ White
- ☐ Hispanic
- ☐ Other____

Year of experience in construction____

Your title/trade ____

Part 2: Safety climate questionnaire:

The following questions are related to the measurement of safety climate in your organization. Safety climate refers to worker perception related to safety and health in an organization. The questions intend to ask you about safety aspects in your project, such as training, safety rules and procedures, your responsibility for safety, and safety support from management.

For each of the following statements, select the one response that most closely reflects your experience:

		Strongly disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
CM_1	Management continues to bring safety information to on-site employees' attention	1	2	3	4	5
CM_2	Management operates an open-door policy on safety issues	1	2	3	4	5
CM_3	Management encourages feedback from on-site employees regarding safety issues	1	2	3	4	5
CS_1	My supervisor seriously considers any worker's suggestions for improving safety	1	2	3	4	5
CS_2	My supervisor gets annoyed with any worker ignoring safety rules, even minor rules	1	2	3	4	5
CS_3	Whenever pressure builds up, my supervisor wants us to work faster, rather than by the rules	1	2	3	4	5
CS_4	As long as work remains on schedule, my supervisor doesn't care how this has been achieved	1	2	3	4	5
CR_1	Current safety rules and procedures are made available to protect us from accidents	1	2	3	4	5
CR_2	Current safety rules and procedures are so complicated that some workers do not pay much attention to them	1	2	3	4	5
CR_3	Current safety rules and procedures require us to report any safety violations by a fellow worker	1	2	3	4	5
CT_1	Safety issues are given a high priority in training programs	1	2	3	4	5
CT_2	Workplace health and safety training covers the types of situations that employees encounter in their job	1	2	3	4	5
CT_3	Employees receive comprehensive training in workplace health and safety issues	1	2	3	4	5
CW_1	I use all the necessary safety equipment to do my job	1	2	3	4	5
CW_2	I use the correct safety procedures for carrying out my job	1	2	3	4	5
CW_3	I ensure the highest levels of safety when I carry out my job	1	2	3	4	5
CP_1	In the last 5 years, how many times have you experienced a near-miss incident of any kind at work? __________________					

CP_2 In the last 5 years, how many times have you suffered from an accident/injury of any kind at work, but did NOT require absence from work? _________________________

CP_3 In the last 5 years, how many times have you suffered from an accident/injury, which required absence from work NOT exceeding three consecutive days?
____

CP_4 In the last 5 years, how many times have you suffered from an accident/injury that required absence from work exceeding three consecutive days? ___________________________

Part 3. Leading indicators questionnaire:
The following questions intend to measure the overall safety performance in the project you are currently working on.

Please answer the following questions:

L1.1. How many times per **month** do you exercise stop work authority? __ per month

L1.2. How many times per **month** do you experience a near miss incident? ___ per month

L.2.1. How many times per month does an owner's representative conduct safety walkthroughs? ___ per month

L.2.2. How many times per month does an owner's representative participate in orientation sessions? ___ per month

L.2.3. How many times per month does an owner's representative participate in daily pre-job meetings? ___ per month

L.3.1. In what percentage of daily safety meetings does contractor leadership participate? _________ %

L.3.2. In what percentage of safety orientations does contractor leadership participate? _________ %

L.4.1. How many times per month does leadership conduct a safety inspection or audit? ___ per month

L.4.2. How many times per month does leadership conduct worker observations? ___ per month

L.4.3. In what percentage of safety audits does a contractor representative participate? _________ %

L.5.1 For what percentage of tasks are pre-task plans conducted? _________ %

L.6.1 In what percentage of field safety activities does upper-level management participate? _________ %

Appendix D: Spanish Questionnaire

PIN del proyecto (Project)____________________ Fecha (mm/dd/aa)___/______/____
PIN del participante__________________________
PIN de la cuadrilla (Crew)______________________________

Primera paerte: Cuestionario Demográfico

Por favor, responda las siguientes preguntas demográficas:

1.1: Informacion personal:

Edad ___________________________ Género: Masculino [ ] Femenino [ ]

¿Con qué raza te identificas?

- ☐ Asiático
- ☐ Afroamericano
- ☐ Blanco/Caucásico
- ☐ Hispano
- ☐ Otro ____

Años de experiencia en la construcción:____

Su cargo / oficio ____

Segunda parte: Cuestionario sobre la seguridad en el trabajo

Las siguientes preguntas están relacionadas con la medición del ambiente de seguridad en su organización. El ambiente de seguridad se refiere a la percepción del trabajador relacionada con la seguridad y la salud en una organización. Las preguntas pretenden preguntarle sobre aspectos de seguridad en su proyecto, como entrenamiento, reglas y procedimientos de seguridad, su responsabilidad con la seguridad y el apoyo de seguridad de la gerencia.

Para cada una de las siguientes afirmaciones, seleccione la respuesta que mejor refleje su experiencia:

		Muy en desacuerdo	Algo en desacuerdo	Ni de acuerdo ni en desacuerdo	Parcialmente de acuerdo	Totalmente de acuerdo
CM_1	La administración continúa brindando información de seguridad a la atención de los empleados en la obra	1	2	3	4	5
CM_2	La gerencia opera una política de puertas abiertas en temas de seguridad	1	2	3	4	5
CM_3	La administración alienta las opiniones y observaciones de los empleados en la obra con respecto a los problemas de seguridad	1	2	3	4	5
CS_1	Mi supervisor considera seriamente las sugerencias de cualquier trabajador para mejorar la seguridad	1	2	3	4	5
CS_2	Mi supervisor se molesta con cualquier trabajador que ignore las reglas de seguridad, incluso las reglas menores	1	2	3	4	5
CS_3	Cada vez que aumenta la carga de trabajo, mi supervisor quiere que trabajemos más rápido, en lugar de seguir las reglas	1	2	3	4	5
CS_4	Mientras el trabajo continúe según el cronograma, a mi supervisor no le importa cómo se haya logrado	1	2	3	4	5
CR_1	Las normas y procedimientos de seguridad vigentes para protegernos de los accidentes están a nuestro alcance para ser consultadas	1	2	3	4	5
CR_2	Las normas y procedimientos de seguridad vigentes son tan complicados que algunos trabajadores no les prestan mucha atención	1	2	3	4	5
CR_3	Las normas y procedimientos de seguridad vigentes nos obligan a informar cualquier violación de seguridad por parte de un compañero de trabajo	1	2	3	4	5
CT_1	Los temas relacionados con seguridad tienen prioridad alta en los programas de capacitación.	1	2	3	4	5

CT_2	Los entrenamientos de salud y seguridad en el lugar de trabajo cubren los tipos de situaciones a las que los empleados se enfrentan en su trabajo.	1	2	3	4	5
CT_3	Los empleados reciben entrenamiento integral en temas de salud y seguridad en el lugar de trabajo.	1	2	3	4	5
CW_1	Uso todo el equipo de seguridad necesario para hacer mi trabajo.	1	2	3	4	5
CW_2	Me guío los procedimientos de seguridad correctos para realizar mi trabajo.	1	2	3	4	5
CW_3	Garantizo los más altos niveles de seguridad cuando realizo mi trabajo	1	2	3	4	5
CP_1	En los últimos 5 años, ¿cuántas veces ha estado cerca de experimentar un incidente por fallas de cualquier tipo en el trabajo? __________________					
CP_2	En los últimos 5 años, ¿cuántas veces ha sufrido un accidente o lesión de cualquier tipo en el trabajo, pero NO solicitó días de ausencia del trabajo?________________________________					
CP_3	En los últimos 5 años, ¿cuántas veces ha sufrido un accidente o lesión que requirió ausencia del trabajo por NO más de tres días consecutivos?____					
CP_4	En los últimos 5 años, ¿cuántas veces ha sufrido un accidente o lesión que requirió la ausencia del trabajo por más de tres días consecutivos?____					

Tercera parte. Cuestionario sobre los indicadores principales:
Las siguientes preguntas pretenden medir el desempeño general de los procedimientos de seguridad en el proyecto en el que está trabajando actualmente.

Por favor, conteste a las siguientes preguntas:

L1.1. ¿aCuántas veces **al mes** ejercitas la autoridad de dejar de trabajar? ______ por mes

L1.2. ¿Cuántas veces **al mes** está cerca de experimentar un incidente? ______ por mes

L.2.1. ¿Cuántas veces **al mes** un representante del propietario realiza recorridos de seguridad? ______ por mes

L.2.2. ¿Cuántas veces **al mes** un representante del propietario participa en sesiones de orientación? ______ por mes

L.2.3. ¿Cuántas veces **al mes** un representante del participa en las reuniones diarias previas al trabajo? ______ por mes

L.3.1. ¿En qué **porcentaje** de las reuniones de seguridad diarias participa el jefe de los contratistas? ___________ %

L.3.2. ¿En qué **porcentaje** de las reuniones de seguridad participa el jefe de los contratistas? ___________ %

L.4.1. Cuántas veces **al mes** el jefe de los contratistas realiza una inspección o auditoría de seguridad? ______ por mes

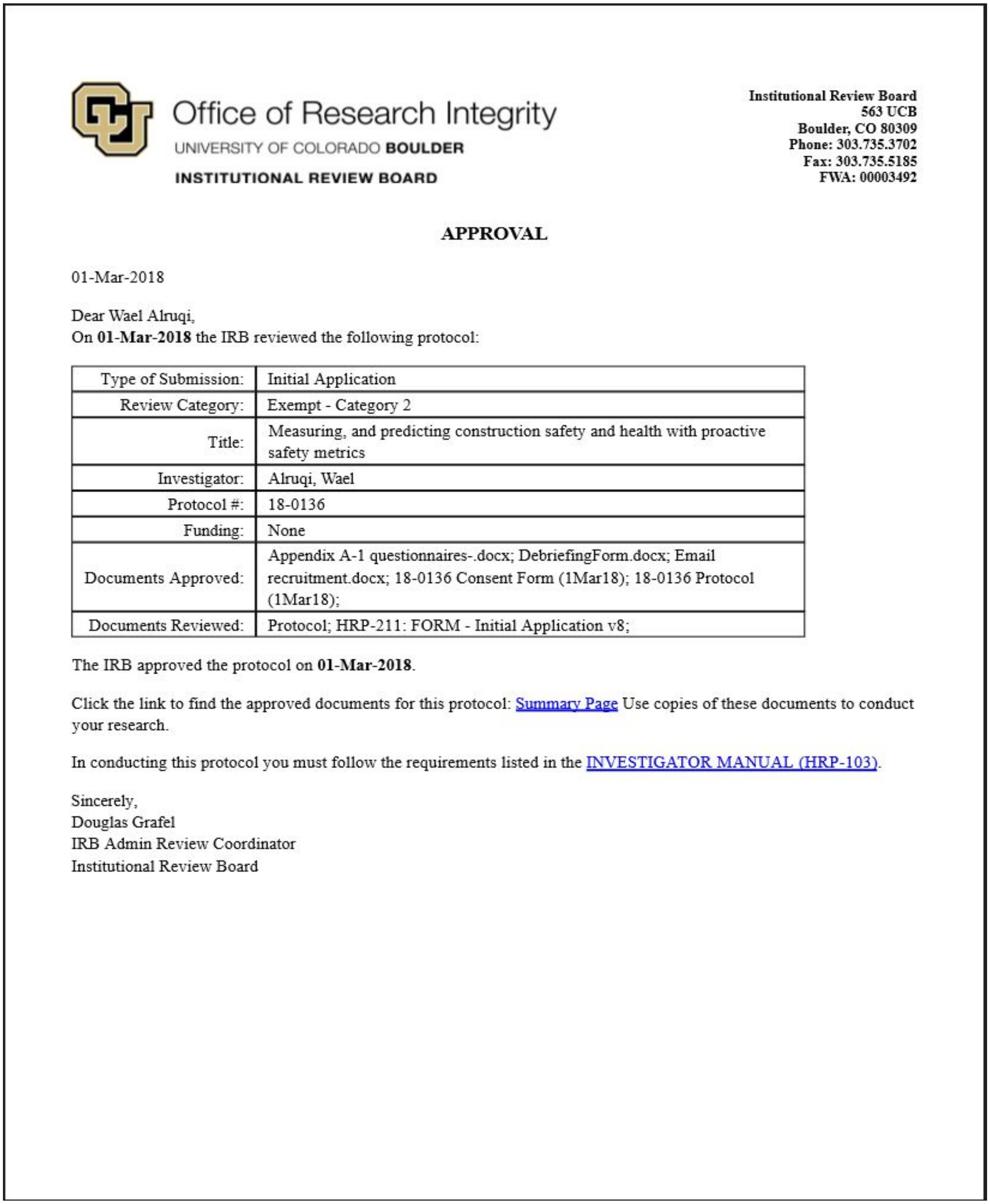
L.4.2. Cuántas veces **al mes** el jefe de los contratistas realiza las observaciones de los trabajadores? ______ por mes

L.4.3. En qué **porcentaje** de auditorías de seguridad participa el representante del contratista? ___________ %

L.5.1 ¿Para **qué porcentaje** de las tareas se realizan planes previos a la tarea? ___________ %

L.6.1 En qué **porcentaje** de las actividades de seguridad en la obra participa la gerencia de nivel superior? ___________ %

Appendix E : IRB Approval



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APPROVAL

01-Mar-2018

Dear Wael Alruqi,
On **01-Mar-2018** the IRB reviewed the following protocol:

Type of Submission:	Initial Application
Review Category:	Exempt - Category 2
Title:	Measuring, and predicting construction safety and health with proactive safety metrics
Investigator:	Alruqi, Wael
Protocol #:	18-0136
Funding:	None
Documents Approved:	Appendix A-1 questionnaires-.docx; DebriefingForm.docx; Email recruitment.docx; 18-0136 Consent Form (1Mar18); 18-0136 Protocol (1Mar18);
Documents Reviewed:	Protocol; HRP-211: FORM - Initial Application v8;

The IRB approved the protocol on **01-Mar-2018**.

Click the link to find the approved documents for this protocol: Summary Page Use copies of these documents to conduct your research.

In conducting this protocol you must follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,
Douglas Grafel
IRB Admin Review Coordinator
Institutional Review Board