DEVELOPING A PROCESS TO MEASURE SAFETY CLIMATE UNDER THE CONSTRUCTION WORKING ENVIRONMENT

A Dissertation in
Architectural Engineering

by

Miaomiao Niu

© 2017 Miaomiao Niu

Submitted in Partial Fulfillment
of the Requirements
for the Degree of
Doctor of Philosophy
August 2017
The dissertation of Miaomiao Niu was reviewed and approved* by the following:

Robert M. Leicht  
Associate Professor of Architectural Engineering  
Dissertation Advisor  
Chair of Committee

John I. Messner  
Charles and Elinor Matts Professor of Architectural Engineering

Somayeh Asadi  
Assistant Professor of Architectural Engineering

Susan Mohammed  
Associate Professor of Psychology

Richard Mistrick  
Associate Professor of Architectural Engineering

*Signatures are on file in the Graduate School
ABSTRACT

Safety climate has been widely used as a leading indicator to predict safety performance across multiple industries. Although extensive studies have focused on safety climate measurement in construction, the interpretations of the results are confusing to project management. There is a lack of theoretical development of safety climate indicators in the dynamic context of the construction industry. This research is aimed at developing a process to measure safety climate under the construction working environment. Four stages are designed to accomplish this research goal, including: 1) Problem identification; 2) development of safety climate contextual indicators, where systematic review and focus group discussions were applied to identify the contextual indicators related to safety climate; 3) development of the safety climate measurement process model, where a case study was conducted to implement the process of safety climate measurement in the construction context; 4) process model validation, where the process model was validated by focus group discussion and expert interviews. The results of this research include a framework of contextual indicators of safety climate, as well as a process model of safety climate measurement under the dynamic construction working environment. By implementing the process model through the case study, the relationship between site dynamics and perceived safety was explored. The research contributes to industry applications of using safety climate as a leading indicator to proactively manage site safety under the dynamic working environment. The findings also contribute to a more holistic understanding of the safety climate concept, and serves as a foundation to explain the mechanisms of the industry context influencing safety climate.
# TABLE OF CONTENTS

LIST OF FIGURES ........................................................................................................................................... vii

LIST OF TABLES ................................................................................................................................................ viii

ACKNOWLEDGEMENTS ..................................................................................................................................... ix

Chapter 1 Introduction ....................................................................................................................................... 1

1.1 Background ................................................................................................................................................ 1

1.2 Statement of the Problem .......................................................................................................................... 3

1.3 Goals and Objectives ................................................................................................................................. 4

1.4 Structure .................................................................................................................................................... 4

Chapter 2 Literature Review ............................................................................................................................. 5

2.1 The Concept of Safety Climate .................................................................................................................. 5

2.1.1 Organizational Culture and Organizational Climate ........................................................................... 6

2.1.2 Safety Culture and Safety Climate ....................................................................................................... 7

2.2 The Measurement of Safety Climate .......................................................................................................... 9

2.2.1 Safety Climate Factorial Structure ..................................................................................................... 9

2.2.2 Safety Climate Multi-level Structure .................................................................................................. 10

2.2.3 The Validation of Safety Climate ......................................................................................................... 11

2.3 Safety Culture Model ................................................................................................................................ 14

2.4 Safety Climate in Construction ................................................................................................................ 18

2.5 Process Modeling in the Construction Industry ....................................................................................... 19

2.5 Summary ................................................................................................................................................... 21

Chapter 3 Research Methodology .................................................................................................................. 22

3.1 Overall Research Process .......................................................................................................................... 22

3.2 Research Steps .......................................................................................................................................... 24

3.2.1 Stage 1: Problem Identification ........................................................................................................ 24

3.2.2 Stage 2: Development of the Contextual Factors .............................................................................. 25

3.2.3 Stage 3: Development of the Process Model ..................................................................................... 26

3.2.4 Stage 4: Validation of the Process Model .......................................................................................... 27

3.3 Summary ................................................................................................................................................... 27

Chapter 4 Developing the Contextual Indicators of Safety Climate under the Construction Working Environment ............................................................................................................................. 29
4.1 Identifying Common Safety Climate Factors .............................................................. 29
  4.1.1 Data Collection ............................................................................................ 30
  4.1.2 Data Analysis .............................................................................................. 31
4.2 Developing the Framework of Construction Context .............................................. 34
4.3 Identifying Construction Safety Climate Contextual Indicators ............................... 38
4.4 A Framework of Safety Climate Contextual Factors in Construction ................. 41
4.5 Summary ........................................................................................................... 42

Chapter 5 Developing a Process of Measuring Safety Climate under the Construction
Working Environment ................................................................................................. 44
5.1 The Process of Measuring Safety Climate under the Construction Working
Environment ............................................................................................................ 44
  5.1.1 The Structure of the Safety Climate Measurement Process Model ............ 45
  5.1.2 The Contents of the Safety Climate Measurement Process Model .......... 47
5.2 The Development of the Safety Climate Measurement Process Model ............... 52
  5.2.1 Literature Review ....................................................................................... 53
  5.2.2 Case Study ................................................................................................. 54
  5.2.3 Workshop Validation .................................................................................. 54
  5.2.4 Interview Validation ................................................................................... 55
5.3 Summary ........................................................................................................... 56

Chapter 6 A Case Study of Safety Climate Measurement under the Construction
Working Environment ................................................................................................. 57
6.1 Introduction ........................................................................................................ 57
6.2 Data Collection .................................................................................................. 58
  6.2.1 Data Collection Project .............................................................................. 58
  6.2.2 Data Collection Instrument ....................................................................... 60
6.3 Data Analysis ...................................................................................................... 65
  6.3.1 Demographics ........................................................................................... 65
  6.3.2 Comparisons between the Two Data Collections .................................... 67
  6.3.2 Perceived Workplace Conditions ............................................................... 71
  6.3.2 Contextual Information Captured by the Process Model ......................... 73
6.4 Summary ........................................................................................................... 74

Chapter 7 Conclusions ............................................................................................... 76
7.1 Research Summary and Contributions .................................................................. 76
  7.2.1 Identify the contextual factors that impact safety climate ......................... 77
  7.2.2 Develop a process model to measure safety climate under the construction
working environment ............................................................................................. 77
  7.2.3 Analyze the relationships between site dynamics and safety climate ....... 78
7.2 Limitations ......................................................................................................... 78
7.3 Future Research ................................................................................................. 80
7.4 Concluding Remarks .......................................................................................... 80

Reference .................................................................................................................. 82
Appendix A Baseline Process Map of the Pilot Case Study ........................................86
Appendix B Questionnaire Used For the Case Study ................................................87
Appendix C Safety Climate Result Report I & II .........................................................89
Safety Climate Survey Report I: .............................................................................89
Safety Climate Survey Result Report II: .................................................................99
Appendix D Safety Climate Follow-Up Interview Report .........................................108
LIST OF FIGURES

Figure 2-1: The Reciprocal Safety Culture Model (Cooper 2000) ........................................ 15
Figure 2-2: Model of construction safety culture (Choudhry et al. 2007) ............................ 16
Figure 2-3: Safety Culture Interaction Model (Fang and Wu, 2013) ................................. 17
Figure 3-1: The Overall Process of the Research ................................................................. 23
Figure 4-1: Functions Required to Support Craftsman, Adapted from Sanvido (1988) ........ 35
Figure 5-1: The Process of Measuring Safety Climate under the Construction Working
Environment ......................................................................................................................... 46
Figure 5-2: Schematic Presentation of the Function Box (Material Laboratory 1981) ........ 47
Figure 5-3: Breakdown of the Pre-survey Step .................................................................... 47
Figure 5-4: Breakdown of the Collect Data Step ................................................................. 49
Figure 5-5: Breakdown of the Analyze Data and Follow-up Step ........................................ 50
Figure 5-6: Breakdown of the Pursue Continuous Improvement Step ................................ 51
Figure 5-7: The Development of the Safety Climate Measurement Process Model .......... 52
Figure 5-8: Perceived Value of the Major Steps ................................................................. 55
Figure 5-9: Clarity of the Major Steps Descriptions ......................................................... 55
Figure 6-1: Case Study Procedures ...................................................................................... 64
Figure 6-2: Overall factors comparison of two samples ..................................................... 67
Figure 6-3: Contextual Indicators of the Carpentry Trade ................................................ 71
Figure 6-4: Work Areas Identified by Workers .................................................................... 72
Figure 6-5: Risk Factors Identified by Workers in Their Work Areas ............................... 73
LIST OF TABLES

Table 2-1: Definitions of Safety Climate ................................................................. 8
Table 2-2: Safety Climate Validation Results ......................................................... 13
Table 2-3: Comparison of Safety Culture Model Studies ....................................... 18
Table 4-1: Safety Climate Factors in Construction Industry within Literature .......... 32
Table 4-2: Human and Environmental Factors of Construction Risks ...................... 37
Table 4-3: Most Commonly Used Safety Climate Factors in the Construction ........... 38
Table 4-4: Environmental Indicators of Safety Climate in Construction ................. 41
Table 6-1: Case Study Project Background ............................................................ 59
Table 6-2: Contextual Indicators that were tested in the Case Study ....................... 61
Table 6-3: Descriptive Properties of Participants ................................................... 65
Table 6-4: Respondents’ Years of Working Experience in Construction .................. 66
Table 6-5: Respondents’ Trades ............................................................................. 66
Table 6-6: Descriptive Statistics of the Contextual Factors .................................... 68
Table 6-7: Perceived Risks by Foremen ................................................................ 70
AKNOWLEDGEMENTS

I would like to take this opportunity to thank all the people who supported me throughout this research. The guidance and support of my committee members in making this a very rewarding research experience. I would like to thank my advisor Dr. Robert Leicht, who has been extremely patient and supportive to provide directions at every step of my research during the past six years. He has also been a great mentor to provide advice on career development and self-improvement. I am also very grateful to Dr. John Messner, Dr. Somayeh Asadi, and Dr. Susan Mohammed for providing valuable feedback and guidance throughout this research.

Thanks to those who participated in the research activities. Special thanks to Jonathan Risley, Don Fronk, and John Bechtel from the Office of Physical Plant at Penn State to support the data collection and coordination with the project teams. I would like to thank the participants of the focus group discussions for their valuable input and feedback, and the project management team of the case study project for their support in this research and their effort in creating a safe site.

Finally, I would like to thank my friends and colleagues in Architectural Engineering program. It was wonderful experience to study and live in Penn State during the past six years. Thanks to my family for their encouragement and support in my pursuit of my PhD.
Chapter 1 Introduction

1.1 Background

The construction industry has long been considered to be one of the most hazardous industries (Ringen and Englund 2006; Hallowell et al. 2013). According to the 2013 industrial safety accident data reported by the U.S. Bureau of Labor Statistics (BLS), the U.S. construction industry recorded the highest number of fatalities by industry, accounting for 18% of all fatalities (BLS 2013). Although the number has seen a downward trend during recent decades, the fatalities and injury rates are still higher than any other industries. Safety failures endanger the lives of the workers, delay the completion time of projects, lower productivity, and result in construction cost overruns (Kim et al. 2013). Therefore, efforts have been made by researchers and practitioners through implementation of various techniques, safety programs and initiatives to promote safety and health in the construction workplace (Hinze and Wilson 2000; Gambatese et al. 2005; Choudhry et al. 2007).

Traditionally, lagging indicators, or reactive indicators, are used by the construction industry to measure the safety performance of projects or companies, such as the Occupational Safety and Health Administration (OSHA) Recordable Incident Rate (RIR), days away, restricted work, or transfer (DART) injury rate; and experience modification ratings (EMRs). These have provided information for the construction industry averages and served as foundations to cross compare construction firms (Hinze et al. 2013).

However, Glendon and Litherland (2001), Chen and Jin (2013), and others have discussed the problems of lagging indicators, such as their insufficient sensitiveness, inaccurate reporting, and ignorance of risk exposure. Moreover, due to the complex and dynamic nature of the construction workplace and the fragmentation of multiple organizations; it is challenging to
identify and measure the ‘true’ safety performance of an active project based on these lagging indicators (Fang et al. 2006; Lingard et al. 2010). Consequently, there has been a shift of research interest towards the application of leading indicators to predict safety performance. While the lagging indicators focus on the outcome of accidents, leading indicators evaluate the level of effectiveness of the safety process (Hinze et al. 2013). Leading indicators monitor the management programs or individual behaviors linked to accident prevention, which helps to identify problematic areas that will potentially lead to accidents and improve safety performance through managing positive safety behaviors.

Safety climate or safety culture is one of the most widely used leading indicators to measure and predict safety performance. Safety climate is defined as “a summary of molar perceptions that employees share about their work environment” (Zohar 1980). The concept of safety culture and safety climate was derived from organizational culture, which is separated from other characteristics of an organization, such as business strategy and decision-making (Zohar 1980, Choudhry et al. 2007). Climate is based on each individual’s perceptions of the practices, procedures, and rewards in the organization. Therefore, the safety climate of a working environment is often measured by the aggregation of the individual employee’s perceptions. Safety climate has been proven to be an effective tool to identify weakness in safety management and communication, which is performed by measuring safety climate in different dimensions, such as management commitment, worker involvement, supervisory environment, and so on. Moreover, as a leading indicator of safety performance, safety climate has been used to predict safety outcomes, such as safe behavior, or increased likeliness of accidents.
1.2 Statement of the Problem

In the construction industry, extensive studies have been focused on safety climate measurement, including the factorial structures (Mohammed 2002; Choudhry et al. 2009), and the multiple levels of organizational safety climate (Melia et al. 2008; Lingard et al. 2010) to quantitatively construct the dimensions of safety climate. However, there is little consensus on the factor structure for safety climate. This implies the complexity of the concept of safety climate and its multiple facets. Traditional tools of safety climate measurement often emphasized on human-related managerial or operational factors, such as management commitment, rules and procedures, and communication between the management and the workers. The working environment is often neglected. This creates more challenges in the construction industry when interpreting the results of safety climate measurement, as the working condition varies greatly at different points of time and the trade composition is often different. There needs to have industry-specific scales incorporate contextual norms and benchmarks to collect diagnostic information that uncovers the nature of the employees’ emphasis on assessing the safety of their working environment.

Although there is extensive research on safety climate measurement, the vast majority of studies have relied on survey data and statistical data analysis techniques (Hopkins 2006). The process of safety climate measurement is not streamlined, especially in construction, where the working environment is constantly changing. This creates a critical conceptual ambiguity in the effort to accurately capture safety climate when creating a safe working environment on a given project. There needs to be a process of safety climate measurement in the context of construction industry to help understand the underlying determinants and outcomes of safety climate.
1.3 Goals and Objectives

The primary goal of this research is to develop a process for capturing the dynamics of construction working environment and the perceived project safety climate. To achieve this goal, the research objectives are established:

- Identify the contextual factors that impact perceived project safety climate;
- Develop a process to measure safety climate considering dynamic working environment of construction to incorporate the contextual factors; and
- Analyze the link between the contextual indicators and safety climate.

1.4 Structure

This dissertation is organized as follows: Chapter 1 gives an introduction of the research topic along with the targeted scope and objectives. Chapter 2 reviews previous researches in safety climate and safety culture in construction, and identifies the knowledge gaps in safety climate studies. Chapter 3 describes the methodologies that were used in this research and the detailed research steps. Chapter 4 discusses the development of a framework of safety climate contextual factors. Chapter 5 presents the development of a safety climate measurement process under the construction working environment. Chapter 6 discusses a case study of safety climate measurement using the developed contextual factors and process model. Chapter 7 concludes the dissertation with contributions, limitations and future steps.
Chapter 2

Literature Review

With the goal of developing a process that captures safety climate in the context of construction site dynamics, this chapter defines the previous work and research into both safety climate and process research in construction. The chapter begins with an introduction of the concept of safety climate and some related theories and research, such as safety culture and organizational culture. To tie this back to construction safety, this is followed by a review of previous studies on safety climate measurement, which includes the factorial structures and multi-level structure. Studies on the validation of safety climate are emphasized to highlight the challenges with contextualizing safety climate. Theoretical models of safety culture are reviewed to understand the knowledge gaps in safety climate research related to environment and dynamic conditions, such as construction. To contextualize safety climate in construction, the characteristics of construction projects and safety management in construction are described as a lead-in to process-related research in construction and the need for developing safety climate measurement into a reliable process.

2.1 The Concept of Safety Climate

Although the term safety climate has been widely used among high-risk industries, there is little consensus on the meaning of safety climate, and the related term safety culture. A number of studies have addressed the conceptual ambiguity on what safety climate actually means (Choudhry et al. 2007; Haukelid 2008). This section reviews this literature with the purpose of considering the definitions provided by each study to understand the core concepts underlying safety climate research and practice.
2.1.1 Organizational Culture and Organizational Climate

The concept of safety culture and safety climate was derived from organizational culture, which is separated from other characteristics of an organization, such as business strategy and decision-making (Zohar 1980, Choudhry et al. 2007). Organizational culture gained much attention in the organization and management literature in the 1980s. Organizational culture has been conceptualized as collective values, beliefs, and assumptions being shared among organization members at different levels, influencing employees’ attitudes and behaviors (Smircich 1983; Detert et al. 2000; Glisson and James 2002; Schein 2004). Two themes emerged from these different studies to best conceptualize organizational culture: values and attitudes (the way people think), and behavior (the way people act or behave) (Cooper 2000; Hopkins 2006). Guldenmund (2000) concludes the characteristics of organizational culture as:

- It is an abstract concept;
- It is relatively stable;
- It has multiple dimensionalities;
- It is shared by (groups of) people;
- It consists of various aspects; and,
- It constitutes practices.

A further discussion is the relationship between culture and climate. Various writers argue that there are conceptual differences. Much research was undertaken under the title of organizational climate in the 1970s, but it was gradually replaced by the term of organizational culture in the same vein of research (Guldenmund 2000). Hofstede (1986) distinguishes organizational culture and climate from a multi-level perspective. He narrows organizational climate down to job satisfaction which is typically considered by lower or middle management; while organization culture is the concern of top-management. Schien (2004) concludes that climate is the reflection and manifestation of culture; therefore, climate is replaced by culture and culture then conveys a broader and more profound meaning. Mearns et al. (2003) argued that
climate us a manifestation of culture, and climate is directly measurable while culture is too abstract to measure. The practical implications are that culture is the underlying definition of the companies values and drivers, with climate serving as the localized recognition, and often nuanced feel, of those same values and drivers as the tangible perception in a given environment.

2.1.2 Safety Culture and Safety Climate

While climate has predominantly been replaced by culture within the organization and management research, they are both notably in use in the field of social psychology research (Hopkins 2006). Also, there is debate within the safety literature regarding the use of the terms safety climate and safety culture, and if any difference exists between them. The terms are used interchangeably in many areas of the safety literature (Cox and Flin 1998; Mohamed 2003). Cooper (2000) distinguished the concepts and specified three aspects of safety culture including psychological, behavioral, and situational aspects. Among these aspects, the psychological aspect refers to how people feel about safety and safety management systems, and is often referred to as safety climate. Conner et al. (2011) stated that culture represented the more stable and enduring characteristics of the organization while climate represent a more visible manifestation of the culture. Fang et al. (2006) suggested that safety climate is a “snapshot” of safety culture. The ambiguity of the concepts poses theoretical challenges in not only measuring, but fully defining and understanding safety climate. Table 2-1 lists the definition of safety climate suggested by various studies.
Table 2-1: Definitions of Safety Climate

<table>
<thead>
<tr>
<th>Study</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zohar 1980</td>
<td>A summary of molar perceptions that employees share about their work environment.</td>
</tr>
<tr>
<td>Brown and Holmes 1986</td>
<td>A set of perceptions or beliefs held by an individual and/or group about a particular entity.</td>
</tr>
<tr>
<td>Dedobbeleer and Béland 1991</td>
<td>Molar perceptions people have of their work settings.</td>
</tr>
<tr>
<td>Coyle et al. 1995</td>
<td>The objective measurement of attitudes and perceptions towards occupational health and safety issues.</td>
</tr>
<tr>
<td>Mohamed 2002</td>
<td>A construct that captures employees’ perceptions of the role that safety plays within the organization [and] a descriptive measure reflecting the workforce’s perception of, and attitudes towards, safety within the organizational atmosphere at a given point in time.</td>
</tr>
<tr>
<td>Cooper and Phillips 2004</td>
<td>Shared employee perceptions of how safety management is being operationalized in the workplace, at a particular moment in time.</td>
</tr>
<tr>
<td>Hahn and Murphy 2008</td>
<td>Shared perceptions of employees about the safety of their work environment.</td>
</tr>
</tbody>
</table>

Although the interpretation of safety climate is different by different authors, there are some common themes that can be drawn from these definitions. First, all of the definitions mentioned “perceptions”; therefore, safety climate is differentiated from other aspects of culture such as behaviors. It is more about the psychological aspects of culture. Second, safety climate is shared by the employees within their working environments. This implies there may be multiple levels of safety climate within one organization, as there may be multiple working environments. Lastly, safety climate is measurable. This indicates that there should be descriptive metrics to
quantify safety climate at certain points of time, which also means that safety climate is dynamic and may be changing over time.

### 2.2 The Measurement of Safety Climate

Since the 1980s, the number of safety climate studies has increased dramatically across many industries, especially those with high accident rate and fatalities, such as nuclear, aviation, manufacturing and construction (Glendon 2008). Most studies have focused on the measurement of safety climate. This section reviews the empirical studies that have been performed to establish the structures, factorial and multi-level, as well as the validation of safety climate.

#### 2.2.1 Safety Climate Factorial Structure

Early studies within safety climate literature were conducted in manufacturing by Zohar (1980) and Brown and Holmes (1986). Zohar (1980) developed an eight-factor model to measure the safety climate among factory workers in the metal fabrication, food processing, chemical, and textile industries in Israel. Brown and Holmes (1986) validated Zohar’s model in a different sample of the U.S. production workers and introduced a three-factor model due to inconsistent findings. DeDobbeleer and Beland (1991) further tested Brown and Holmes’ three-factor model of safety climate in the construction industry and proved that a two-factor model provided a better model fit, statistically. Extensive empirical studies were conducted in the construction industry to validate the factorial structures, sometimes called dimensions, of the safety climate model using tools either self-developed or derived from previous studies (Mohammed 2002; Choudhry et al. 2009; Patel and Jha 2015). Little consensus has yet been achieved in defining the common factors for safety climate in the construction industry. Factors are used to represent relationships among multiple sets of the perceptual questions about safety to simplify the constructs of safety climate.
and identify the underlying areas of safety issues. The factors of construction safety climate that occur in multiple studies help identify the key areas of the development and execution of construction safety management. However, the factors are inconsistent and fragmented, which makes it difficult to understand the mechanism within the causal relationships among the antecedents and outcomes of safety climate.

2.2.2 Safety Climate Multi-level Structure

Most of the studies on safety climate have focused on viewing the construction organization as the unit for safety climate analysis. Recently, studies have been analyzing safety climate from a multilevel perspective. Zohar (2002) argued that the organizational policies, procedures, and practices should be differentiated because the senior managers develop the policies and procedures to achieve multiple goals of the organization; and the supervisors should develop corresponding practices. He further proposed two levels of safety climate: (1) that arising from the formal organization-wide policies and procedures established by top management; and (2) that arising from the safety practices associated with the implementation of company policies and procedures within workgroups. Melia et al. (2008) suggested that each safety climate statement can be analyzed from the view of the agent that performs or is responsible for the safety activity or issue involved, and introduced a four-level structure of safety climate in the construction industry, including: the Organizational Safety Response (OSR), the Supervisors’ Safety Response (SSR), the Co-Workers’ Safety Response (CSR), and Worker Safety Response (WSR). Lingard et al. (2010) further developed a typology for safety climate analysis with two dimensions: the level, and the strength. The strength of climate was defined as the degree of consensus within members of a group; and the safety climate level referred to the relative priority placed upon safety within a group as perceived by the members.
Some empirical studies have shown the variations among these multiple levels in construction. Glendon and Litherland (2001) found significant between-group differences in safety climate within an Australian road construction and maintenance organization. Melia (2008) proved that there was a close relationship between the organizational safety response and the supervisors’ safety response, but a more complex relationship between the management involved safety responses and the non-management safety responses based on the survey of Spanish and Chinese construction companies. Lingard et al. (2010) reported significant between-group variance and within-group homogeneity in group-level safety climate perceptions in the Australian construction context. Sparer et al. (2013) surveyed nine construction companies in the U.S. and found statistical difference between the management and the workers in terms of their safety perceptions.

The complex nature of construction makes it challenging to measure the construction safety climate of a project. Workers on construction projects vary day-to-day, with different social interactions and networks (Sparer et al. 2013). Also, as Melia et al. (2008) suggested, the subcontracting activities cause loose connections and isolation between the workers and the general contractors’ company and the workers own company. These contextual differences affect the relationship among the safety perceptions at different levels.

2.2.3 The Validation of Safety Climate

As one direction of the safety climate research is to measure safety climate, whether through the factorial or the multilevel structure; the other direction is to validate the role of safety climate in monitoring and mediating safety performance in workplace across multiple industries, such as the chemical processing (Hofmann and Stetzer 1996); manufacturing (Zohar 2002); and construction (Mohamed 2002). While safety climate itself is often considered one of the leading
Indicators of safety performance, defining a process model of safety climate measurement contributes to the understanding of the safety management and risk mediation.

The safety performance or outcome measures are used to validate the value of the ‘effects’ of safety climate by different studies, including safety behavior (Glendon and Litherland 2001; Mohamed 2002); involvement in safety activities (Cheyne et al. 1998); “microaccidents” or minor injuries (Zohar 2002); injury severity (Gillen et al. 2002); and lost time and medical treatment injury rates (Lingard et al. 2010). These measures can be divided into two categories: process measures and outcome measures (Laufer and Ledbetter 1986). Process measures include safety behaviors, which could be obtained through direct observation or indirect sources, such as questionnaires and interviews. Outcome measures include traditional safety indicators, such as accidents and injuries. These measures reflect different aspects of safety and often have varying sensitivity, so it is challenging to establish a direct link between safety climate and these factors at single point of time. Moreover, as Clarke (2006) and Neal and Griffin (2006) suggested, there is often a reverse causality, which means the past experience of the individuals or organizations influences their perceptions of safety and risk, thus will impact the safety climate. Therefore, it would be difficult to cross compare safety climate with other safety measures without considering the dimension of time.

The results are not consistent across different studies in the construction. For example, some studies found significant positive relationships between safety climate and self-reported safety behavior (Mohamed 2002; Pousette et al. 2008; Choudhry et al. 2009). On the contrary, Glendon and Litherland (2001) suggested there was no relationship between safety climate and observed safety behaviors. Sparer et al. (2013) also found no significant relationship between safety climate and the EMR, lost time, nor OSHA recordable injury rate. Some other studies discussed complex results in terms of the relationship. Lingard et al. (2010) found that lost time and medical treatment injury rates are related with safety climate strength, but unrelated with safety climate levels. Chen et al. (2013) found that incident rates and safety violation rates are
related with safety climate in the short term (4 months), but not related in the long term (17 months). Table 2-3 compares the results of past safety climate validation based on the safety performance measures that were used and the results that were found.

Table 2-2: Safety Climate Validation Results

<table>
<thead>
<tr>
<th>Process Measures</th>
<th>Significant Linear Relationship</th>
<th>Complicated/Non-Linear Relationship</th>
<th>No Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-reported safety behavior</td>
<td>(Mohamed 2002; Pousette et al. 2008; Choudhry et al. 2009)</td>
<td>Self-reported safety behavior</td>
<td>(Patel and Jha 2015)</td>
</tr>
<tr>
<td>Injury severity</td>
<td>(Gillen et al. 2002)</td>
<td>Lost time and medical treatment injury rates</td>
<td>(Lingard et al. 2010)</td>
</tr>
<tr>
<td>EMR and RIR</td>
<td>(Molenaar et al. 2009)</td>
<td>Incident rates and safety violation rates</td>
<td>(Chen et al. 2013)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>EMR, lost time, and OSHA recordable injury rate</td>
<td>(Sparer et al. 2013)</td>
</tr>
</tbody>
</table>

There are many reasons for the discrepancy between safety climate and other safety performance measures. First, these measures reflect different facets of safety. Safety climate measures the psychological, or intangible, aspect of safety, and is often considered as a subjective measure. Other subjective measures, such as self-reported safety behavior, tend to be aligned with those same perceptions that are captured by safety climate. Objective measures, on the other hand, such as observed safety behavior, are not always consistent with safety climate (Glendon and Litherland 2001). Second, the sensitivities of these measures are different. Outcome measures, such as injuries and accidents, are the result of rare events and may not be sufficient to monitor the subtle changes in safety performance during the process (Lingard et al. 2010). While safety climate is considered as a snapshot of safety culture, it reflects the workgroup’s perceptions of the safety policies, plans, and procedures at the workplace. Lastly, the level of analysis will affect the results. Safety climate measures the perceptions of a work group while
other safety measures, such as safety behavior and accidents, often reflect the individual level activities (Zohar and Luria 2004; Neal and Griffin 2006). Moreover, most research is based on prospective designs instead of retrospective designs. The effect of the time dimension on the relationships between safety climate and other outcome measures is not fully addressed. Although there have been efforts to validate safety climate against other safety measures, the process and valid factors are not consistently applied in a fashion to allow for the understanding of the project specific context, specific construction activities or risks being undertaken, and the underlying relationships between worker perceptions and site safety conditions.

2.3 Safety Culture Model

Despite the extensive research in safety climate measurement and validation, there are few studies conceptualizing safety climate and the related underlying constructs, especially in the construction industry. This section reviews previous theoretical studies in the field of safety climate and safety culture, with a focus on the construction industry.

Due to the close relationship between safety culture and safety climate, the safety culture model is presented to understand the underlying causal relationships among the concepts of safety climate within the context of organizations. A safety culture model outlines the manner in which safety culture is thought to be embedded in an organization’s practices and safety management systems (Choudhry et al., 2007). Bandura (1977) described a triad consisting of the person, environment (situation), and behavior in the model of reciprocal determinism. The model of reciprocal determinism explains the psychosocial functioning of the triadic reciprocal causation, where each individual’s internal (psychological) factors, the environment they are in, and the behavior they engage in, all operate as interacting feedback loops that influence each other bidirectionally. In the context of safety culture, Geller (1997) developed the Total Safety Culture Model to illustrate the descriptive composition of safety culture of the three domains without
specifying the relationships among them. Cooper (2000) developed a reciprocal safety culture model of three constructs, based on Bandura’s model, including safety climate as the personal construct, safety management system as the environment construct, and safety behavior. Cooper’s reciprocal safety culture model is shown in Figure 2-1.

Figure 2-1: The Reciprocal Safety Culture Model (Cooper 2000)
Choudhry et al. (2007) further proposed a Model of Construction Safety Culture (as shown in Figure 2-2) by incorporating the safety climate, safety behavior and safety management systems as three constructs, incorporating the specific conditions of the construction projects to contextualize the environment construct. Fang and Wu (2013) focused on interactive dynamism
between owner, contractor and subcontractors in a project team as a temporary organization and developed a safety culture interaction model, shown in Figure 4. In this model, multiple stakeholders are included into a two level structure that distinguishes the workforce attributes and the management attributes of construction. This model contextualized safety culture in the construction industry. However, further comparison over time in terms of these constructs was not addressed. Only descriptive constructs were discussed without detailed analysis on the impact of the multiple layers of interactions.

Figure 2-3: Safety Culture Interaction Model (Fang and Wu, 2013)
### Table 2-3: Comparison of Safety Culture Model Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Core concepts</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandura 1977</td>
<td>Triad constructs in the model of reciprocal determinism</td>
<td></td>
</tr>
<tr>
<td>Geller 1996</td>
<td>Total Safety Culture Model: safety culture of the three domains</td>
<td>Only descriptive components were provided without relationships among the construct</td>
</tr>
<tr>
<td>Cooper 2000</td>
<td>The Reciprocal Safety Culture Model: three safety culture constructs with reciprocal determinism relationships</td>
<td>Not including contextual variables of the construction industry</td>
</tr>
<tr>
<td>Choudhry et al. 2007</td>
<td>Construction Safety Culture Model: three safety culture constructs with reciprocal determinism relationships and contextualized the environment</td>
<td>Only environment construct was contextualized without addressing physical working environment</td>
</tr>
<tr>
<td>Fang and Wu 2013</td>
<td>The Safety Culture Interaction (SCI) Model: incorporates evolvement of construction project safety culture and the specific interactive dynamism.</td>
<td>Not including time effect and physical working environment</td>
</tr>
</tbody>
</table>

### 2.4 Safety Climate in Construction

The conceptual framework of safety climate is more complicated due to the unique characteristics of the construction industry in management process and organization structure.
Construction project management is distinguished from the common organization management by the task-oriented and multi-party nature of construction projects (Fang and Wu, 2013). Previous studies have focused on either the organizational safety climate of one single construction firm or the multiple projects without analyzing the dynamic environment. While project safety climate could be measured by the workforce perceptions, the creation of the project safety climate is impacted by the physical working environment and the specific context.

The construction industry has its unique characteristics of being temporary, dynamic and fragmented nature. The construction working environment is dynamic with different levels of risks and different trades. Construction sites, unlike other production facilities, undergo changes in topography, topology and work conditions throughout the duration of the projects (Rozenfeld et al. 2010). When measuring the safety climate of the construction project, the staging or timing effect should be incorporated. Moreover, with the subcontractor workforce isolated from the organization of general contractor or construction manager, even from their own organization; it is difficult to differentiate the management commitment of their firm with the overall project management from the workers’ perceptions. However, there are challenges to conduct longitudinal studies to measure construction project safety climate. It is time-consuming and expensive to collect safety climate data regularly over the project lifecycle. Moreover, since safety climate data are perceptions, it may be very sensitive to environmental constructs, thus making it difficult to determine the causes of safety climate variations.

2.5 Process Modeling in the Construction Industry

Although there are extensive studies on safety climate measurement, the process is not defined. This research aims at developing a process to measure safety climate under the dynamic construction working environment; therefore, process modeling techniques were considered as a means to define the process. Process modeling is the method of capturing business activities and
supporting information in an ordered sequence. There are many process modeling methods/techniques, including Data Flow Diagrams; Integrated DEFinition Methods (IDEF); and Business Process Modeling Notation (BPMN), to name a few.

In the construction industry, efforts have been made to define the workflow and activities using different process modeling techniques. Sanvido (1988) developed an Integrated Building Process Model (IBPM) using IDEF0. Phases of planning, design, construction, and operation and maintenance to provide a facility were developed. Each activity was defined by inputs, outputs, conditions and mechanisms. The University of Salford developed the Generic Design and Construction Process Protocol, which breaks down the design and construction process into 10 distinct phases. With the advancement of technology application in construction, especially the adoption of building information modeling (BIM), coordination and interoperability is required to engage the functional disciplines involved in the building project delivery process. Chunduri et al. (2014) developed an Integrative Building Lifecycle Process Model (IBLP) for the planning and design phases of retrofit buildings to support the implementation of repeatable, consistent retrofit processes, along with the identification of important information exchanges that take place between the project participants. The value of process modeling lies in the ability to make the abstract processes that underlie many construction processes into explicitly defined tasks, resources, and control mechanisms.

The process of safety climate measurement is a subset of the facility lifecycle where minimal IT was incorporated based on current tools. However, with multiple stakeholders involved in this process, and the various contextual data captured, a process model is needed to define the workflows and mechanisms that relate the physical and contextual dynamic elements of the work place with the dynamic feedback loop the workers experience when interpreting how the change environment influences their perceptions of the level of safety they experience.
2.5 Summary

Despite the popularity of safety climate in construction industry, there exist several knowledge gaps in understanding the nature of safety climate and the relationships between safety climate and other safety aspects. Although there are various tools used to measure safety climate, there is a lack of industry-specific scales or indicators to capture the contextual information which may be important to understand the results of safety climate. There is a lack of streamlined safety climate measurement process to address the dynamics of the construction working environment.
Chapter 3

Research Methodology

A review of literature indicated that there exists a knowledge gap between perceived safety and the working environment, which makes it difficult to understand the concept of safety climate, as well as to interpret the results of safety climate measurement. The dynamics of the construction working environment increase the challenges of measuring safety climate and using safety climate as a predicting indicator of project safety performance. This research developed a framework of safety climate contextual indicators, as well as a process model to measure safety climate under the dynamic construction working environment. The protocol was then validated and the results were analyzed to understand the link between the contextual factors and safety climate. This chapter describes the research methodology pursued to achieve the research objectives, as well as the detailed research steps of data collection and analysis.

3.1 Overall Research Process

The research goal is to develop and validate the contextual elements and the process for measuring safety climate under the dynamic construction working environment. To achieve this goal, the research objectives were established:

- Identify the contextual factors that impact perceived safety climate;
- Develop a process model to measure safety climate under the dynamic working environment to incorporate the contextual factors;
- Analyze the link between the contextual factors and safety climate.

Based on the research objectives: four stages of research were conducted: 1) problem identification; 2) development of the contextual factors; 3) development of the process model to
measure safety climate; and 4) process model validation. The flow of the four stages is shown in Figure 3-1. The research techniques and procedures are discussed in the subsequent sections.

**Stage 1: Problem Identification**

- **Literature Review:**
  - To define the research scope

**Stage 2: Development of Contextual Factors**

- **Systematic Literature Review:**
  - To identify most commonly used safety climate factor, as well as working environment impacting factors
- **Focus Group Discussion:**
  - To develop and validate the contextual factors of safety climate

**Stage 3: Development of the Process Model**

- **Pilot Study Observation:**
  - To identify the baseline process for safety climate measurement
- **Case Study:**
  - To implement the protocol of safety climate measurement under the construction working environment and analyze the results

**Stage 4: Process Model Validation**

- **Focus Group Discussion:**
  - To validate the process model and procedures
- **Expert Interviews:**
  - To further validate the process model

**Figure 3-1: The Overall Process of the Research**
3.2 Research Steps

Research techniques were selected based on the research objectives for each stage. Explanations for the detailed research method selection and descriptions for the procedures are provided in the following sections.

3.2.1 Stage 1: Problem Identification

The initial stage of the research was to identify the research problem and define the research scope. A review of existing literature on safety climate and safety culture, safety management, and project management was conducted to identify the knowledge gaps within safety climate research. The initial literature review found three major themes within safety research: safety climate measurement, safety climate validation, and theoretical safety culture models. Despite the extensive efforts made to empirically measure and validate safety climate on construction projects as a leading indicator of safety performance, few studies have been focused on theoretical development of safety climate models in dynamic context, such as the construction industry. This creates challenges to understand the creation of safety climate, thus leaving the project stakeholders potentially confused about interpreting the safety climate results and developing intervention strategies to improve safety climate. Moreover, the temporary and dynamic nature of construction projects pose challenges to contextualize safety climate. While previous studies have focused on describing the impact of organizational safety commitment on safety climate, no research explains the relationship between the dynamic physical working environment and the perceived safety by different construction trades. Therefore, this research was aimed at developing a process to measuring safety climate under the dynamic construction working environment.
### 3.2.2 Stage 2: Development of the Contextual Factors

With the research goal and objectives defined, the next step was to identify the contextual factors of safety climate and to develop the metrics to measure safety climate to incorporate the contextual factors. Factors are used to represent relationships among multiple sets of the perceptual questions about safety to simplify the constructs of safety climate and identify the underlying areas of safety issues. Although different questions were asked in each study, there are some common questions and factors. The initial step was to identify these factors of existing tools as baseline. A systematic review of existing safety climate literature in the construction industry was conducted to identify the most commonly used safety climate factors. Systematic review offers a methodology for summarizing results from existing studies in order to derive an overall effect size (Clarke 2006). According to the review, few tools incorporate contextual factors to address construction industry-specific or project site-specific indicators. A review of safety risk management and organizational management studies was conducted to establish a framework of contextual indicators that would impact construction site safety.

Focus group discussion was adopted to further identify the industry-specific indicators of safety climate for the construction working environment. Focus groups are widely used as a data collection technique in social science as a controlled group discussion, which intends to obtain perceptions on specific topics in a defined environment (Krueger and Casey 2009). The knowledge and experiences of the participants are stimulated through the interactive group discussion to widen the range of opinions on specific topics and avoid individual bias drawbacks (Morgan et al. 1998). A focus-group discussion with 17 safety experts was conducted to identify the specific influences from the construction context, notably dynamic aspects unique to construction sites that affect safety, such as locations of work, interactions with other trades, or weather. Discussions on multiple topics were facilitated in four parallel working groups and the results were captured. The results identified a framework of dynamic and environmental safety
climate indicators that could influence on-site safety and potentially be captured through safety climate survey methods. The objective information questions, such as the list of equipment in use, were further validated through a follow-up focus group discussion to ensure that the list was comprehensive, that the wording was clear and accurate, and that there were no further topics to be added to the list. The detailed research steps and results of the contextual factors framework are discussed in Chapter 5.

3.2.3 Stage 3: Development of the Process Model

To provide empirical evidence on the contextual indicators and the process model in providing more diagnostic information on safety management, the process model of safety climate measurement was then validated through case studies. Case study is widely used as “an empirical inquiry that investigates a contemporary phenomenon in depth and within real-life context, especially when the boundaries between phenomenon and context are not clearly evident (Yin 2009).” From a technical perspective, the case study method covers the logic of design, data collection techniques and specific approaches to data analysis. There are various sources of evidence for case studies, including documentation, archival records, interviews, direct observations, participant-observation, and physical artifacts (Yin, 2009). Multiple sources of evidence need to be used to ensure the reliability of the case study. Based on the research objectives and the research questions, a mixed research methodology was used to collect and analyze data.

A pilot case study was observed to capture the baseline process using traditional safety climate questionnaire. A case study was then conducted to develop and validate the process model to incorporate construction contextual factors. Observations of project site safety audit, questionnaire-based surveys with the workforce, and interviews with foremen were conducted
during the case study. Both qualitative and quantitative data were analyzed. Detailed steps of the case study and results analysis are discussed in Chapter 6.

### 3.2.4 Stage 4: Validation of the Process Model

The process and information flow of the case study project was captured to develop the process model. The process model was validated through a focus group discussion with 15 safety experts. The defined process model was presented and comments for revisions were captured to refine the process model. To further validate the results, expert interviews were conducted with senior safety officials and safety representatives experienced in use of safety climate. Interviews are an effective qualitative data collection method. The ambiguity of the questions that lead to interviewees misunderstanding can be clarified in time, so the interviewers can ensure the quality of the data collected (Polit and Hungler 1998). Semi-structured interviews are the most widely used interview format, which typically proceed around open ended questions that are either predetermined or merging from the dialogue in the interview (DiCicco-Bloom and Crabtree 2006). To verify the process model results and facilitate open discussions, semi-structured interviews were selected in this research. In this research, each interview took 45 minutes to an hour, during which the interviewees evaluated the clarity of current process model and made comments for revision. The detailed steps and results of the process model validation are presented in Chapter 5.

### 3.3 Summary

This research included four major stages to achieve the objectives. Both qualitative and quantities research techniques were used to collect and analyze data. Systematic literature review and focus group discussions were selected to develop the contextual factors of safety climate. A
A case study approach was conducted to develop the process model of safety climate measurement to incorporate the contextual factors. The process model was validated through focus group discussions and expert interviews. Data analysis of the case study supported the linkage between safety climate and the working environment. The detailed procedures and results were presented in the following chapters.
Chapter 4

Developing the Contextual Indicators of Safety Climate under the Construction Working Environment

Based on literature review, there is a lack of contextual indicators when measuring safety climate, especially under the constantly shifting physical environment that is a common challenge for safety on construction sites. This chapter discusses the process of the contextual indicators development and proposes a framework of safety climate indicators under the construction working environment. Common safety climate factors were identified based on systematic review as baseline. Contextual indicators that are specific to the construction industry were then developed through focus group discussions.

4.1 Identifying Common Safety Climate Factors

Extensive studies have been focused on safety climate measurement, including the factorial structures, and the multiple levels of organizational safety to quantitatively construct the dimensions of safety climate. However, there are wide discrepancies in the studies relative to the dimensions of safety climate. Even when the instruments used to assess safety climate are similar, the factorial structures are often not replicated across different industries and organizations (Flin et al. 2000). This implies the complexity of the concept of safety climate and its multiple facets. Most studies have focused on methodological rather than theoretical issues regarding the conceptualization of safety climate. This creates a critical conceptual ambiguity in the effort to accurately capture the drivers and effects in play when creating a safe working environment and climate on a given project. In an attempt to address the knowledge gap, this research explores the theoretical constructs of the various safety climate studies in the construction industry to date in conjunction with the factors analyzed, in an effort to identify the current scope and gaps in
reconciling the targets of safety climate with the implementation of safety management and the 
creation of a safe working environment within construction. Systematic review was adopted as 
the methodological approach to review the existing literature of safety climate in the construction 
industry. The major steps of data collection in this study included literature search, inclusion 
criteria, and literature coding. Data analysis was based on the collected literature.

4.1.1 Data Collection

The preliminary search was conducted within the main databases including Science 
Direct, EBSCO Host, Engineering Village, and Scopus, which involve the main peer review 
journals in the topic of safety climate and safety culture. To focus on the construction industry, 
several journals were chosen to further investigate for related papers, including the ASCE Journal 
of Construction Engineering and Management, Journal of Management in Engineering, Safety 
Science, Journal of Safety Research, and Accident Analysis and Prevention. Searches include 
terms of “safety climate”, “safety culture”, and “construction” in title, keywords, and abstracts. 

This study is focused on the safety climate studies in the construction industry. Therefore, 
studies in other industries were not the focus within the systematic review. However, core papers 
on safety climate theoretical models in other industries and review papers of safety climate 
literature across multiple industries were included due to the limited pool of theoretical studies in 
the construction industry. They serve as potential foundations of exploring the conceptual 
framework of safety climate in the construction industry.

The title, author, year of publication, and journal title of the selected papers were used for 
literature coding. The selected papers were divided into two major categories: safety climate 
measurement and validation.
4.1.2 Data Analysis

Within the selected literature, 13 studies have focused on establishing or validating the safety climate factorial structures. Factors are used to represent relationships among multiple sets of the perceptual questions about safety to simplify the constructs of safety climate and identify the underlying areas of safety issues. Although different questions were asked in each study, there are some common themes of the factors. Table 1 compares the studies and major themes of these safety climate factors in chronological order. Each of these factors will be discussed in more detail based on their adoption in the identified studies. In terms of the validation of the factors, different safety outcome indicators were used as shown in Table 4-1, such as observed safety behavior, self-reported safety performance, and injury severity. Some studies only focused on establishing the factorial structures without validating these factors against safety outcome indicators.

*Management commitment* is a central element of safety climate (Zohar 1980). The perceptions of the workforce are rooted in the mission, value or policies developed and advocated by the top management. All of the 13 surveys included some questions regarding the perception of the commitment and priorities by the management regarding safety. The terms used for management commitment were slightly different across the tools. For example, Pousette et al. (2008) and Wu et al. (2015) used safety priority to represent the management commitment to safety.

*Workforce’s involvement* in safety activities was also considered as a common factor of safety climate, occurring in 8 of the 13 tools. By adopting a bottom-up approach, the management encourages the workforce to participate in developing the safety plan and practice, which enables the workforce to better understand the safety information. In the construction industry, worker’s involvement may include activities such as procedures for reporting injuries and identifying work hazards.
Table 4-1: Safety Climate Factors in Construction Industry within Literature

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>management commitment</td>
<td>13</td>
<td>√</td>
<td>#</td>
<td>@</td>
<td>√*</td>
<td>√*</td>
<td>√</td>
<td>√</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
</tr>
<tr>
<td>worker involvement</td>
<td>8</td>
<td>√</td>
<td>#</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
<td>√</td>
<td>√</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
</tr>
<tr>
<td>rules and procedures</td>
<td>8</td>
<td>√</td>
<td>#</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
<td>√</td>
<td>√</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
</tr>
<tr>
<td>personal risk appreciation</td>
<td>6</td>
<td>√</td>
<td>#</td>
<td>@</td>
<td>√*</td>
<td>√*</td>
<td>√</td>
<td>√</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
</tr>
<tr>
<td>communication</td>
<td>5</td>
<td>√</td>
<td>#</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
<td>√</td>
<td>√</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
</tr>
<tr>
<td>supervisory environment</td>
<td>5</td>
<td>√*</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√*</td>
<td>√</td>
<td>√</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
</tr>
<tr>
<td>work pressure</td>
<td>4</td>
<td>√</td>
<td>#</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
<td>√</td>
<td>√</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
<td>√*</td>
</tr>
<tr>
<td>safety training</td>
<td>2</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>appraisal of work hazards</td>
<td>3</td>
<td>√*</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>supportive environment</td>
<td>2</td>
<td>√*</td>
<td>√*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>competence</td>
<td>2</td>
<td>√*</td>
<td>√*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>workmate’s influence</td>
<td>2</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>safety responsibility</td>
<td>2</td>
<td>√*</td>
<td>√*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>relationships</td>
<td>1</td>
<td>√</td>
<td>#</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>personal protective equipment</td>
<td>1</td>
<td>√</td>
<td>#</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>reporting of accidents</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>obstacles to safe behavior</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>safety resources</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>safety motivation</td>
<td>1</td>
<td>√*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: 1 indicates construction workers, 2 indicates construction management. √ indicates that the factors were only analyzed with statistical methods rather than validated with safety outcomes. √# indicates that the factors were validated against with observational safety behavior; √* indicates that the factors were validated against self-reported safety performance; √@ indicates that the factors were validated against injury severity.

Rules and procedures are the core component of safety management systems (Mohamed 2002). The extent to which workers perceive safety rules and procedure is often related to their risk-taking behavior. Rules and procedures are commonly the focus of safety communication to the workforce in the task-oriented construction industry, compared with upper level organizational policies and plans. The challenge regarding measuring safety rules and procedures lies with the inconsistency of adoption and implementation of operating procedures in projects when multiple parties are involved in the tasks.
Personal risk appreciation includes activities such as self-reported risk taking, perceptions of risk or hazards in the workplace and attitudes towards risk and safety. Although individuals differ in their perception of risk and willingness to take risks, the safety climate of the working environment plays an important role in risk-taking behavior. In addition, each worker’s level of experience and training will influence their knowledge of the risks and impacts of different risk-taking behaviors.

Communication of safety activities is complicated in the construction project context. As discussed, there are multiple stakeholders; each develops their safety plans and procedures based on their own organizational safety culture and their roles in the project. Moreover, with multiple levels of management at the project, the delivery process of safety information is often iterative. The complexity of the safety communication poses a challenge for the workforce to effectively receive and fully understand the safety information, especially when messages may differ or conflict.

The supervisory environment is separated from the management commitment as the role of the supervisors is considered to be executing the organizational safety programs instead of policy-making. The workers communicate with their supervisors directly and frequently on the jobsite, therefore, supervisory environment is also considered as one important aspect of safety climate.

The common factors of construction safety climate are to help identify the key areas of the development and execution of construction safety management. However, the factors are inconsistent and fragmented, which makes it difficult to understand the mechanism within the causal relationships among the antecedents and outcomes of safety climate. Moreover, the tools used to measure safety climate in previous studies were originated and adapted from other industries, which may neglect the safety issues in one specific industry, or more specifically the dynamics on one construction site.
4.2 Developing the Framework of Construction Context

To address the inconsistency of previous studies on safety climate in contextualizing construction specific indicators a framework is proposed to identify the relevant measures. The framework builds upon a worker-task specific interaction model, developed by Mitropoulos et al. (2009). The model identifies that perceived task demands will influence worker behavior, which in turn influences the work situation and the actual task demands. However, this model focuses on the individual worker level. When considering the project level safety climate, the link between the workers and the working environment is more complex. Sanvido (1988) developed the Conceptual Construction Process Model that defines the essential processes regarding how the function of a crafts worker is supported by the site organization. While safety management is considered to be part of the process, it serves to support and enable the craft worker by providing the necessary process inputs, such as raw materials, as well as the necessary resources. It also identifies how the outputs of the work are used to manage the process at increasing tiers of management, across workers, across crews, and across trades. In the context of construction safety management, to achieve the safety goal, a series of process control approaches are commonly used to address the safety specific concerns created by worker and site construction risk factors. Safety perception reflects the understanding, or potentially the ‘control’ of their safety behavior, by the construction worker of the working process, including the human factors, environmental factors, as well as the process control, that, in return, helps to refine the process and controls. Safety climate assesses the safety perception, however, previous tools often focused on feedback generic to the Project Manager level, as shown in Figure 4-1, making it difficult to diagnose how the feedback loop can be used to influence the process controls as it relates to the site dynamics or managing interactions across trades at the discipline and area levels.
The primary challenge of the human and environment interaction in the construction project context is that the physical context is dynamic. There are multiple layers of process control: the top management develops the organizational safety policies; the middle level of the organization is the project management, who implement and communicate the safety plans and procedures for the specific project; and the workforce conforms to and implements the safety rules and procedures (Chen and Jin 2013). On the workforce level, concurrent activities also pose a challenge to communicate safety effectively, since the workforce under the same working environment may come from different organizations, and perform various tasks required by their specific trade or scope of work.

To further understand the human-environment interactions under the dynamic context on a construction site, a literature review in management and organizational development identified the common features of dynamic environments. Scharf et al. (2001) developed a typology of dynamic and hazardous working environments and identified the commonalities, including:

- Controllability of the process and the hazards through engineering controls;
- Predictability of the process and hazards;
• Hidden/unexpected/obscure hazards;
• Extent of restriction of equipment movement path; the degree of speed, force, and change in the hazards or the conditions;
• Extent to which the hazard is required for the work to happen;
• Multiple and interacting hazards; and,
• Potential for generation of hazards by humans.

The typology provided a schema to systematically observe the dynamic nature of the hazards that can be identified across different sectors regardless of the specific situations.

The next step was to identify the specific hazards that a construction worker is exposed to by analyzing literature on construction risk assessment. Risk assessment is one of the common methods in construction to predict the likelihood of an accident and the potential severity of the accident in the working environment (Hallowell et al. 2013). Safety risk assessment typically involves quantifying potential hazards in terms of probability, severity, and exposure (Rozenfeld et al. 2010). Research studies have developed multiple approaches to safety risk assessment. Despite the differences in data collection methods and the level of analysis, these studies identified the human and environment risk factors or the sources of potential hazard, and grouped them in different categories based on the purpose of the study (Chi et al. 2013). Table 4-2 summarizes the risk factors identified in construction, as well as the related project control elements. The level of detail for these factors varies based on their unit of analysis. Hinze et al. (1998) suggested that a greater level of detail of the risk factors helps to initiate more specific prevention actions.

The identified risk factors and categories provided the categorization for identifying environmental safety climate indicators. Since the risk factors are sources of incidents that the workers are exposed to under the construction working environment, the perceptions of the risks
should be incorporated to investigate the workplace conditions as well as the management
initiatives to address the workplace conditions. Table 4-3 lists the common safety climate factors
in the process of environmental dynamics and process control elements. In this structure, most
safety climate factors are concerned with the personnel category. Moreover, the dynamics of
construction project predictability, hidden or unexpected field issues, especially the interactions,
are not addressed by current tools. There is a need to develop the industry-specific safety climate
indicators to address these site dynamics and the process control elements.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Team; Time</td>
<td>Task-related Actions</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Management Actions /Interactions</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resources</td>
<td>Materials</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tools</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equipment</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Workplace</td>
<td>Working Surface/Location</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Surrounding Objects</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Housekeeping</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Weather Condition</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Exposure to gas/liquid/solid</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Table 4-3: Most Commonly Used Safety Climate Factors in the Construction

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Personnel</th>
<th>Time/Production</th>
<th>Physical Resources</th>
<th>Workplace</th>
</tr>
</thead>
</table>
| Controllability             | • Rules and procedures  
• Personal risk appreciation  
• Safety Training  
• Competence  
• Safety motivation  
• Management Commitment  
• Worker Involvement  
• Supervisory Environment | • Safety Priority (over production) | • Personal Protective Equipment  
• Safety Resources |                                |
| Predictability              |                                                                           |                               |                                |                                |
| Hidden, unexpected          | • Appraisal of work hazards                                               |                               |                                |                                |
| Multiple & Interacting      | • Communication  
• Workmate’s influence                                                      |                               |                                |                                |
| Human-generated             | • Work Pressure                                                            |                               |                                |                                |

4.3 Identifying Construction Safety Climate Contextual Indicators

Focus group discussion was used to further identify the industry-specific indicators of safety climate for the construction working environment. The sample for this study includes 17 safety experts from multiple national construction firms, who had experience engaging in the safety management activities for construction projects. The experts include safety directors, project managers, superintendents, and owner’s safety representatives with an average of 16 years working experience in the construction industry. During the focus group, the moderator first presented the purpose of the study, explained the safety framework discussed in previous
sections. All participants were then encouraged to develop a list of safety topics individually that explores safety based on their experiences. These listed items were then sorted, by the participants, into the categories from Table 4-2. A series of questions were then used to facilitate small group discussion amongst the participants to understand the topics and categories. These questions were:

- What safety concerns might a worker have that are hard for the management to see or capture in an audit?
- What are issues are hard to “quantify” but could be rated by the workforce?
- What are the contextual or project safety concerns that change throughout the project?
- What interactions or dynamics are often difficult to capture or report in traditional processes?

Participants were then randomly divided into 4 groups: personnel, time/production, physical resources (materials, tools, and equipment), and workplace. Each group was given a specific category to discuss the developed topics, expand the list, and organize the topics if they overlapped. Four researchers facilitated the discussion for each group and helped to record the identified indicators. To evaluate the generated indicators, participants were invited to prioritize the developed topics based on their importance to construction safety. For example, “housekeeping on site” under the workplace category was considered a higher priority than “exposure to confined space,” since the latter is more unusual and is less likely to be an unexpected issue perceived by the workers to be a concern. Another evaluation criterion was the reliability of the topic or question to provide an accurate assessment when the workforce evaluates it through a survey. An example topic that was given low reliability was “owner’s role in safety.” Although the owner plays an essential role in the project safety management, the workforce might not directly observe the owners role, thus making it difficult for the workforce to accurately assess. After discussion, the moderator asked all participants whether they had any
further suggestions within or outside the categories. Focus groups were complete when there were no further comments. Worksheets and immediate note taking were used to collect qualitative data during the discussion. In total 66 topics were generated and captured from the focus group discussion.

To analyze the collected data, the topics were analyzed with examination of the individual responses and identified common keywords that interpreted actual phenomena (Timlin-Scalera et al. 2003). Keywords and phrases were then grouped and arranged into indicators. For example, one of the topics provided by the participants was “Is your equipment new and/or recently inspected?” The keywords in this response were “equipment” and “inspection,” thus the response was recorded as “regular inspections on the equipment.”

Repetitive topics were grouped and the categories were re-classified to structure the topics. For example, “Supervisors Focus: Is production or safety the priority?” is repetitive with “Schedule driven affecting safety.” The two responses were re-classified as “Production pressure created by the supervisor/management.” The generated topics were then compared with the current safety climate tools to remove the repetitive indicators. The final list of safety climate environmental indicators includes 25 new indicators in addition to the previously documented safety climate measures.

To verify the researchers grouping and classification, a follow-on focus group discussion was performed with the same group of industry experts. The full list and the categories were presented back to the safety experts, and the grouping and re-classification process was briefly described. Again, discussion was facilitated to ensure that the list was comprehensive, that the wording was clear and accurate, and that there were no further topics to be added to the list.
4.4 A Framework of Safety Climate Contextual Factors in Construction

A primary classification of the safety indicators was based on two measures: the dynamic features of working environment adapted from Scharf et al. (2001)’s model and the process control elements (Table 4-4). Five environmental dynamics are considered in this research, including controllability, predictability, hidden/unexpected, multiple and interacting, and human-generated. The categories of “moving and movable equipment” as well as “speed, force, and rate of change” were removed because they are redundant with “resources” in a construction context. Similarly, “Work process hazard” was removed, since this research focused on the project level environment, without focusing on the detailed risks that emerge for one specific trade.

The indicators developed by the focus group discussions topics all of the dynamics of a hazardous environment and the major project process control elements. As a comparison, previous safety climate factors concern with the human factor of the process, i.e. management interventions and individual attitudes. Since safety climate is considered as the indicator of safety management and individual safety attitudes, the workplace factor is neglected by most tools. Also, individual controllability and human-generated dynamics were focused upon by previous tools. Other environmental dynamics, however, are limited, such as the interaction among trades. The developed indicators are seemingly at a greater level of detail than the commonly used safety climate factors, and provide more specific information for the management to identify opportunities to improve site safety by different process control elements. The environmental indicators serve as a supplement of current safety climate measurement tools by incorporating the environmental dynamics of workplace, and the interactions among multiple trades.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Personnel</th>
<th>Time/ Production</th>
<th>Physical Resources</th>
<th>Workplace</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controllability</td>
<td>• Personal</td>
<td>• Pace of work /</td>
<td>• Access to</td>
<td>• Jobsite</td>
</tr>
</tbody>
</table>
4.5 Summary

Despite the popularity of the use of the safety climate as a forecasting metric in the construction industry, there are significant limitations to its current value as a tool to understand more specific risks to the workforce on construction sites. Extensive studies have focused on validating the relationship between safety climate and safety behavior/outcomes. The outcomes of previous research of the value of safety climate for construction are variable. The environmental

<table>
<thead>
<tr>
<th>Understanding on safety rules/procedures</th>
<th>Compressed schedule resources that is required to perform the task safely</th>
<th>Orientation (when it changes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adequate manpower to perform the task</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Predictability</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Worker involvement in pre-task planning/hazard identification</td>
<td>Awareness of upcoming tasks</td>
<td>Awareness of upcoming deliverables</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hidden, unexpected</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication of unexpected conditions</td>
<td>Impact of schedule changes on safety</td>
<td>Regular inspection on equipment</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Multiple &amp; Interacting</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety communication between/among trades</td>
<td>Task schedule affected by other trades</td>
<td>Hazards exposure created by other trades (e.g. noise, hazardous materials)</td>
</tr>
<tr>
<td>Communication of expectations/Recognition of safety performance</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Human-generated</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatigue increases</td>
<td>Priority of safety over production</td>
<td>Balancing of resources of multiple trades</td>
</tr>
<tr>
<td>Attention Drift</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
factors, especially physical workplace conditions and trade interactions, are notably neglected and yet of notable importance to the dynamic context of construction safety. Furthermore, the diagnostic value is limited when using generic questions. By identifying construction specific environmental indicators this research serves as an initial step toward improving the value of safety climate measures as predictive or diagnostic tools to inform construction leadership about field safety concerns before they become accidents.

From a process-based perspective, as discussed by Sanvido (1988), humans interact with the environment to achieve the safety goal, the interactions include: 1) the process control elements that are developed to achieve the goal and to address the constraint of human and environment factors; and 2) the perceptions of individuals working under the environment. While safety climate measures the individual perceptions, theoretically, it serves as an indicator of the overall process. However, only the human factor is emphasized by current safety climate tools, neglecting environmental influences. This stage of the research developed the initial list of environmental factors to begin to address this conceptual and implementation gap using the typology of environment dynamics developed by Scharf et al. (2001). The other attribute of the environmental factors are the process control elements, including personnel, time/production, physical resources, and workplace. Analyzing the indicators by these attributes provided a framework to ensure more comprehensive identification of environmental safety climate indicators.
Chapter 5

Developing a Process of Measuring Safety Climate under the Construction Working Environment

This chapter explains the development of safety climate measurement process under the construction working environment. The purpose of developing this process is to describe the key activities of measuring safety climate under the dynamic construction working environment and the information flow that are needed throughout the process. This chapter presents the structure of the safety climate measurement process, as well as the basis and methodology to develop the process.

5.1 The Process of Measuring Safety Climate under the Construction Working Environment

With the contextual safety climate factors developed (as described in Chapter 4), there is a need to develop a process to measure safety climate to incorporate these factors under the dynamic construction working environment. Previous studies have relied on questionnaire-based survey and statistical data analysis techniques to measure safety climate. The questionnaire requires minimal efforts from the researcher and the participants to capture a large amount of data, and provide a basis to benchmark safety climate statistically. However, there are some limitations of the process: 1) only generic safety climate factors were analyzed instead of specific contextual information, which makes it difficult to diagnose the project safety management in practice. There is a need for mixed research methods to measure safety climate; 2) few studies have incorporated in longitudinal analysis in safety climate measurement, especially in construction, where workplace conditions and interactive activities are frequently changing. While safety climate captures the snapshot of the project safety management, there is a need to
measure safety climate across multiple construction phases to incorporate the impact of project dynamics.

This research developed a process model of safety climate measurement under the construction working environment to address the limitations of previous safety climate measurement process (Figure 5-1), including five major steps: pre-survey, data collection, data analysis, follow-up and develop a plan, and pursue continuous improvement. The purpose of this process model is to facilitate the process of collecting and analyzing data to develop safety improvement plans under the dynamic construction working environment. The structure and contents of the process model are presented in the following sections.

5.1.1 The Structure of the Safety Climate Measurement Process Model

The process model was developed using the Integrated Definition for Function Modeling (IDEF) method, which is one of the most widely used methods in design and construction process modeling, particularly IDEF0 (Austin et al. 1999). IDEF0 models the functions of a process, which receive inputs, process them with certain mechanisms and under certain controls, and then produce outputs to feed into other functions, as shown in Figure 5-2. The IDEF0 method is selected for the following reasons: 1) it allows a manageable size of functions which makes it easy to use and understand; 2) the method is expressive with many elements (inputs, outputs, control, and mechanism), which is important in the safety climate measurement process; 3) it represents the system from a viewpoint of data and allows iterative activities. Since the safety climate measurement process requires multiple data collection, this method is helpful to illustrate the process and the information flow.
Figure 5-1: The Process of Measuring Safety Climate under the Construction Working Environment
5.1.2 The Contents of the Safety Climate Measurement Process Model

There are five major steps of the safety climate measurement process: pre-survey (P), collect data (C), analyze data and follow-up (A), develop a plan (D), and pursue continuous improvement (I).

5.1.2.1 Pre-survey

The pre-survey step is divided into two sub-steps: identify goals (P.1) and develop data collection plan (P.2), as shown in Figure 5-3.

Identify Goal: This step is for the project leadership to define the values of safety management of the project. Examples of the goals would be: to understand the perceptions of the workforce...
towards management, to compare the safety perceptions across trades, or to mitigate the impact of site dynamics on safety. A planning meeting or a workshop discussion is recommended for the project team to define the values based on the project context.

**Develop Data Collection Plan:** This step is for the safety lead to adapt the data collection process details to the specific project context, which needs to consider the construction schedule and phases, construction means and methods, and site constrains. The details may include the intervals of data collection, specific data collection dates (if possible), whether there is a need to customize the questionnaire based on defined goals, and how to distribute the questionnaire (in large group or by sections/trades). The information that are needed to develop the detailed data collection plan may include the construction schedule, Work Breakdown Structure (WBS), working hours, shifts, workforce experience and site specific safety plan. A planning meeting is recommended to coordinate project team and gather project information. The detailed data collection plan should be based on the project context. Multiple data collections throughout the construction phase are highly recommended. The intervals for data collections should be determined based on the overall schedule of the project, so that the perceptions of the major trades at different construction phases would be captured. The purpose of this is to address the impact of workplace conditions and construction activities throughout construction. The planning process should be iterated based on changing phases/conditions/seasons.

**5.1.2.2 Collect Data**

The next step is to collect data based on defined goals and plans. The data collection step is also divided into two sub-steps: capture site conditions (C.1) and collect worker response (C.2), as shown in Figure 5-4.
Capture Site Conditions: This step is to capture the site conditions before the climate survey to understand the construction progress, physical working environment conditions, as well as worker behavior. The purpose of capturing the site conditions is to provide a baseline for the perceived safety climate as the site conditions are constantly changing and safety climate is a specific snapshot of the workforce perception. It is recommended to conduct a safety walk with an independent safety auditor who is not from the full time project team to provide unbiased evaluation of the site conditions. Representatives of other firms (trades, designer, owner) could participate in the safety walk.

Collect Worker Responses: This step is to collect the perceptions of the workforce using the safety climate questionnaire. The safety lead coordinates the data collection process to gather the workers and distribute the questionnaires in person. The safety lead should explain the purposes of the survey, verify the anonymity of the respondents, and collect the responses. It is recommended to encourage all the workers to participate in the survey with honesty. Collecting the responses anonymously and making sure the project management team is not present while the workers are completing the survey are approaches to increase the response rate.

With the collected site contextual information and worker responses, the next step is to analyze the data.

5.1.2.3 Analyze Data and Follow-up

With the collected data, the next step is to analyze data and follow-up to support the development of action plan (Figure 5-5):
Figure 5-5: Breakdown of the Analyze Data and Follow-up Step

**Analyze Data:** This step is to input the individual responses in the data analysis tools using pre-established data structures. The data analysis tool generates the analysis results. Responses to open-ended questions should be captured and organized by emerging themes as well. It is recommended to complete the analysis results in a timely manner (within 1-2 days).

**Follow-Up Evaluation:** Based on the results against stated goals and the phases of construction, the safety lead determines if the results are detailed enough to achieve the defined goals and to develop a plan for future improvement. If there is not enough information to understand some emerging topics of the results, a follow-up diagnostic visit or discussion helps to investigate the context and details which may not be reflected by the survey itself. The safety lead identifies a list of factors that require more information based on the survey results. Various approaches could be used to collect the contextual information, such as discussions at toolbox talks, supervisor meetings, and non-supervisory worker meetings, etc. It is recommended to engage the supervisors to discuss preliminary findings and interpretations of the survey results investigate the safety perception from the site leadership perspective. It is also recommended that appropriate trades should be engaged in the follow-up data collection to further interpret the results.

5.1.2.4 Develop a Plan
Based upon the collected results and interpretation, the next step is to identify target actions for improvement in terms of specific safety practices. To develop the action plan, the safety lead focuses on the resulting factors which need more safety commitment or emerging safety concerns based on the open ended questions to identify targeted areas. For example, engage the workers in hazards identification to improve awareness of workplace risks. Another way to develop the action plan is to focus on trades with lower perceived safety compared with other trades by analyzing the detailed data. For example, increase the communication between the workers and the supervisors of a specific trade to improve perceived supervisory environment. A workshop discussion within the project management team and higher level of safety management of the organization is recommended to develop the action plan for improvement.

5.1.2.5 Pursue Continuous Improvement

This step is to implement the action plan to achieve continuous improvement (Figure 5-6). As safety climate captures the snapshot of the safety perception, it is necessary to conduct multiple data collections throughout the construction phase to proactively manage the site safety. By repeating the data collection process at different times across the construction stage, the implementation of the action plan would be evaluated by the survey results of next phase as well as through the traditional lagging indicators, thus providing the foundation for continuous improvement.

![Diagram of Pursue Continuous Improvement Step](image)

**Figure 5-6: Breakdown of the Pursue Continuous Improvement Step**
It is recommended to share the data collection results and the action plan with the workers to demonstrate transparency and management commitment. It is also recommended to adjust the open-ended questions in the questionnaire to reflect the changing focus of safety management on site conditions to support the continuous improvement of safety given changing conditions.

5.2 The Development of the Safety Climate Measurement Process Model

To develop the safety climate measurement process model, five steps were conducted as shown in Figure 5-7.

![Figure 5-7: The Development of the Safety Climate Measurement Process Model](image-url)
5.2.1 Literature Review

The initial literature review defines the research scope, i.e. developing a process model to measure safety climate under the dynamic construction working environment. Although safety climate survey has been widely used by both researchers and industry practitioners, the process is not well defined or streamlined. The level of analysis varies depends on the goal of the survey. This research focused on the project level to incorporate the project contextual information and provide diagnostic data to the project management.

**Pilot Study Observation:** Based on the defined scope, a pilot study was conducted to develop the baseline process of measuring safety climate in traditional approach. The process of a safety climate survey of a recreation facility project was conducted by the construction management firm. The process was observed and the results were shared with the research team. The baseline process map was shown in Appendix A. The processes of the baseline process include four major steps:

- **Plan for the Survey:** The safety personnel discussed with the project management team to understand the context of the project, and to explain the purpose of the survey.

- **Collect Data:** The safety personnel distributed the questionnaires to the workers in person and collected responses.

- **Analysis Data:** The responses were analyzed based on pre-established data structures and scores for safety climate factors were calculated.

- **Develop and Share the Action Plan:** The results were shared with the project management team to discuss areas for improvement. The project management developed an action plan based on the results. The results and action plan were then shared with the workers.

The baseline process map helps to define the data collection details and establishes the structure of the questionnaire-based survey approach in measuring the safety climate of a project. However, there is minimum contextual information collected and analyzed to incorporate the
impact of site dynamics. There are limited opportunities for continuous improvement due to a lack of longitudinal data collection.

5.2.2 Case Study

According to the defined scope and the baseline process map, the process model of safety climate measurement under the dynamic construction working environment was developed and a case study was conducted to validate the process model. The detailed steps for the case study and the results are described in Chapter 6.

5.2.3 Workshop Validation

To further validate the process model, a workshop discussion was conducted. 15 safety professionals from national construction firms were participated in the workshop. The process model was presented at the workshop and comments were collected at the workshop. The perceived value of the major steps and clarity for each step in the process model was evaluated by the safety professionals on a 1 to 5 scale. As indicated by Figure 5-8, all steps were perceived as valuable in facilitating proactive safety management on site, with an average score above 4. The first three steps were perceived with moderate to high clarity, and the last two steps were perceived with high clarity, as shown in Figure 5-9. Additional comments included:

- Change the first step to pre-survey to focus on the planning of the safety climate survey at the project level, as developing safety climate questions may not be the primary focus for the project management;
- Incorporate the step of sharing results with the workers.
5.2.4 Interview Validation

Three interviews were conducted with safety experts to further validate the process model. The interviewees include: a project safety engineer, a regional safety director, and an owner’s safety representative. Each interview took 45 minutes to an hour. The modified process model was presented to the interviewee and comments for the process model was collected and
recorded to refine the process model. The revisions from the focus group discussion and the interviews are summarized in Table 5-1.

<table>
<thead>
<tr>
<th>Focus Group Discussion</th>
<th>Interview 1</th>
<th>Interview 2</th>
<th>Interview 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change &quot;Questionnaire Development&quot; to &quot;Pre-Survey&quot;</td>
<td>Change &quot;Schedule&quot; to &quot;Project/Construction Schedule&quot;</td>
<td>Specify &quot;management&quot; as &quot;project management&quot; and/or &quot;management of workers' own organization&quot;</td>
<td>Combine &quot;Follow-up Evaluation&quot; as a sub-step to Step 3 &quot;Analyze Data&quot;</td>
</tr>
<tr>
<td>Add Open-ended Responses as the output of Step 4</td>
<td>Add organizational safety professional to the Step 4 and Step 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Add Result-sharing with workers as a sub-step of &quot;Pursue Continuous Improvement&quot;</td>
<td>Add descriptions for each step</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.3 Summary

Traditional safety climate measurement relied on questionnaire-based surveys, which focused on human-generated or managerial issues. This research developed a process model of safety climate measurement to incorporate the contextual indicators under the construction working environment. The process model provided a foundation for industry practitioners to use safety climate as a leading indicator proactively manage site safety, while providing guidance on customizing the process details based on the specific project context. A case study was conducted to implement and validate the process model. Focus group discussions and semi-structured interviews with safety experts were used to further validate the process model.
Chapter 6

A Case Study of Safety Climate Measurement under the Construction Working Environment

The contextual factors of safety climate under the construction working environment and the process model of safety climate measurement were validated through a detailed case study. This chapter describes a case study project of safety climate measurement using the defined process. It concludes with data analysis, as well as the impact of site dynamics on perceived safety, followed by discussion of the results, providing a foundation to understand the site safety and to develop continuous improvement plans.

6.1 Introduction

The core components of safety climate have been examined by many studies, however, few safety climate instruments have been reused by researchers and few studies have successfully replicated safety climate dimensions found by other researchers (Pousette et al. 2008). The discrepancies are due to a lack of contextual factors and a streamlined process to incorporate the contextual factors. This research developed a framework of safety climate contextual factors and a process model to measure safety climate in the construction context. To further validate the results, a case study was conducted to collect and analyze safety climate. The research scope focused on new construction of commercial buildings. Due to changing conditions of the physical workplace, new construction projects often provide a more dynamic scope of physical workplace conditions than renovation projects. Projects in early construction phase were considered to collect data at different construction phases.

This case study examined the safety climate in the dynamic construction context to answer the following questions:
• How are the contextual indicators changing over different construction phases?
• What indicators help capture the workplace conditions?
• What contextual information could be captured by the process model to facilitate the decision-making of safety management?

6.2 Data Collection

The data collection was based on two safety climate surveys at different construction phases. The research project studied safety issues within a major construction project that is part of a multi-year, multi-phase residence hall rebuild and renovation plan throughout the Penn State University campus. There was approximately 5 months between measurements, aligning with notable changes in the type and context of physical construction work taking place on the site. The project background information, data collection instrument, and procedures are presented in the following sections.

6.2.1 Data Collection Project

The case study project was a six-story, 95,737 square-foot dormitory, expected to house 336 students. The design-build project was scheduled to take 18 months and cost approximately $35,000,000. The background of the project is shown in Table 6-1.
The site was located on the University Park campus, adjacent to a major road, which made it easier for material delivery. However, the site area itself was quite small compared to the footprint of the building, with close proximity to several existing dormitory buildings. There was an ongoing renovation project of a dining hall adjacent to the site, which limited the space for this project. A mobile tower crane was positioned in the middle of the building, and two smaller mobile cranes, one for the West phase and one for the East phase of the building, were used. Material storage areas were located around the perimeter of the site. The project management offices were located in a neighboring building, which increased useable space for other trades. The project is scheduled to be completed by August 2017 in order to house the new students who will be moving onto campus, making the schedule of critical importance for this project.

A site specific safety plan was created for this project, in line with typical safety requirements for Penn State. A full-time safety engineer was assigned to the project to oversee the safety program development and implementation. Weekly safety meetings were held on site for all designated subcontractor representatives to discuss job progression and safety issues. Weekly
safety audits were conducted on the project, led by the safety engineer. A detailed Job Hazard Analysis (JHA) for each construction task was created, including: pre-mobilization (emergency routes, traffic flow, public safety, security etc.); earthwork and site preparation; concrete placement; steel erection; and roof work. A safety recognition program was established to encourage safe behaviors of supervisors of subcontractors and field workers.

6.2.2 Data Collection Instrument

The questionnaire used in this case study was developed based on the framework of safety climate contextual indicators as discussed in Chapter 4. The contextual factors were first compared with an instrument that has been validated by previous studies. New indicators were added to the existing instrument to explore the impact of project dynamics on perceived safety. Since the contextual indicators have not been validated by any previous studies, only a few of the indicators were tested in this case study, piloting topics from each category. The criteria for selection included: 1) priority of the indicators, which means the level of impact of the indicators on perceived safety; 2) reliability of the indicators. Some of the indicators may not be easily captured at the workforce level. For example, balancing of resources of multiple trades would be an interest of the project management and foreman, but is not easily perceived by the workers. Therefore, it may not be appropriate to use these indicators for workforce feedback. Eight contextual indicators were tested in this case study, as shown in Table 6-2. Specific questions were developed based on these eight indicators. Since the indicators were specific, it was possible to turn the indicators to questions without ambiguity. For example, “workplace congestion” was developed to the question of “I have enough space to perform my tasks.” The complete questionnaire was shown in Appendix B.
Table 6-2: Contextual Indicators that were tested in the Case Study

<table>
<thead>
<tr>
<th>Category</th>
<th>Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time/Production</td>
<td>Awareness of upcoming tasks</td>
</tr>
<tr>
<td>Time/Production</td>
<td>Adequate planning time before task</td>
</tr>
<tr>
<td>Physical Resources</td>
<td>Access to equipment that is required to perform the task safely</td>
</tr>
<tr>
<td>Team</td>
<td>Worker involvement in pre-task planning/hazard identification</td>
</tr>
<tr>
<td>Team</td>
<td>Communication among trades</td>
</tr>
<tr>
<td>Workplace</td>
<td>Awareness of the jobsite changes over the next period</td>
</tr>
<tr>
<td>Workplace</td>
<td>Workplace Congestion</td>
</tr>
<tr>
<td>Workplace</td>
<td>Workplace Condition</td>
</tr>
<tr>
<td>Workplace</td>
<td>Awareness of hazardous materials on site</td>
</tr>
</tbody>
</table>

6.2.3 Data Collection Procedures

The data collection procedures were designed based on the process model, as discussed in Chapter 5. As illustrated by Figure 6-1, the initial step was to identify the safety climate measurement goals and develop a detailed data collection plan with the project team. The initial goal for the project was to conduct all construction operations with zero injury rate as well as zero property damage and environmental incidents. The safety goal was based on reactive indicators of injury rate and incident. Although there was a hazard identification system in place to foresee and manage risks, there is a lack of proactive approaches to manage safety. By discussing with project management team, the goal for the safety climate measurement was established as:

- Constantly work to improve conditions and reduce hazards with the construction progression, and analyzing safety trends and formulating corrective actions;
Focus on solving safety issues identified by workers and others, communicate with workers about specific context of the safety issues, engage the workers to observe changes and provide additional feedback;

Develop effective safety policies and procedures to integrate safety and health in the operational plans.

The primary goal for the safety climate measurement was to shift from reactive indicators to proactive approaches. To achieve the safety goal of the project and the research goal for this study, two data collections were scheduled to engage the major trades on site: one at the structural erection phase (T1), and the other during the rough-in and drywall installation phase (T2). Data collection was scheduled to engage the major trades at different construction phases so that different workplace conditions and construction activities were addressed.

During the first measurement, a safety walk was conducted two days before the survey to capture the site conditions on housekeeping, equipment conditions, temporary facility conditions, as well as worker behaviors. The safety audit was conducted by the owner’s safety representative to provide an unbiased perspective of the site conditions. The safety audit report was generated by iAuditor, which is a commercial tool for safety inspection with a pre-defined checklist used by the owner. The results of the safety audit indicated that the project was a safe site by the time of the data collection. Among the 38 items of the checklist, only five items were evaluated as non-compliant, including:

- Main gate was not secured;
- Improper use of lock-out/tag-out lock;
- One employee was observed straddling a ladder;
- Worn blade on one metal stud saw;
- Combustible material stored near flam storage.
After the safety audit, questionnaires were distributed directly to the workers in one large group during the safety luncheon at this project. 45 valid responses were collected and analyzed using pre-established data structures. The result of average scores for each indicator and analysis of the implications were shared with the project team. The full result report is provided in Appendix C. A similar process was followed for the second data collection. A safety audit was conducted before the survey, without any major safety issues documented this time. Questionnaires were then distributed to the workers and responses were collected and analyzed. The full result report is provided in Appendix D. Due to the phase of work, a larger sample size (111 valid responses) was collected. Follow-up interviews were conducted with the foremen to further investigate the details of the project context and dynamics at the crew level, to understand the challenges faced by the workers that may influence the site safety climate, including differences from the previous survey. To understand the thoughts, a series of semi-structured interviews were performed to capture the perceptions of the foremen from multiple trades on site. During the interviews, four categories of questions were addressed, including:

- Perceived trade risks;
- Project context of safety management;
- Forecasted safety risks; and
- Trade interactions.

The semi-structured interviews provided a consistent flow of ideas to compare across multiple trades, and the participants were allowed to provide new directions of conversation based on specific topics, generally related to specifics of their trades. The full result report of the interviews is provided in Appendix E. Aggregated results were shared with the project management team to facilitate the development of future safety plans and procedures.

The following section presents a discussion of the results to achieve the research goals of the safety climate measurement.
Figure 6-1: Case Study Procedures
6.3 Data Analysis

6.3.1 Demographics

Demographic data was collected through the questionnaire, including the role, trade, and years on working experience in construction of the respondents. Descriptive properties of participants in two samples are summarized in Table 6-3.

<table>
<thead>
<tr>
<th></th>
<th>Sample 1 (T1)</th>
<th>Sample 2 (T2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Responses</td>
<td>45</td>
<td>111</td>
</tr>
<tr>
<td>Response Rate</td>
<td>97%</td>
<td>78%</td>
</tr>
<tr>
<td>Number of Trades</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>Frontline Worker (%) (non-foremen)</td>
<td>71%</td>
<td>81%</td>
</tr>
</tbody>
</table>

The distribution of respondents’ years of work experience in construction is summarized in Table 6-4. For the first sample, roughly half of the workforce had between 10-30 years of experience, with 1/8 of the sample having more than 30 years. More notably for safety, approximately 15% of respondents had working experience of 2 years or less. For the second survey, worker with 10-30 years of experience were around the same percentage with the first survey. 20% of the workers had over 30 years working experience, which increased from last survey.
Table 6-4: Respondents’ Years of Working Experience in Construction

<table>
<thead>
<tr>
<th></th>
<th>Sample 1 (T1)</th>
<th>Sample 2 (T2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 10 years</td>
<td>36%</td>
<td>32%</td>
</tr>
<tr>
<td>10 – 20 years</td>
<td>20%</td>
<td>24%</td>
</tr>
<tr>
<td>20 – 30 years</td>
<td>29%</td>
<td>23%</td>
</tr>
<tr>
<td>More than 30 years</td>
<td>16%</td>
<td>21%</td>
</tr>
</tbody>
</table>

The distribution of the workforce by trades was also considered, as shown in Table 6-5.

Seven major trades were identified by the workers’ responses of the first survey, and 13 trades were identified by the second survey. Six trades were consistent across the two surveys.

Table 6-5: Respondents’ Trades

<table>
<thead>
<tr>
<th>TRADE</th>
<th>Sample 1 (T1)</th>
<th>Sample 2 (T2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpenter</td>
<td>12</td>
<td>19</td>
</tr>
<tr>
<td>Plumber</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Electrician</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Sheet Metal</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Cement Mason</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Operator</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Laborer</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Pipefitter</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Insulation</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Roofer</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Painter</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Bricklayer</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Demolition</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>45</strong></td>
<td><strong>111</strong></td>
</tr>
</tbody>
</table>
6.3.2 Comparisons between the Two Data Collections

The overall scores of the two samples were compared with all factors (Figure 6-2). Most factors remained stable while crew commitment, rules and procedures, as well as the contextual indicators changed. This research focused on the contextual indicators which were new indicators that were added to existing tools.

![Figure 6-2: Overall factors comparison of two samples](image)

Table 6-6 calculates the means and standard deviation of the nine contextual indicators of the two samples.
Table 6-6: Descriptive Statistics of the Contextual Factors

<table>
<thead>
<tr>
<th>Contextual Factors</th>
<th>Sample 1 (Time 1)</th>
<th>Sample 2 (Time 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Awareness of upcoming tasks</td>
<td>3.84</td>
<td>4.02</td>
</tr>
<tr>
<td></td>
<td>1.08</td>
<td>1.07</td>
</tr>
<tr>
<td>Adequate planning time before task</td>
<td>3.79</td>
<td>3.81</td>
</tr>
<tr>
<td></td>
<td>0.96</td>
<td>1.14</td>
</tr>
<tr>
<td>Access to equipment</td>
<td>4.16</td>
<td>4.03</td>
</tr>
<tr>
<td></td>
<td>1.03</td>
<td>1.05</td>
</tr>
<tr>
<td>Worker involvement in pre-task planning</td>
<td>4.05</td>
<td>3.92</td>
</tr>
<tr>
<td></td>
<td>0.87</td>
<td>1.09</td>
</tr>
<tr>
<td>Communication among trades</td>
<td>3.87</td>
<td>3.67</td>
</tr>
<tr>
<td></td>
<td>1.12</td>
<td>1.30</td>
</tr>
<tr>
<td>Awareness of the jobsite changes</td>
<td>3.82</td>
<td>3.89</td>
</tr>
<tr>
<td></td>
<td>1.11</td>
<td>1.12</td>
</tr>
<tr>
<td>Workplace Congestion</td>
<td>3.40</td>
<td>3.84</td>
</tr>
<tr>
<td></td>
<td>1.42</td>
<td>1.08</td>
</tr>
<tr>
<td>Workplace Condition</td>
<td>2.61</td>
<td>2.88</td>
</tr>
<tr>
<td></td>
<td>1.29</td>
<td>1.25</td>
</tr>
<tr>
<td>Awareness of hazardous materials on site</td>
<td>3.03</td>
<td>4.01</td>
</tr>
<tr>
<td></td>
<td>1.31</td>
<td>1.22</td>
</tr>
</tbody>
</table>

There are two approaches to analyze the data. The first approach is to analyze the difference between the two samples to assess if there is a difference of perceived safety across multiple construction stages. To simplify the model, a one-way ANOVA analysis was then conducted, where only the contextual indicators were analyzed. The p-value for the analysis was 0.403, which is greater than 0.05. This indicates that there is not a statistical difference between the two samples at 95% confidence interval. Although there are a lot of changing properties of the site conditions, the project management was able to maintain a stable safety climate on site by implementing an effective safety management program. There is no statistical evidence to indicate that there is a significant difference in the overall project safety climate between the two surveys. Given the high scores, this is a good indicator of the approach to safety taken on the project. This may be partly due to the relatively small sample size in this study. Moreover, there
are many mediating factors that may affect the perceptions of safety, such as individual experience and attitudes and the nature of the work, these factors are not focused in this study. However, the analysis of the differences across different stages helps to understand the context of project as well as the site conditions.

The other approach is to analyze the differences across trades. Construction trades often differ in terms of work activities and requirements, as well as risk exposures (Cigularov 2013). For example, job task activities are considered to be more physically demanding on daily basis for iron workers, elevator constructors, and electricians than other trades. Also, some trades have more strict requirements on personal protective equipment due to the nature of their work, such as insulators, iron workers, and painters. Based on the one-way ANOVA analysis with trades as variable for both samples, the p-value for the analysis was 0.039 and 0.003, which are smaller than 0.05. This indicates that there is a statistical difference in perceived safety across multiple trades on site. The variation in trade safety climate perceptions can be attributed to differences in work activities, environment, and risk exposures among different construction trades, and the safety culture of the subcontracting firms. The responses of the follow-up interviews validated this finding. Each foreman was asked to evaluate the level of risk for their trade at this project, and the responses were various as shown in Table 6-7.
The results of safety climate differences across time and trades provide directions to develop safety management plans for project management. For example, Figure 6-3 illustrates the changes of the contextual indicators for the carpentry trade on site. The general trend is relatively stable with improved priority of safety and communication among trades, which were the lowest two indicators among all other contextual indicators. There are some other indicators that decreased, such as awareness of upcoming tasks, awareness of hazardous materials, and workplace congestion. To investigate the reason for the changes in these indicators, more contextual data should be collected. The safety audit results indicated a more congested site by the time of the second survey, which may impact the safety climate perceptions of the carpenters on workplace conditions. This was further validated by the foreman interviews. The carpentry foreman stated there was an increase of manpower on site and the trade stacking in the interior space. By analyzing these contextual indicators and the collected data on workplace conditions and foremen insights, the understanding of the site safety issues was improved, and concerns

<table>
<thead>
<tr>
<th>Trade</th>
<th>Perceived Risk</th>
<th>Identified topics that influence this perception, per foremen comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Work</td>
<td>High</td>
<td>Exposure to heavy equipment; Changing site conditions</td>
</tr>
<tr>
<td>Mis. Carpenter</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Electrician</td>
<td>Moderate</td>
<td>The advancement of safety in training and requirements decreased the risk</td>
</tr>
<tr>
<td>Bricklayer</td>
<td>High</td>
<td>Exposure to heights</td>
</tr>
<tr>
<td>Sheet Metal</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Carpenter</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Plumber and Pipefitter</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Asbestos Abatement</td>
<td>High</td>
<td>Exposure to dangerous materials; Proper use of PPE can reduce the risk</td>
</tr>
<tr>
<td>Demolition</td>
<td>Moderate</td>
<td>Changing site conditions; Exposure to heights</td>
</tr>
</tbody>
</table>
from the workforce could be captured, understood, and appropriately addressed in order to proactively manage site safety.

![Graph showing safety climate indicators](image)

**Figure 6-3**: Contextual Indicators of the Carpentry Trade

### 6.3.2 Perceived Workplace Conditions

Many factors contribute to the creation of safety climate at one project. This research focused on the impact of contextual indicators, which can be measured by the safety climate indicators, as well as the perceived workplace conditions. The workers were asked to identify their primary working areas and common safety concerns or hazards that are seen onsite relative to their work area (Figure 6-4 and Figure 6-5). The major working areas shifted from trenches and floor openings to scaffold and portable ladders, which aligns with the construction
progression at the time of the survey. Based on the results, reinforcing fall protection and proper use of equipment should be a focus after the second survey. The perceived risk contributing factors were also evaluated by the respondents. With more interior work at the second time, changing risks, such as higher electrocution risks and less struck-by risks were perceived.

The results of the perceived work place conditions revealed the site dynamics from a different perspective than the safety climate indicators. The identification of the primary working areas and recognition of risks that are created by the workplace conditions helped to capture the site dynamics from a more objective, and less perceptual perspective, which also facilitates the development of a dynamic safety plan with the construction progression. Previous studies have focused on the psychological attributes of safety climate, which makes it difficult to interpret the meaning behind results. By incorporating the workplace conditions in the safety climate measurement tool, the site dynamics are captured in terms of working area and risks.

![Figure 6-4: Work Areas Identified by Workers](image-url)
Figure 6-5: Risk Factors Identified by Workers in Their Work Areas

6.3.2 Contextual Information Captured by the Process Model

Although there are experimental and qualitative studies which have provided valuable insight in conceptualizing safety climate assessment, the vast majority of studies have relied on survey data and statistical data analysis techniques (Hopkins 2006). Despite the prevalence, the methodology of measuring safety climate has been questioned in terms of the reliability of the results. Questionnaire-based approach provided a narrower analytical scope than the causal investigation, which only focused on perceptions rather than the way in which other cultural interacts (such as risks) with other aspects of the organization. Moreover, insufficient sample size and reporting bias may affect the results when analyzing the safety climate on a project level. Thus a triangulation of and qualitative data was recommended for assessing safety climate of a project. This case study employed a triangulation methodology to collect data, including qualitative data on site condition observations and foremen insights captured through interviews, as well as quantitative data on safety climate indicators.

By adopting a mixed research methodology, the findings were considered to be more relevant and useful to the project management team. In this case study, the questionnaire data
indicated a strong and positive safety climate on this project, which on the other hand, created diagnosis challenges to understand the underlying problematic areas of safety management. In this case, qualitative data was interpretive and emphasized the specific cases that arise in the actual context. The overall results from the interviews validated the result of the survey, where almost all of the foremen interviewed stated this was one of the safest projects that they have experienced. By asking questions on the specific project context in terms of site logistics, trades communication, rules and procedures, and project schedule, the challenges of safety management at this project were identified. One of the consistent safety concerns captured by the interviews was due to the limited site space and large amount of work that is being performed concurrently. While the logistics issue was not linked to any specific safety incidents or injuries, it increased the chances for safety incidents. This is also validated by the survey results of the “workplace congestion” indicator. The other challenge that was perceived by the participants was to develop approaches to improve the awareness of safety for workers on daily basis. While safety training and orientation improved the attitudes and awareness of safety for the workers, there are further opportunities to help the workers be vigilant and aware with regard to safety when the pressures on the project for schedule or to work with a greater number of less experienced personnel, or workers from other crews may be adding to the potential distractions.

6.4 Summary

This case study adopted the process model of safety climate measurement by incorporating the contextual indicators to measure the safety climate of a residence hall construction project. Two data collection surveys were conducted at a 5-month interval. Although there is not enough statistical evidence to support the difference between the perceptions on the contextual indicators of the two surveys, the results provided more specific information on the
attitudes and perceptions of the workers towards the environmental factors (workplace, time/production, team, and physical recourses). The perceived workplace conditions provided a more subjective perspective to understand the changes of working areas as well as risks created by the workplace conditions. A mixed research methodology used by this case study provided more diagnostic information to construction industry and practitioners when measuring safety climate at the project level, while at the same time contributing to the understanding of the relationship between working environment and worker perceptions.
Chapter 7

Conclusions

This research is developed a process for capturing safety climate under the dynamic construction working environment. A review of existing literature on safety climate and safety culture as they related to construction safety management identified that there is a knowledge gap in defining and incorporating the working environment within the safety culture model. Four stages of research were conducted to accomplish the research goal, including: 1) Problem identification: The research goal and objectives were established based on a review of existing literature. The research scope was defined based on the goal and objectives. 2) Development of contextual indicators: A systematic review of previous safety climate tools and focus group discussions were adopted to develop a framework of contextual indicator; 3) Development of the process model: a pilot study observation and a case study was conducted to develop a process model of safety climate measurement to incorporate the contextual factors and address site dynamics; 4) Process model validation: focus group discussions and expert interviews were used to validate the process model.

This chapter concludes the research with primary findings and contributions, limitations and future work directions.

7.1 Research Summary and Contributions

This research developed a framework of safety climate contextual factors, as well as a process model to measure safety climate under the dynamic construction working environment. The research objectives are achieved:
7.2.1 Identify the contextual factors that impact safety climate

This research developed a framework of safety climate contextual indicators based on two attributes: Scharf et al.’s (2001) environmental dynamics and Sanvido’s (1988) conceptual construction process model elements. The framework of contextual indicators provides the theoretical foundation to link the environmental aspects and perceived safety within the safety culture model. Analyzing the indicators by these attributes provided a framework to ensure more comprehensive identification of contextual safety climate indicators. Twenty-five contextual indicators were identified within the framework through focus discussions with safety experts. The contextual indicators serve as an initial step toward improving the value of safety climate measures as predictive or diagnostic tools to inform construction leadership about field safety concerns before they become accidents.

7.2.2 Develop a process model to measure safety climate under the construction working environment

A process model of safety climate measurement was developed and validated in this research. The process model consists of five major steps: pre-survey, collect data, analyze data and follow-up, develop a plan, and pursue continuous improvement. The required resources, information flow, and mechanisms of each step were identified. The process model incorporates the specific contextual information using mixed research methods, which streamlines the procedures of measuring safety climate of construction projects. The process model also provides a better understanding of the safety climate concept. While previous studies focus on the psychological aspects of safety climate, the process model enhance the impact of environmental aspects by incorporating construction contextual indicators. The process model also contributes to
industry application of using safety climate as a leading indicator to identify safety management improvement opportunities by project management.

### 7.2.3 Analyze the relationships between site dynamics and safety climate

A case study of safety climate measurement was conducted using the developed process model. Two data collections were performed in this case study to explore the relationship between site dynamics and safety climate. The results indicated that while the site conditions and construction activities changed across the two data collections, the project management was able to maintain a relatively stable and positive safety culture on site. However, the contextual information collected by using the process model provided more specific information on the attitudes and perceptions of the workers towards their working environment in terms of workplace conditions, time/production pressure, team, and physical resources. The results contribute to the industry by providing an example of using safety climate as a diagnostic tool to proactively identify and manage safety risks under the changing context. A mixed research method used by this research also contributes to the theoretical development of safety climate measurement studies by providing more qualitative data (observations and interviews) on site conditions and individual attitudes at crew level.

### 7.2 Limitations

Although the research contributes to the theoretical development and industry application of safety climate in construction, there are several limitations:

According to the scope of this research, new construction of commercial buildings at the initial stage was focused to conduct the case study. There were a limited number of projects
available during the time of the case study. Although the contextual indicators provided more useful information to the project management when developing short-term action plans, their abilities in predicting safety outcome were not tested. As the project was still under construction by the time of data analysis, it was difficult to obtain the safety performance data to test the predictive validity of the contextual safety climate indicators. Moreover, as the results indicated that the case study project maintained a very strong and positive safety culture, which limited the opportunities of investigating the impacts of safety concerns or issues of the working environment on perceived safety.

This research explored the relationship between the site dynamics and perceived safety. However, due to a lack of pre-defined metrics of site dynamics, it was difficult to statistically link site dynamics to safety climate. In this research, perceived working areas and risks were captured as indicators of site dynamics. While the information provided guidance to the project management on developing safety plans and risk management, there is not a statistical model available to link the data to perceived safety.

This research focused on individual’s perceptions on safety, in terms of safety management and the specific context. There are other mediating factors that may impact safety climate but are difficult to measure and validate in a dynamic fashion. For example, individual knowledge and experience may affect their perceptions and attitudes towards safety. Demographics of the data collections indicated that the average years on working experience were different for the two samples, which may have an impact of the results. However, it would be difficult to control the individual knowledge and experience as a variable since the trades are always changing on a project.
7.3 Future Research

There are many areas available for further investigation into safety climate research in construction. An extended study is needed to test and validate more contextual indicators identified by the framework. By engaging more construction projects, the predictive validity of the contextual indicators would be verified, which will provide empirical evidence on the impact of context on safety climate.

Another direction would be defining objective metrics of site dynamics in terms of workplace conditions, team, production, and physical resources to establish the relationship between the changing context and perceived safety. Therefore, the relationships among the site dynamics and perceived safety would be established and validated, which will provide empirical evidence of the relationship between safety climate and site dynamics. This research explored the relationship between perceived job risks and safety climate. There is opportunity to use safety climate survey as a tool to perform hazards analysis from the perspective of the workers. This will provide information for the project management of the individual awareness of job hazards.

Future research can also explore metrics to evaluate the validity of leading indicators. Previous studies have focused on validating leading indicators against safety outcome, such as incident rates and injuries. However, there is a conceptual gap between leading indicators and lagging indicators in terms of their attributes on sensitiveness and level of analysis. There should be other metrics or methods developed evaluate the effectiveness of leading indicators.

7.4 Concluding Remarks

A process of safety climate measurement under the construction working environment was developed and validated. Unlike traditional approaches of using questionnaire-based surveys
that focusing on safety management; this process used a mixed research method to incorporate contextual indicators on workplace conditions, team, production, and physical resources. The process and defined contextual indicators will provide guidance to construction industry and practitioners when using safety climate as a leading indicator to diagnose safety management and understand site safety, while at the same time contributing to the development of safety culture model by providing an approach to contextualize safety climate under a dynamic working environment.
Reference


Appendix A Baseline Process Map of the Pilot Case Study
Appendix B Questionnaire Used For the Case Study

Project Safety Climate Survey

SECTION I: GENERAL INFORMATION

1. What position best describes you?
   - Crew Leader
   - Construction Worker
   - Superintendent
   - Foreman
   - Other

2. Please select your job trade:
   - Roofer
   - Electrician
   - Drywall installer
   - Carpenter
   - Glazier
   - Insulation worker
   - Plumber
   - Iron worker
   - Sheet metal worker
   - Masonry worker
   - Mason and bricklayer
   - Other trade

3. How long have you worked in construction? _________ Years.

4. My primary work area currently has the following items, related to safety & equipment (check all that apply):
   - Trench(es)
   - Roof/Slab Edges
   - Structural erection
   - Enclosed Areas
   - None of these above
   - Scaffold
   - Floor Opening(s)
   - Portable Ladders
   - Moving Construction Equipment
   - None of these above

5. My work area is adjacent to:
   - Fly/Swing Objects
   - Overhead power lines
   - Machinery with moving parts
   - None of these above
   - Potential Falling Items
   - Energized sources
   - Vehicles / Unloading of materials
   - None of these above

6. Compared to my previous project experience, I experience the above safety concerns:
   - Frequently
   - More often than typical
   - On par / Average for my tasks
   - Less often than typical
   - Rarely

SECTION II

Instructions: For the following statements, please check the appropriate box indicating "Strongly Agree," "Agree," "Neither Agree nor Disagree," "Disagree," or "Strongly Disagree," based on your level of agreement. If an answer does not apply, please mark the "N/A." box on the left of the statement.

<table>
<thead>
<tr>
<th>No.</th>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neither Agree nor Disagree</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>My supervisor seriously considers my workers suggestions for improving safety.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Sometimes I am not given enough time to get the job done safely.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>The project management sometimes turns a blind eye to health and safety procedures being broken.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Some safety rules and procedures are not very practical.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>My supervisor compliments me whenever he sees a job done safely.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>I always have control over what happens to my safety on the jobsite.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>I am aware of the hazardous materials on this project.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>All people who work in my crew are fully committed to health and safety.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Co-workers should be warned when their actions are unsafe.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>I have enough space to perform my work.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>My supervisor does not always inform me of current safety concerns or issues.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>There are regular safety meetings/inspections at this jobsite.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>I feel comfortable to correct other trades when they are not following the safety rules.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Written work procedures match the ways tasks are done in practice.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Risk-taking is sometimes part of my work.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1
# Project Safety Climate Survey

## SECTION II

<table>
<thead>
<tr>
<th>N/A</th>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>Some safety rules and procedures are not very practical.</td>
<td>🌟</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>I was given instructions on the safety policy, safety requirements of the company.</td>
<td>🌟</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>I feel involved when health and safety rules/procedures are developed or reviewed.</td>
<td>🌟</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Under pressure I need to ignore normal safety requirements at the project for the sake of getting the work done.</td>
<td>🌟</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>I am told when changes are made to working environment on a jobsite.</td>
<td>🌟</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>My supervisor always follow the safety policy/rules.</td>
<td>🌟</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>I feel that my supervisors and other top manager care about my safety.</td>
<td>🌟</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>I am informed how my jobsite changes over the next day/week/month will impact me.</td>
<td>🌟</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>I am clear about what my responsibilities are for health and safety.</td>
<td>🌟</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Sometimes, the workplace conditions can hinder my ability to work safely.</td>
<td>🌟</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>I can always get the right safety equipment to do my job safely.</td>
<td>🌟</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>My supervisor only keeps track of major safety problems and overlooks routine problems.</td>
<td>🌟</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>There is sometimes pressure to put production before safety at the Project by the GC management.</td>
<td>🌟</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>The safety orientation I have received at the project covers all the health and safety risks associated with the work for which I am responsible.</td>
<td>🌟</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>There is sufficient &quot;thinking time&quot; to enable workers to plan and carry out their work to a adequate standard.</td>
<td>🌟</td>
<td></td>
</tr>
</tbody>
</table>

## SECTION III Comments

Please list / share any recent safety concerns you would like to bring to our attention:

Please identify upcoming changes or site activities that you think may affect your personal safety in future tasks:
Appendix C Safety Climate Result Report I & II

Safety Climate Survey Report I:

DEMOGRAPHICS

On Wednesday, October 12, a Safety Climate survey was distributed to the current workforce for the case study project. The purpose of the survey is to measure the safety perceptions of the workforce at the project and to understand the potential opportunities for improvement of current and future safety concerns by management. The project is in the structural phase with a mix of masonry work, concrete and structure panel installation, some limited site work, as well as early Mechanical, Electrical, and Plumbing work.

![Pie Chart: Distribution of Respondents' Role](image)

Figure 1: Distribution of Respondents’ Role

Responses were collected by means of a questionnaire distributed directly to the construction workforce on the construction projects. 45 respondents returned the questionnaires with valid responses. The distribution of the respondents’ roles is plotted in Figure 1. The majority of the respondents are front-line workers (32 out of 45), with 5 foreman and 6 superintendents. 2 respondents did not indicate a trade, as indicated by “other”.
The distribution of respondents’ years of work experience in the construction industry is summarized in Figure 2. Roughly half of the workforce has between 10-30 years of experience, with 1/8 of the sample having more than 30 years. More notably for safety, approximately 15% of respondents have working experience of 2 years or less.

![Figure 2: Distribution of Respondents’ Trade](image)

The distribution of the workforce by trades was also studied, as shown in Figure 3. Six major trades were identified by the workers’ responses, with two respondents having selected “other”—these respondents were grouped with laborers, bringing the count to nine. The distribution of workers is logical given the phase of the project.

![Figure 3: Distribution of Respondents’ Trades](image)
The workers were asked to identify common safety concerns or hazards that are seen onsite relative to their work area. The summary of the hazards seen is shown in Figure 4. Only one worker indicated they do not encounter any of the listed hazards. Among the rest, moving vehicles, potential for falling items, and swinging objects (e.g. crane) were identified as the three most commons safety risks encountered on the jobsite.

![Common Hazards Noted by Workers](image)

Figure 4: Hazards identified by workers in their work areas.
SAFETY CLIMATE SURVEY RESULT SUMMARY

Management Commitment: This factor indicates that the employees believe that management cares about their personal safety, higher levels usually indicate workforce is more cooperative to improve safety performance.

Priority of Safety: The priority of safety indicates the perceived prioritization of safety by management against other project pressures, such as schedule deadlines. It indicates whether workers feel obligated to report concerns and their comfort that management will follow-through with addressing issues.

Rules and Procedures: This factor indicates the level to which rules and procedures for safety are implemented. Many safety incidents can be traced back to improper safety procedures or procedures being modified for comfort or convenience.

Supervisory Environment: The ability of supervisory personnel to ensure that the program is carried out during daily operations.

Safety Training: The essence of this factor is the workforce’s perception of the general level of the effectiveness of the safety training and education they received at the project.

Worker Involvement: Evidence suggests worker involvement in safety planning & decisions is important. Items, such as procedures for reporting injuries or potential hazards allow engagement and buy-in to the safety policies and processes.

Work Environment: This factor suggests the workers’ perception of the physical environment in which they work. Well laid out and clean sites provide higher levels of safety performance.

Personal Appreciation of Risk: This factor indicates the personal perceptions relative to tensions in safe work performance and project pressures. Lower scores may suggest workers perception they get injured, as well as the message regarding the importance or need for safe work.

Crew Commitment: This factor refers to the degree of trust and support within a group of workers, confidence that people have in working relationships with coworkers, and general morale.
SAFETY CLIMATE SURVEY RESULT SUMMARY

Reviewing the results, a few items stand out for further consideration. Starting with the high points in the feedback, there are several areas that the workforce indicates that the project and management are doing extremely well with regarding to creating a safe working environment:

Crew Commitment and Management Commitment to safety are both extremely high. This suggests consistent perceptions across the onsite workforce that their safety is valued by their fellow workers and by management.

Safety Training was also ranked quite high, suggesting the instruction on policy and safety requirements is consistent and clear, as well as the quality of communication for items such as safety orientation.

Supervisory Environment was rated highly, indicating that supervisors’ positive reinforcement for safe working behaviors is strong and that they are open to suggestions by the workforce. It also suggests workers are receiving up to date information on safety concerns. While the overall scores are good, there were several areas indicated in the survey that suggest there are areas for improvement, or areas where the reasons for decisions may not be well understood by the workforce:

Safety Rules and procedures had the lowest average score of all of the scales. In particular, there were quite a few respondents that felt some of the safety rules or procedures were not practical. Often times, this response indicates workers are frustrated with a particular rule or procedure, how it is being implemented, or the communication for why it is being implemented is unclear.

Work Environment was rated a little lower than desirable, with the average slightly below 4. In particular, areas of concern related to having sufficient space to work safely, or the workplace conditions hindered workers ability to work safely.
The Priority of Safety was rated a little low, with an average score of 3.76. This suggests that the balance between the need to hit schedule or production targets sometimes seems to take priority over safety.

Worker Involvement and Personal Appreciation of Risk were both a little lower than desirable. Regarding involvement, there was an indication that communication about changes on the jobsite or working environment could be improved. For Risk Appreciation some workers indicated that they do not have the desired level of control over their personal safety on the jobsite, or that some level of risk is inherent in the tasks they perform.

Again, the overall responses were generally very positive. The intent in breaking out some of the areas of concern is to help clarify why some workers may feel the jobsite and working environment could have some opportunities for improvement.
TRADE RESPONSES

To better understand the breakdown of responses by area of work and trade, the scores for the Factors are summarized in Table 0-1. The green circle indicates positive perceptions for safety for that factor, and the orange circle indicates a generally positive perception a little room for improvement. The red circle indicates areas of concern or more strongly felt opportunities to improve safety. For example, all trades feel high management commitment on safety and effective delivery of safety training. The carpenter and mason trade indicate the strongest concerns for some of the safety rules and procedures are not very practical. This needs further investigation to understand what specific rules and procedures, but should help in identifying the items that are common among those crews.

Table 0-1: Perception of Safety by Trade

<table>
<thead>
<tr>
<th></th>
<th>Carpenter (n=12)</th>
<th>Mason (n=8)</th>
<th>Excavation (n=6)</th>
<th>Plumber (n=4)</th>
<th>Electrician (n=4)</th>
<th>Laborer /Other (n=9)</th>
<th>Sheet Metal (n=2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal Appreciation of Risks</td>
<td>![Orange Circle]</td>
<td>![Orange Circle]</td>
<td>![Orange Circle]</td>
<td>![Orange Circle]</td>
<td>![Orange Circle]</td>
<td>![Orange Circle]</td>
<td>![Orange Circle]</td>
</tr>
</tbody>
</table>
The researchers have attempted to provide some quantification of risk at a general risk level, based on Baradan’s and Usmen’s\textsuperscript{1} analysis of historical risks by trade. They identify risk levels, based on five years of injury and fatality from Bureau of Labor Statistics data for construction over a five year period. Then, based upon the severity and fatality data, assign the relative risk by trades. This is not specific to forecast work on any one project.

The data shown in Figure 5, uses these risk scores in conjunction with the current level of workforce in each trade to provide a generic risk assessment of the workforce currently on site. For obvious reasons, larger workforce will have greater chance of injury, but according to Baradan and Usmen’s risk scores, Masons and Electricians have the highest risk levels, regardless of worker count, of the current on-site trades. These two trades are followed closely by Carpenters, Laborers, and Plumbers as still having substantial risk levels for their daily activities.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{general_risk_score.png}
\caption{General Risk Score Assessment of Current Trades}
\end{figure}

\begin{itemize}
\item Carpenters
\item Masons
\item Plumbers
\item Electricians
\item Laborers / Sheetmetal
\item Cement Masons
\item Equipment Operators
\end{itemize}

\begin{itemize}
\item 0
\item 20
\item 40
\item 60
\item 80
\item 100
\item 120
\item 140
\end{itemize}

\begin{itemize}
\item 0
\item 20
\item 40
\item 60
\item 80
\item 100
\item 120
\item 140
\end{itemize}

\begin{itemize}
\item General Risk Score
\item Risk Score
\item Number of workers on site
\end{itemize}

\begin{itemize}
\item Masons
\item Plumbers
\item Electricians
\item Laborers / Other
\item Sheetmetal
\item Cement Masons
\item Equipment Operators
\end{itemize}

The numbers above are based upon the worker count taken from the questionnaire, and may not accurately represent the regular worker count on site. For example, there are masonry tasks on the project, but the day of the climate survey there were no brick masons present.
OPEN-ENDED RESPONSES

In addition to the standardized questions with Likert scale responses, the workers were also given room to address areas of concern with the current site and operations, as well as perceived future risks. There were only a handful of written in responses, which are summarized below:

- Site Conditions:
  - Concrete piles around jobsite should be removed;
  - Delivery trucks should be assigned personnel to ensure safety for the entire duration of their delivery;
  - Wet / Slippery conditions should be taken care of; pools of water on site should be addressed.
  - Falling mortar under mason’s work area is a problem.

- Future Concerns:
  - Fall/winter weather conditions soon arriving, the plans and/or procedures for cold-weather work have not yet been communicated.

In summary, the overall perception of the on-site safety climate was positive. The commitment by crews and management were strongly felt, as well as having a positive supervisory environment. There are some areas for potential improvement, in the execution of safety procedures and in the communication of upcoming changes on site which will influence worker safety. In addition, some specific areas for attention, such as having sufficient space and cleaner conditions were suggested for areas that could improve safety on the project. In addition, it is important to note that this data is based upon the perceptions of the workforce. This is not a forecast of specific risks or safety hazards on the site, but additional information management can use to understand the concerns of the workforce as they conduct their daily tasks.
Safety Climate Survey Result Report II:

DEMOGRAPHICS

Two Safety Climate surveys were distributed to the current workforce for the case study project on February 21, 2017, for Phase 1a – Earle Hall, and on March 1, 2017, for Phase 1b. The purpose of the survey is to measure the safety perceptions of the workforce at the project and to understand the potential opportunities for improvement of current and future safety concerns by management. By the time of this survey, the project is in the rough-in phase with a mix of drywall installation work.

![Figure 01: Distribution of Respondents’ Role](image)

Responses were collected by means of a questionnaire distributed directly to the construction workforce on the construction projects. 125 respondents returned the questionnaires, 14 responses were excluded from the analysis due to incomplete information. The distribution of the respondents’ roles is plotted in Figure 1. The majority of the respondents are front-line workers (90 out of 111), with 18 foreman, and 3 superintendents.

The distribution of respondents’ years of work experience in the construction industry is summarized in Figure 2. Roughly half of the workforce has between 10-30 years of experience, which is similar with the survey participants of Oct, 2016. 20% of the workers have over 30 years working experience, which increased from last survey.
The distribution of the workforce by trades was also studied, as shown in Figure 3. 13 trades were identified by the workers’ responses.

![Figure 2: Distribution of Respondents’ Trade](image)

The workers were asked to identify their work areas and the common safety concerns or hazards that are seen onsite relative to their work area. The summary of the work area is shown in Figure 4. The most common workplace is portable ladders and scaffolds. Fall hazards should be taken into account when developing safety plans at this phase of construction.

![Figure 3: Distribution of Respondents’ Trades](image)
The most common hazard as identified by the respondents is potential falls, including potential falling items, and fly/swing objects (Figure 5). 30 workers identified none of these hazards in their primary working areas.

**Figure 4: Work areas identified by workers**

**Figure 5: Hazards identified by workers in their work areas.**
SAFETY CLIMATE SURVEY RESULT SUMMARY

Management Commitment: This factor indicates that the employees believe that management cares about their personal safety, higher levels usually indicate workforce is more cooperative to improve safety performance.

Priority of Safety: The priority of safety indicates the perceived prioritization of safety by management against other project pressures, such as schedule deadlines. It indicates whether workers feel obligated to report concerns and their comfort that management will follow-through with addressing issues.

Rules and Procedures: This factor indicates the level to which rules and procedures for safety are implemented. Many safety incidents can be traced back to improper safety procedures or procedures being modified for comfort or convenience.

Supervisory Environment: The ability of supervisory personnel to ensure that the program is carried out during daily operations.

Safety Training: The essence of this factor is the workforce’s perception of the general level of the effectiveness of the safety training and education they received at the project.

Worker Involvement: Evidence suggests worker involvement in safety planning & decisions is important. Items, such as procedures for reporting injuries or potential hazards allow engagement and buy-in to the safety policies and processes.

Work Environment: This factor suggests the workers’ perception of the physical environment in which they work. Well laid out and clean sites provide higher levels of safety performance.

Personal Appreciation of Risk: This factor indicates the personal perceptions relative to tensions in safe work performance and project pressures. Lower scores may suggest workers perception they get injured, as well as the message regarding the importance or need for safe work.

Crew Commitment: This factor refers to the degree of trust and support within a group of workers, confidence that people have in working relationships with coworkers, and general morale.
SAFETY CLIMATE SURVEY RESULT SUMMARY

The overall result is consistent with the survey result conducted in last October, indicating a stable safety climate on this project. There are several areas that the workforce indicates that the project and management are doing extremely well with regarding to creating a safe working environment:

- Management Commitment and Crew Commitment to safety are both extremely high, which is consistent with last survey. This suggests consistent perceptions across the onsite workforce that their safety is valued by their fellow workers and by management.
- Safety Training was also ranked quite high, suggesting the instruction on policy and safety requirements is consistent and clear, as well as the quality of communication for items such as safety orientation.
- Safety Rules and Procedures improved compared with last survey. Although it still had the lowest score of all the scales, the average increased from 3.17 to 3.43.
- Worker Involvement increased slightly since last survey, suggesting improved communication between the workforce and the management.
- Priority of Safety also increased slightly. This suggests that although there are more construction tasks performing at this stage, the management and the workforce place safety at higher priority than production.

While the overall scores are good, there were several areas indicated in the survey that suggest there are areas for improvement, or areas where the reasons for decisions may not be well understood by the workforce:

- Work Environment decreased from 3.86 to 3.72. Some respondents stated that the workplace sometimes hindered their tasks. Considering the tightness of the construction site, the responses are reasonable. Improvement could be made by communicating with the trades to investigate the site conditions.
- Supervisory Environment decreased slightly. Although the score of this factor remains above the overall average, some respondents stated that while their supervisor keeps track major safety problems, they may overlook routine problems.

Again, the overall responses were generally very positive. The intent in breaking out some of the areas of concern is to help clarify why some workers may feel the jobsite and working environment could have some opportunities for improvement.
SAFETY CLIMATE SUVERY RESULT DETAILS

There are some specific questions that are improved compared with last survey, including:

- Under pressure I need to ignore normal safety requirements at the project for the sake of getting the work done.
- Some safety rules and procedures are not very practical.
- I have enough space to perform my work.

The questions that are decreased from last survey are:

- Sometimes, the workplace conditions can hinder my ability to work safely.
- I am aware of the hazardous materials on this project.
- Co-workers should be warned when their actions are unsafe.
- My supervisor compliments me whenever he sees a job done safely.

Overall, the result is consistent with last survey. Both surveys indicate positive and strong safety culture on this project. Many factors could impact the results of the survey, such as the individual experience of the respondents, construction tasks that are performing at the time of the survey, and the physical working environment. The survey result helps to start the conversation of identifying opportunities to improve safety.
TRADE RESPONSES

To better understand the breakdown of responses by area of work and trade, the scores for the Factors are summarized in Table 1. The green circle indicates positive perceptions for safety for that factor, and the orange circle indicates a generally positive perception a little room for improvement. The red circle indicates areas of concern or more strongly felt opportunities to improve safety. For example, all trades feel high management commitment on safety, effective delivery of safety training, and high crew commitment. The sheet metal and the painter trade indicate concerns for safety rules and procedures. This needs further investigation to understand what specific rules and procedures, but should help in identifying the items that are common among those crews.

It is worth mentioning that the majority of the trades indicate concerns for work environment.

Table 1: Perception of Safety by Trade

<table>
<thead>
<tr>
<th></th>
<th>Plumber and Pipefitter</th>
<th>Carpenter</th>
<th>Demo</th>
<th>Electrician</th>
<th>Laborer</th>
<th>Sheet Metal</th>
<th>Cement Mason</th>
<th>Insulation</th>
<th>Bricklayer</th>
<th>Painter</th>
<th>Roofer</th>
<th>Operater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management Commitment</td>
<td></td>
<td>20</td>
<td>19</td>
<td>17</td>
<td>16</td>
<td>10</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Priority of Safety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rules and Procedures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supervisory Environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety Training</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Worker Involvement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work Environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personal Appreciation of Risk</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crew Commitment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TRADE RESPONSES AND RISKS

The researchers have attempted to provide some quantification of risk at a general risk level, based on Choe and Leite’s\(^2\) analysis of historical risks by trade. They identify risk levels, based on the injury and fatality data from Bureau of Labor, was calculated by the Relative Days-Away Injury Index and the Relative Injury Index. This is not specific to forecast work on any one project. The data shown in Figure 6, uses these risk scores as well as the number of workforce, in conjunction with the perceived safety climate in each trade. The numbers above are based upon the worker count taken from the questionnaire, and may not accurately represent the regular worker count on site.

![General Risk Score Assessment of Current Trades](image)

Figure 5: General Risk Score Assessment of Current Trades

OPEN-ENDED RESPONSES

In addition to the standardized questions with Likert scale responses, the workers were also given room to address areas of concern with the current site and operations, as well as perceived future risks. There were only a handful of written in responses, some of the responses recognized the

- The watch out for your partner works well. The safety department is doing a good job;
- Paint concerns. The painters have been corrected to use hepa fitters and ventilations;
- This is one of the best jobs. The management care about your safety.

However, there are some concerns that the workers would like to bring to Clayco’s attention:

- Some of the safety rules are too strict to follow;
- The heat in the break area and job area is often turned off;
- Congestion of the trades on site;
- The work areas should be kept clean at all times;
- Mud;
- It would be great to have free parking on site.

In summary, the overall perception of the on-site safety climate was quite positive and stable. The commitment by crews and management were strongly felt, as well as having an effective delivery of safety training. There are some areas for potential improvement, in the execution of safety procedures and in the communication of upcoming changes on site which will influence worker safety. In addition, with multiple trades working on site, having sufficient space and cleaner conditions were suggested for areas that could improve safety on the project. In addition, it is important to note that this data is based upon the perceptions of the workforce. This is not a forecast of specific risks or safety hazards on the site, but additional information management can use to understand the concerns of the workforce as they conduct their daily tasks.
Appendix D Safety Climate Follow-Up Interview Report

EXECUTIVE SUMMARY

Safety climate surveys have been widely used in the construction industry to proactively identify opportunities for safety improvements. Two consecutive safety climate surveys have been conducted at the case study project on Oct 21, 2016 and Feb 12, 2017. While the survey results provide the lens of the frontline workforce in terms of safety management and working environment, it is beneficial to further investigate the details of the project context and dynamics at the crew level to understand the challenges faced by the workers that may influence the site safety climate. To understand the thoughts a series of semi-structured interviews were performed to capture the perceptions of the foremen from multiple trades on site. During the interviews, four categories of questions were addressed, including:

- Perceived trade risks;
- Project context of safety management;
- Forecasted safety risks; and
- Trade interactions.

The semi-structured interviews provided a consistent flow of ideas to compare across multiple trades, and the participants were allowed to provide new directions of conversation based on specific topics, generally related to specifics of their trades. The evaluations overall were extremely positive and noted the high level of commitment to safety across the project. The most common concerns revolved around the limited space on site and the increasing congestion of the workforce. As the project moves forward, the expectation is for these concerns to increase slightly with the approach of the turnover and the added site work that will be taking place. The most common areas noted for continued improvement lie in the clear communication behind policies that are over and above typical requirements, as well as potentially new or additional means to communicate safety, as well as other topics, using more visual methods. Overall the assessment aligns with the feedback from the surveys, and was very positive with the comments focused primarily on incremental improvement opportunities.
DEMOGRAPHICS

Nine foremen participated in the interviews; the distribution of participants’ trades is shown in Figure 1. The average interview time was 15 minutes. During the interview, the researcher asked open-ended questions on the four major categories, the participants offered their feedback, perceptions, and impressions on the questions. In several cases they also provided new directions of conversation based on their work experience on the East Halls project. The responses are summarized in the following sections.

Figure 1: Distribution of Participants’ Trade
Perceived Trade Safety Risks

The participants were asked to evaluate the level of risk for their trades in general. The purpose of this question was to capture the personal appreciation of risk based on the nature of their occupation, which will impact their perceptions of site specific safety. The responses are summarized in Table 1. The responses are compared with the conclusion of Baradan and Usman’s rankings of trade risks based on historical data, to inform how the foremen perceive the level of risk as compared to the average level of risk for their trade.

Table 1. Responses of Perceived Risk by Trade

<table>
<thead>
<tr>
<th>Trade</th>
<th>Risk Based (Historical Data)</th>
<th>Perceived Risk (by foremen)</th>
<th>Identified topics that influence this perception, per foremen comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Work</td>
<td>n/a</td>
<td>High</td>
<td>Exposure to heavy equipment; Changing site conditions</td>
</tr>
<tr>
<td>Mis. Carpenter</td>
<td>Moderate</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Electrician</td>
<td>High</td>
<td>Moderate</td>
<td>The advancement of safety in training and requirements decreased the risk</td>
</tr>
<tr>
<td>Bricklayer</td>
<td>High</td>
<td>High</td>
<td>Exposure to heights</td>
</tr>
<tr>
<td>Sheet Metal</td>
<td>Low</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Carpenter</td>
<td>Moderate</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Plumber and</td>
<td>Low</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Asbestos Abatement</td>
<td>n/a</td>
<td>High</td>
<td>Exposure to dangerous materials; Proper use of PPE can reduce the risk</td>
</tr>
<tr>
<td>Demolition</td>
<td>n/a</td>
<td>Moderate</td>
<td>Changing site conditions; Exposure to heights</td>
</tr>
</tbody>
</table>

The perception of risk was generally consistent with historical data, as indicated by Table 1. The participants, as foremen for their respective trades, have a knowledgeable understanding of the risks for their trade in general as well as the specific risks they see on the East Halls project. Two trades perceived lower risk than historical data: electricians and carpenters. The electrician foreman mentioned that the advancement of safety in training and requirements in the construction industry have lowered their risk. The carpenter foreman suggested that, compared with other project, their risk is low for this project in particular.

---

Project Context of Safety Management

In the following section, the participants were asked to describe the project context with regard to how safety management is addressing the project risks. The purpose of this question was to understand the specific context of safety management, such as the major challenges for safety on this project, or differences that they have perceived in terms of safety management or project conditions compared with other projects that they have worked on previously. Almost all participants stated this was one of the safest projects that they have experienced. The specific responses are grouped under four areas the foremen typically raised in their open-ended responses:

- Logistics: Five participants mentioned the challenges created by the limited space available at the site. Deliveries and storage of materials are the most common difficulties that they came across on daily basis; however, they also mentioned that they were working on coordinating the deliveries at the morning meetings on a daily basis. One of the participants mentioned the traffic outside the building is a little bit congested due to the limited room they have to move around. The logistics are not directly related to any major safety concerns; however, it can sometimes increase the probability of struck-by or caught-in-between risks.

- Schedule: All participants commented on the priority of safety over production placed by project management and themselves. Three of the participants mentioned the coordination of schedule among multiple trades was a challenge to them due to the limited space and fast schedule.

- Communication: All participants perceived good communication with the project management and other trades. Three participants specifically noted the morning meetings as a good approach for them to communicate and coordinate the upcoming issues.

- Rules and Procedures: Most participants agreed that the project followed strict safety rules and procedures, and they recognized the necessity of the rules and procedures. Two examples of higher standard in safety rules and procedures than other projects were: 100% glove policy and the prohibition of the use of stilts. For the glove policy, some specific tasks might be hindered by wearing gloves, such
as using screw guns, when the screws can catch the gloves and hurt the worker, while it will not injure the worker, it can create temporary concerns or damage the gloves. It was noted that while they understand that there are safety concerns specific to the use of stilts, the over-arching reason for the policy was not clearly understood by all. The lack of consistent understanding could be contributing to workers’ attitudes towards using scaffolds as a substitute that may need to be communicated in a different manner. While the safety rules and procedures are perceived as strict, one participant mentioned a good example of adjusting current rules based on specific situation. The policy of tie off above 6 feet on ladders was adjusted specific to work in the basement the options for working at heights are extremely limited for options, like scaffold, but require the workers to be just above the 6 foot threshold due to the structure of the building. Higher standards on safety rules and policies were seen to reduce potential hazards by providing protection to the workers; however, communication and education when policies exceed the normal requirements will likely continue to be an ongoing area to improve the workers’ understanding. In specific scenarios, it is helpful to allow approaches for workers to see management have flexibility regarding application of policies, while still ensuring the safety of the workforce.
**Forecasted Safety Concerns Over Next Month**

The participants were also asked to describe the future tasks that they will be performing over the next month and the risks they foresee. The purpose of this question was to understand the changing work on the project site, and the impact on safety. Construction is a dynamic process, with changing site conditions and personnel. Forecasting safety risks can help to coordinate upcoming issues and identify proactive actions that can be taken to mitigate potential safety concerns. All participants had a good understanding of the future tasks for their trade, their response of forecasted safety concerns are summarized as follows:

- **Deadline/Production Pressure.** One of the participants mentioned that as the deadline of projects approaches, there is often higher pressure of productivity that will push some worker to take short cuts. There needs to be more emphasis and communication on the priority of safety over production, especially for trades that may have increases in workers to address schedule challenges.

- **Fall hazards for upcoming activities.** As more tasks will be performed on the roof, there are more fall hazards for certain trades. Setting up proper fall protection could be one of the biggest changes over next month for some trades.

- **Increasing manpower.** One of the participants identified the increasing manpower on site, which might need more coordination, increasing congestion in the interior spaces, and the need to maintain expectations and safety oversight with the larger workforce.

- **Vehicles on site.** There will likely be more vehicles or small equipment on site with the site work taking place during the summer. There are already concerns about congestion for deliveries, so there needs to be more coordination of the traffic and more communication to improve the awareness of the workers communication of when and where site tasks will be taking place conveyed to all of the workforce more often or in greater detail.
Interactions with Other Trades

The last item for discussion was focused on investigating the interactions among trades. The purpose of this question was to understand the impact of concurrent activities on perceived safety. The overall evaluation of trade interactions is good. Some of the local trade workers have experience working together on previous projects on campus, which increases their default level of communication and in many cases creates collegial relationships.

One of the concerns that were brought up was related to the site logistics, as discussed in previous sections. Unexpected deliveries and the storage of materials was one of the major concerns in terms of trade interaction as perceived by the participants. While this was common, it was unclear if this was a broad concern of all of the workforce or specifically of the foremen due to the amount of time they have been engaged coordinating deliveries on a daily basis.

The other issue was the communication of schedule to allow efficient flow of work among multiple trades. There are a lot of repeatable spaces and much potential to find simple visual methods or possibly matrix schedule representations to make it easy for each trade to know where the crews and workforce will be working on a given day / week that might ease delivery coordination for materials and worker movement.
Conclusions of Interview Findings

The results of the interviews were consistent with the outcomes from the survey responses. Both indicated a strong and positive safety culture of this project in many areas, including management commitment, crew commitment, priority of safety, and safety training. For the factors of relatively lower scores, such as rules and procedures, the details of the context were investigated. The forecasted safety concerns of the participants over the next month and the evaluation of trade interactions helped to identify the impact the project dynamics on perceived safety. One of the consistent safety concerns perceived by the participants was due to the limited site space and large amount of work that is being performed concurrently. While the logistics issue was not linked to any incidents, it increased the chances for safety incidents. The other challenge that was perceived by the participants was to develop approaches to improve the awareness of safety for workers on daily basis. While safety training and orientation improved the attitudes and awareness of safety for the workers, there are further opportunities to help the workers vigilant and aware with regard to safety when the pressures on the project for schedule or to work with more or newer personnel from other crews may be adding to the potential distractions.

As this project is perceived by the workers to be one of the safest they have worked on, there are some opportunities for continuous improvement:

- One mechanism that could be considered to develop continuous improvement as an approach would be to engage workers from some or all of the trades in a safety ‘quality circle’. A quality circle is a lean concept in which the workers meet to discuss ways to improve. While they usually focus on the processes and quality, the concept has been applied to construction safety to engage the boots on the ground to inform what the workers consider areas or priorities for safety in the field.
- To improve the understanding of the specific project context as related to safety, communication of the purposes or intent behind certain specific safety policies is
recommended. This could be incorporated into site specific safety orientation. If
the policy affects a specific trade, it could be used specifically in their orientation.

- To improve the awareness of safety, visual communication is recommended. The
  project management has put a lot of efforts in safety signage around the site.
  There are opportunities for more use of visual communication in the requirements
  for PPE, and the potential opportunity to use the BIM model to create better /
easier to read visuals regarding specific safety concerns. One simple example
would be to replace the existing 2D egress path maps with a 3D representation
that is more intuitive for wayfinding.
VITA

Miaomiao Niu

Miaomiao Niu received her Bachelor’s Degree from Tianjin University, China, in 2011. In August 2011, she enrolled in the graduate program at the Pennsylvania State University with a research assistantship, studying the information exchange for commercial building energy audits. Along the way, she was introduced to Building Information Modeling (BIM) and the changes that BIM technology can bring to the industry. Analyzing the exchange of information between completed BIM content and energy analysis, she developed an approach to analyzing the content across the information exchanged comparing the energy auditing requirements and energy analysis schema for BIM. After she completed a Master’s of Science (M.S.) in Architectural Engineering in 2013, she continued the doctorate program of the Department of Architectural Engineering at the Pennsylvania State University. Through the Ph.D. study, she focused on safety climate measurement under the construction working environment.