Measuring Safety Attitude Differences in the Construction Supply Chain

Lance W. Saunders

Dissertation submitted to the faculty of Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

In

Industrial and Systems Engineering

Brian M. Kleiner, Chair
Kimberly P. Ellis
Andrew P. McCoy
Tonya L. Smith-Jackson
Christian Wernz

March 21, 2013
Blacksburg, VA

Keywords: construction safety, occupational safety and health, systems safety, socio-technical systems, macroergonomics

Measuring Safety Attitude Differences in the Construction Supply Chain

Abstract

Construction worker safety is normally a construction activity in the United States, even though there is an emerging body of literature discussing the positive effects of considering safety earlier in the construction lifecycle. This literature has discussed the fragmentation in terms of safety attitudes between owners and designers and those carrying out the construction of a project. Quantitatively identifying the specific areas that the differences exist in terms of safety attitudes between common roles on a construction project could be a step toward reducing the fragmentation that currently exists in the work system and promoting safety to be more of a consideration earlier in the project lifecycle. One common technique for measuring safety attitudes is the use of safety climate survey instruments, but in the construction industry these have historically focused on just construction personnel. This research will discuss the development of a survey instrument to measure differences in safety attitudes between typical members of the entire construction project work system in order to identify specific areas that gaps exist. Phase I of the research include the development of an instrument using Mohammed's (2002) survey as a base, validation of the measurement model using Confirmatory Factor Analysis, and using applied nonparametric statistics to analyze the data and identify significant differences. These results will be used in Phase II to develop a training tool to educate relevant project personnel on differences that were identified in Phase I, and to determine the best mediums for conveying this type of information.

Acknowledgements

I would first like to thank my advisor Dr. Brian Kleiner for being a great mentor over the past few years, and being a great resource for not only this research but for my career in general. He had to learn to translate my Tennessee accent, but once he did I could not have asked for more support or patience from an advisor when needed. I would also like to thank the rest of my committee for their contributions to this work in their different ways. Dr. Ellis was always there with encouragement and advice and taught me how to use Panera as an office, Dr. Smith-Jackson could not have been more helpful giving me advice on the survey development and analysis aspects of the research, Dr. Christian Wernz was a great friend and resource for guiding me through the process, and Dr. Andrew McCoy was an invaluable friend in terms of teaching me the technical side of construction, collaborating on this and other research, and even having a little fun in Melbourne.

To my wife Bethany: Thanks for always being there to support me, and for not automatically ignoring the calls from an old guy back in school 250 miles away. I definitely out-kicked my coverage, and am very thankful for that every day. I look forward to the next chapter in our life together.

To my parents: Thanks for all of your support and encouragement through this process. It would have been easy to go in shock when your 30-year-old son said he was leaving his good job and going back to school for 4 years, but you did just the opposite and I am eternally grateful.

To my brother, other family, and friends: Thanks for all of your support, phone calls, and good times over the years (and to David for almost getting a hernia moving me into my apartment). It is impossible to name you all, and I could not ask for a better set of family and friends. I have never felt like I was very far away from home (because most of the time I wasn't). I also met many new friends in Blacksburg, and could not have gotten through this process without them. I would especially like to thank Andrew Henry who went step for step through this process with me (and had a few fun times as well), and Bethany's family for being a constant source of support and help on anything I needed (and also for not just kicking me out on the spot when she brought a 30 year old student back to meet you).

Finally, this work is dedicated to my grandparents who are an immeasurable reason I am where I am today.

Table of Contents

List of Figures

List of Tables

1 Chapter 1 - Introduction and Background

1.1 Construction Industry Background

1.1.1 Construction Industry Overview

The construction industry is a very significant component of the United States (U.S.) economy. As of 2008, it accounted for 8,552,000 jobs or 4.8% of all workers in the economy (Bureau of Labor Statistics 2010). The industry also had an output of $860.6 billion in 2008, which accounted for 4.4% of the entire U.S. economic output (Bureau of Labor Statistics 2010). The recent economic downturn has affected the construction industry rather harshly. As of September 2009, 1.4 million construction workers had lost their jobs due to the recession. This downturn is further highlighted by the fact in August of 2009 construction layoffs accounted for 30% of all non-farm layoffs when the construction industry was only 5 percent of the workforce (Rombel 2009). As of November 2010, the construction industry still accounted for 5,617,000 seasonally adjusted employees, but still had a 17.2% unemployment rate (Bureau of Labor Statistics 2010) versus the overall rate 9.6% (Bureau of Labor Statistics 2010). Despite the losses in the industry, this data highlights the importance of the industry to the U.S economy, and suggests that even small incremental improvement or cost savings can have large ramifications.

1.1.2 Construction Industry Challenges

While construction in the U.S. is a large component of the economy, it also still faces several significant challenges that impact innovation within the industry. The “one-off” nature of the industry in which firms and workers move from project to project inhibits innovation, as solutions to problems are seen as applicable to a specific project (Blayse and Manley 2004). This inhibits the incentive of firms to innovate, and also is a barrier to creating an organizational memory of knowledge development that is a catalyst for organizational growth (Dubois and Gadde 2002). Construction projects also generally involve a large number of separate firms, as projects can involve owners, designers, contractors and sub-contractors that are all responsible for their individual elements of the project. This is a challenge to communication and accountability among participants, inhibits innovation as firms are often evaluated on only their specialized piece, and involves a large number of small firms without resources to dedicate to innovation and change management (Blayse and Manley 2004).

One specific area within the construction industry in which innovation of current processes could have a large worker well-being and financial impact is occupational safety and health (OSH). In 2009, the construction industry had 816 fatalities, or 18.8% of the 4,340 workplace fatalities in the United States that year (Bureau of Labor Statistics 2010). The industry's 9.7 fatal work injury rate (per 100,000 full-time workers) was also the 4th highest rate among all industries in 2008 (Bureau of Labor Statistics 2010). The private construction industry also reported 4.3 injuries per 100 full-time workers in 2009, which was 10.3% higher than the private industry average of 3.9 injuries per 100 full-time workers (Bureau of Labor Statistics 2010). This data illustrates the need for improvement in OSH within the construction industry, and is further heightened when approaching OSH from an economic standpoint.

A National Institute of Health (NIH) study found that the total cost of all fatal and nonfatal injuries in the construction industry was $11.5 billion. This was 15% of all OSH costs in the entire economy (Waehrer, Dong et al. 2007), which is in contrast to the industry being only less than 5% of all private workers and output of the economy

(Bureau of Labor Statistics 2010). Additionally, the costs of occupational injuries and illnesses in the construction industry represented 11.9% of the total costs within the industry as a whole in 2004 (Fang, Choudhry et al. 2006). Obviously, improvements in OSH performance would have a large impact on costs within the construction industry.

Furthermore, the average fatality has been estimated to cost $4 million and the average nonfatal injury that resulted in time away from work for the employee cost $42,000 in direct, indirect, and quality of life costs (Waehrer, Dong et al. 2007). The same study found that the average fatal or nonfatal injury regardless of severity costs $27,000 compared to $15,000 for U.S. industry as a whole. Other estimates of average non-fatal injury costs range from $7,500 to $10,000, but these estimates are just based on worker's compensation data but are not comprehensive because they do not include indirect or quality of life costs (CPWR 2002; Horwitz and McCall 2004). The most recent NIOSH data estimates each fatality in construction costs $864,000 (NIOSH 2006), but this estimate does not include quality of life costs and the NIH estimate is $1 million with this factor excluded (Waehrer, Dong et al. 2007). Regardless, of the estimate used, the data highlights the large economic impact every injury has on both the respective company and industry as a whole.

1.2 Improvement in the Construction Industry

Improvement approaches such as lean, total quality management (TQM), and supply chain management, which are typically associated with other industries such as manufacturing, have been introduced into the construction industry. One roadblock to more widespread use of these techniques is the perceived differences between the construction industry and the more traditional ones in which these approaches have been employed. One key difference is that the fragmentation of the construction supply chain makes the innovations created by these techniques difficult to sustain (Blayse and Manley 2004). The implementation of these techniques has led to construction worker safety benefits however, and identified gaps in the overall construction process in regards to safety. Further work in these areas will hopefully work to close these gaps and improve OSH performance in the industry.

Lean construction is a growing field that has incorporated lean tools such as production scheduling, Kaizen, "huddle meetings", 5S, and visualization to improve all facets of the construction process including safety. Salem and Solomon (2006) discuss the use of visualization techniques such as mobile signs to attract attention to important information, daily huddle meetings in which safety is addressed, use of 5S to ensure materials and tools are in a safe place, and use of safety checklists to highlight potential safety issues for each crew. Lean production planning tools used in the construction industry such as the "Last Planner" method have also shown to improve OSH performance by shifting superintendents' focus more to external and internal "flows", and shifting responsibility for daily schedules down to personnel such as the foreman (Bertelsen, Henrich et al. 2007). One reason for this is the increased ownership workers receive from being involved in the planning process, and the increased transparency of the schedule for everyone in the supply chain (Bertelsen 2004).

Total Quality Management (TQM) is another technique usually associated with manufacturing that has also been adopted as an improvement technique in the construction industry (Arditi and Gunaydin 1997). TQM advocates continuous improvement focused on meeting both internal and external customer needs. This is done by concentrating on improving quality in all components of the production process through partnership and teamwork of all stakeholders in the supply chain (Arditi and Gunaydin 1997). Incorporating a continuous improvement mentality within the organization is a key component of implementing TQM (Arditi and Gunaydin 1997; Delgado-Hernandez and Aspinwall 2008), and this mentality can provide benefits in regard to safety improvement. A recent survey in Hong Kong of 40 construction companies found that that the second highest score in the TQM section involved implementing continuous review processes of the safety environment in order to promote continuous improvement (Lau and Tang 2009). While it is also debatable whether quality assurance programs are a component of TQM, it does appears that a high percentage of construction firms are adopting ISO 9000 certifications as a means to incorporate quality (Delgado-Hernandez and Aspinwall 2008; Lau and Tang 2009). This certification forces the organization to have formalized process and procedures that must be followed in regards to construction safety.

1.3 Construction Supply Chain Management

As stated above, the implementation of systemic improvement approaches in construction such as lean can be difficult because of the fragmented nature of the industry (Vrijhoef and Koskela 2008). The typical construction supply chain involves multiple firms that from a safety perspective all have an important impact. Figure 1.1 (adapted from Wong 1999; Gould 2005) is a high-level diagram of the supply chain from the perspective of the supply chain being “a network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer” (Christopher 1999) is shown below. This illustration only depicts the 'internal' firms that are usually involved in the design and construction of project. This actual construction work system is even more complex, as 'external' stakeholders such as bankers, insurance companies, regulatory agencies, and the public can also heavily influence the decision-making process.

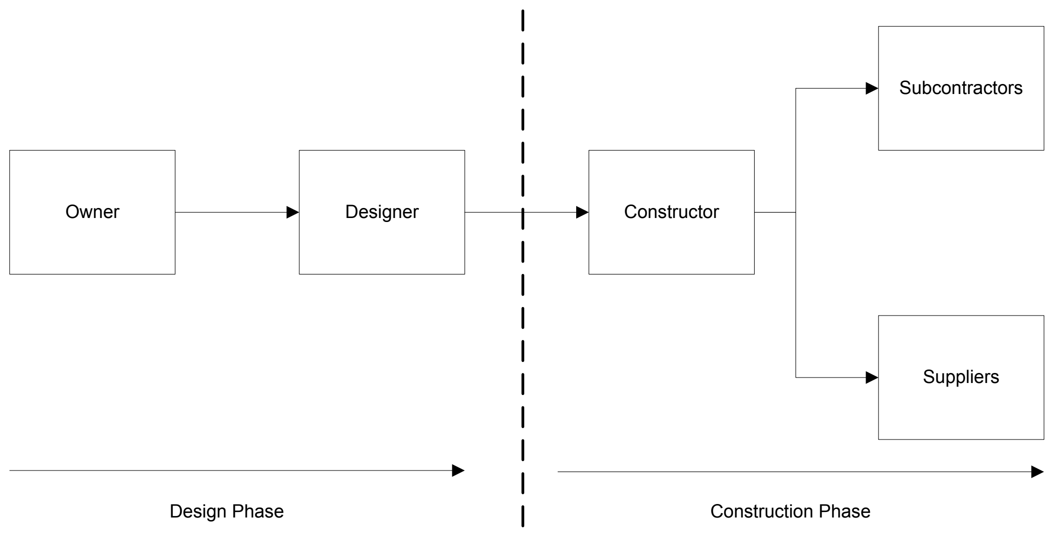


Figure 1-1 Construction Supply Chain (adapted from Wong 1999; Gould 2005)

Supply chain management (SCM) is another holistic approach that can also be employed within the construction industry to drive improvement. Techniques such as sharing information with suppliers and reducing the supplier base are not common in the construction industry because of the large use and amount of sub-contractors and material suppliers (Wong 1999), as these entities are generally worried about only their hand-off instead of one overall goal (Vrijhoef and Koskela 2000). Partnering in the supply chain is one method to increase the trust in the relationships between members such as contractors, sub-contractors, and suppliers, and lead to improvements in overall quality, safety, cost, and productivity (Matthews, Pellew et al. 2000). However, the long history of distrust between these members and reliance on price as the sole determinant of many decisions is a barrier to implementing a SCM approach within the construction industry (Dainty, Briscoe et al. 2001; Fernie and Thorpe 2007). Studying the construction industry from a holistic supply chain perspective is an opportunity to determine where incongruences in terms of safety exist.

All of the organizations in the construction supply chain, as well as specific roles within these firms, have a potential impact on safety. A brief description at the firm level of each organization's role and an overview of their impact on safety is summarized below.

Owner – The owner is the organization that determines the scope of the project, determines scheduling requirements, pays for design and construction, and usually take over ownership of the structure at completion of construction (Gould 2005). Huang (2003) described six ways that owner's of a project have an effect on safety. They are 1) establish and communicate attitudes toward safety, 2) consider safety in contractor selection, 3) include contractual safety arrangements, 4) address safety during design and constructability review, 5) participate in safety during construction, and 6) promote a total safety culture and behavior-based safety.

Designer – The owner usually uses an external architectural and engineering firm or internal employees such as an architect, engineer, or other design professional to assist in transforming the concept into construction documents that can be used through the construction process to build the project. These professionals' expertise also can aid the owner in developing a realistic scope, budget, and schedule (Gould 2005). The design professional also has a very important downstream effect on safety, as the design for safety principal has become a much more prevalent topic in the construction safety arena.

This concept involves consideration of the safety of construction workers during the design phase of a project, as eliminating a hazard during the design phase is preferable to using personal protective equipment (PPE) onsite to avoid the hazard (Behm 2005; Gambatese, Behm et al. 2005). This concept is important, as studies have shown that activities that occur during the design phase such as planning, scheduling, and developing the project's design have been a common root cause of accidents that occur during the construction phase (Whittington, Livingston et al. 1992; Suraji, Duff et al. 2001).

Constructor – The term constructor is used to designate the entity responsible for the interpretation of the construction documents and physical construction of the project. This can either be a construction manager, general contractor, internal construction department, or other entity responsible for delivering a completed project that meets the requirements of the contract and design documents (Gould 2005). The constructor is generally responsible for ensuring that workers have the appropriate PPE and that warning signs and other safeguards are present on site. They are also accountable to ensuring that safety performance and conditions meet what is specified between the owner and constructor in the contract documents, as well as overseeing the safety performance of subcontractors onsite (Toole 2002).

Subcontractors – Subcontractors are specialty contractors that are responsible for a specific part of the project such as the electrical, plumbing, drywall, or excavation. The division of work and management of subcontractors is done by the constructor (Gould 2005). Subcontractors perform a large amount of the construction work on certain projects, and thus are exposed to a large percentage of the safety risk onsite (Hinze and Gambatese 2003). They are also responsible for ensuring that their employees meet the safety performance and have any training required by the contract documents (Toole 2002)

Suppliers – Suppliers are the organizations that supply materials and equipment for the project. The constructor is usually responsible for the procurement process of choosing suppliers, and ensuring that the materials fulfill the requirements of the contract documents. These organizations are responsible for supplying materials and equipment that are safe to use by construction workers, and can work with the designer or constructor to ensure the materials or equipment meet the needs of the design (Matthews, Pellew et al. 2000).

The construction supply chain can also take different forms depending on the type of project delivery method used. The project delivery method can also have an effect on OSH, as the firms and their personnel have different relationships depending on the method. A brief overview of the different types of delivery methods, as well as their potential impact on safety is given below.

Design-Bid-Build (Traditional) – This project delivery mechanism is very common, and involves the owner using a design professional to design a project (in-house or consultant), and then opening the project for bid to construction managers. The construction management firm is then in charge of managing the construction the project including hiring and over-seeing any sub-contractors under a contract between the owner and construction manager. In this method, there is usually a separation between the personnel responsible for the design and the constructor (Hecker and Gambatese 2003). Furthermore, the design firms are usually not responsible for construction safety issues, unless the owner writes it in the contract. Most of the responsibility for OSH on the project therefore falls on the constructor (Gambatese, Behm et al. 2005)

Design-Build – This type of project involves the design and construction of a project being done by the same firm. This results in safety being considered in design more often, as the design and construction is done by the same company who are not as isolated from one another in the supply chain (Hecker and Gambatese 2003). This firm may be hired by the owner, or could also be personnel of the owner itself.

Collaborative – Collaborative projects involve contractors and builders early in the design process to give input on design features. It often involves partnerships between firms, and sharing of information that normally does not happen in the traditional construction supply chain because of the adversarial nature that is common in the industry (Akintoye, McIntosh et al. 2000; Baiden, Price et al. 2006). At the extreme end, collaborative projects can use alliance contracts in which partners on the project (owner, designer, constructor, etc.) share risks and rewards in a formal partnership contract with the goal of eliminating the adversarial relationships normally found on construction projects (Baldwin, Thorpe et al. 1999). These kinds of partnerships can help improve OSH if the goals of the firms are aligned, and each firm has an incentive in OSH on the project.

Accelerated – Accelerated projects involve shortening the normal construction timeline, and are sometimes referred to as “fast track” or “expedited” projects. A common technique for fast tracking a project includes overlapping the design and construction phases of the project in small work packages so that construction starts early in the design phase (Waltz and Montgomery 2003). One of the major disadvantages of this type of project has been found to be coordination between the designer and constructor (Fazio, Moselhi et al. 1988), which can have an impact on OSH if safety considerations are not properly communicated. Another mechanism to expedite the construction is the use of multiple shifts to accelerate construction. These type of project can have safety implications because the construction site changes between shifts and there is a handoff between personnel at shift changes (Jun and El Rayes 2010).

1.4 Systems Approach to Safety

The firms and roles in the construction supply chain all must work together to provide a safe working environment. Thus, safety must be a focus of upstream activities such as design just as it is on downstream activities such as construction. Safety however is many times thought of in the context of being a worker behavioral issue, as there is usually a large emphasis on construction sites on elements such as workers following safety procedures or wearing the appropriate personal protective equipment (PPE). The behavioral perspective is a key concept in safety, but the systems perspective of safety is also an important concept that should be a research focus. The systems perspective to safety involves analyzing how all of the complementary parts of the supply chain fit together and perform in regards to safety as a system (Lytle 1998). The main idea at the root of this concept is that hazards on the construction site are most effectively and economically avoided if they are anticipated and controlled as early in the construction lifecycle as possible (Manuele 2003). Thus, this perspective focuses on the overall system, the interdependencies between parts of the system, and the decisions and processes that lead to safety on the construction site instead of just the behavior of workers on the site during the construction phase.

One illustration of the systems approach to safety is the hierarchy of safety control. A depiction of the hierarchy is shown in Figure 1.2 (adapted from SafeWork South Australia 2007), and the main concept behind the hierarchy is that control methods are potentially more effective, protective, and cost-effective from top to bottom on the list (National Institute of Occupational Safety and Health 2010). The controls at the top of the pyramid are normally associated with design aspects earlier in the construction supply chain. Therefore using a systems safety approach has led to more emphasis and procedures for focusing on construction worker safety during the design and engineering stages of a project (Gambatese and Hinze 1999; Behm 2005; Gambatese, Behm et al. 2005).

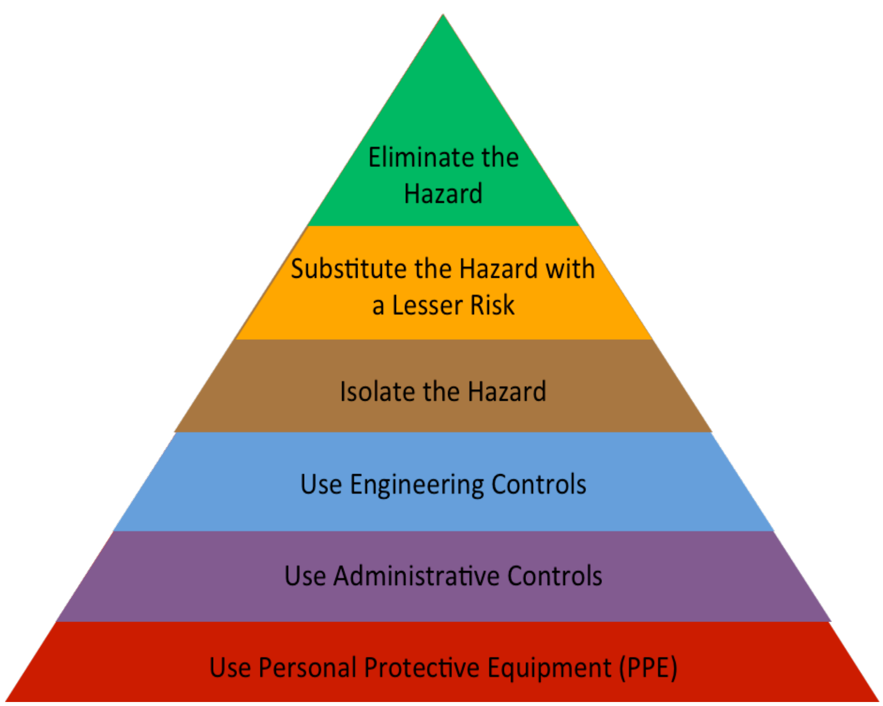


Figure 1-2 Hierarchy of Safety Controls (adapted from SA 2007)

Another perspective that illustrates the systems safety concept is Haddon's Matrix, which assesses factors involved in an accident before, during, and after an accident occurs. A representation of this tool is shown in Figure 1.3 (Runyan 2003; Barnett, Balicer et al. 2005).

	Host	Agent (Equipment)	Physical Environment	Social Environment
Pre-Event				
Event				
Post-Event				

Figure 1-3 Haddon's Matrix

This method is value-added because it not only addresses factors at the time of the accident, but also identifies contributing factors before the event occurred. This approach is similar to the hierarchy of control in that it advocates addressing the root causes that produced a risk before an accident occurs (Runyan 1998) instead of just focusing on the events of the accident itself.

This tool also focuses on the host person(s) involved in the accident, the agents involved during the accident, and the physical and social environmental factors that the accident occurred in during each phase. The Haddon's Matrix objective is for thought to be given within each cell to possible prevention opportunities that could prevent future accidents (Teret). This is another example of assessing safety as a system that is composed of distinctive subsystems that have an effect on safety at different times in the construction process. These subsystems align with the personnel, technical, and environmental sub-systems that are normally associated with socio-technical system literature. This area can also be used to gain a deeper understanding of how assessing construction safety as a system can lead to improved performance.

1.5 Socio-technical Systems (STS)

1.5.1 STS Theory Overview

The socio-technical systems (STS) model views organizations as transformative entities that turn inputs into outputs (Ropohl 1999). Socio-technical systems theory is based on the theory of joint optimization, which is the belief that the personnel and technological subsystems must be designed in concert given the demands of the external environment in order to design the most effective overall work system (Hendrick and Kleiner 2001). The work system in this instance is defined by Hendrick and Kleiner (2002) as “two or more persons interacting with some form of (1) job design, (2) hardware and/or software, (3) internal environment, (4) external environment, and (5) an organizational design.” Key variances within the work system must be controlled, and the range of variances controllable by a group is wider than the range that can be controlled by individuals separately within the group (Trist 1981). Key variances are defined as unwanted deviations from normal conditions that significantly affect production, cost, or social factors (Hendrick and Kleiner 2001). Safety is considered a social factor, and identifying and controlling key variances that affect OSH could be a mechanism to reduce fragmentation in the supply chain.

The parts of the work system defined above can be analyzed to determine how they impact the overall design of the work system. The construction supply chain as a whole can also be analyzed as a socio-technical system, as can each firm within the supply chain. The variances that arise from the analysis between members of the supply chain and personnel within each firm can be used to close gaps in both safety processes and attitudes that currently inhibit safety performance. The next section discusses one method to analyze and improve a socio-technical system, and more specifically to highlight how the role interactions within the construction work system can be analyzed to identify performance gaps.

1.5.2 Macroergonomics

The Macroergonomic Analysis and Design (MEAD) process is based on STS theory and is one mechanism to analyze the socio-technical subsystems of a work system, and determine their effects on the three organizational design dimensions of complexity, formalization, and centralization. These organizational design dimensions can be used to structure the work system and its related processes based on variances and gaps identified in the macroergonomic analysis, and are defined as follows (Hendrick and Kleiner 2001):

- Complexity – amount of differentiation and integrations that are present within a work system's structure
- Formalization – the amount of standardization present within a work system's jobs
- Centralization – level at which formal decision making is concentrated within the organization

Thus, if key variances that affect safety are identified then controls such as integrating mechanisms between roles and standard operating procedures can be developed to improve safety performance in the construction supply chain.

MEAD is a useful framework to explore because the data it collects is a comprehensive view of what information is needed in order to properly structure any work system. The method breaks the work system down into the technical, personnel, internal and external environments, and organizational and managerial structure (Kleiner 2006). This could easily be translated to the construction supply chain and its firms in order to determine if there are gaps in the current structure that could be closed in order to lead to better safety performance. An overview of the data collected as a result of the MEAD process is shown below in Figure 1.4 (adapted from Haro and Kleiner 2008).

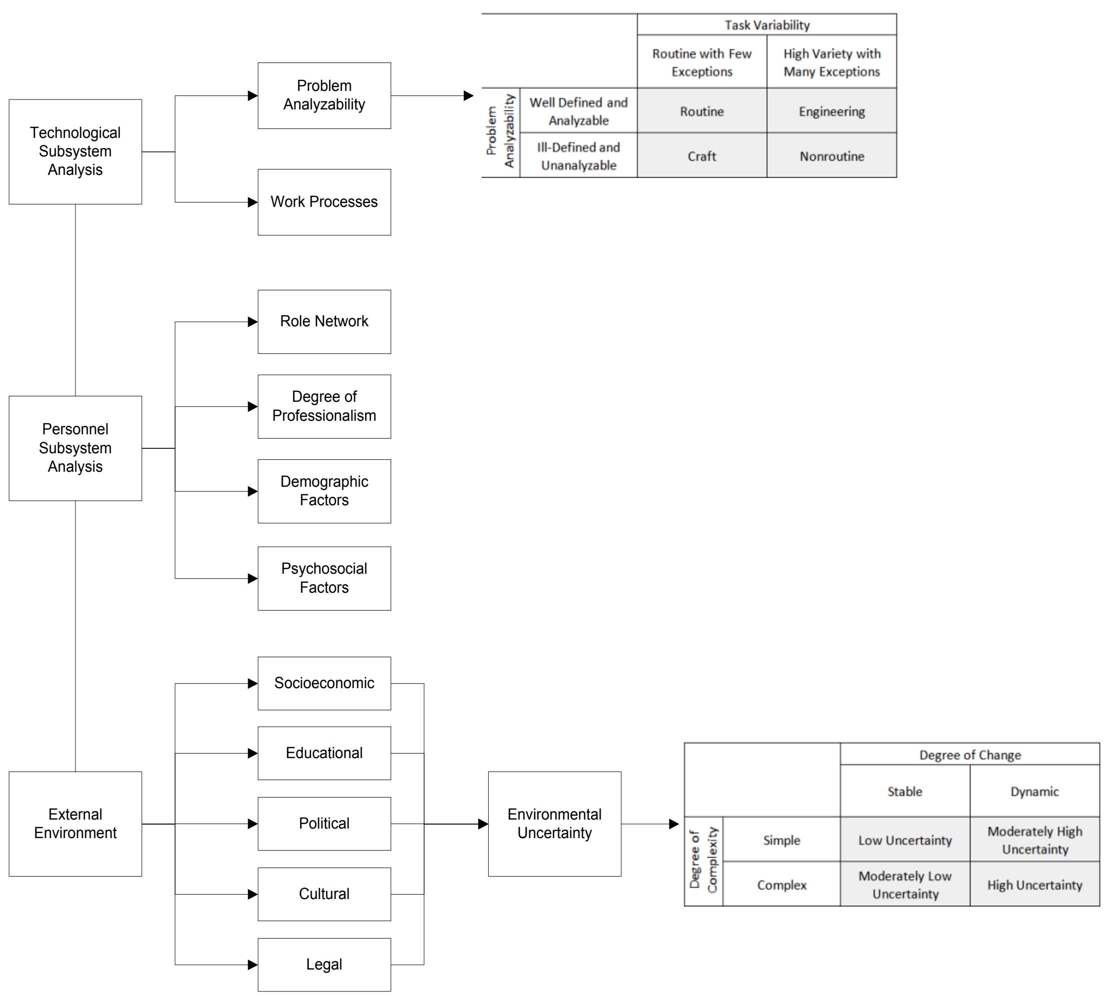


Figure 1-4 MEAD Data Collection Overview (adapted from Haro and Kleiner 2008)

The MEAD framework is representative of how a STS system analysis can be used to examine a work system from all angles, including construction and safety (Kleiner 1999). The personnel subsystem (and more specifically the role network of the construction supply chain) can offer some insights into why the supply chain is so fragmented. The numerous firms and types of personnel in the construction supply chain together form a complex role network that is characterized by a high degree of differentiation, and which often results in no unity of purpose in regard to OSH (Lawrence and Lorsch 1967; Godfrey and Lindgard 2007). Key roles in the supply chain, their interactions, and how they view safety must therefore be understood in order to fully understand all of the factors that contribute to OSH on construction projects. These role relationships can reveal gaps in the safety attitudes and interactions between the key firms and personnel in the construction supply chain that can then be addressed to improve safety performance. Understanding the location of these gaps would be a step in identifying where the variances in the work system occur, and generating prescriptions to address those key variances (Kleiner 2006).

1.6 Safety Culture and Climate

The concept of safety culture can be used to further understand why there are gaps in the construction supply chain role network in term of safety attitudes. Safety culture is defined as the underlying values, attitudes, and beliefs shared by an organization's employees as they relate to safety (Guldenmund 2000; Choudhry, Fang et al. 2007). The different firms in the construction supply chain each has its own safety culture that all come together to create an overall project safety culture and its related OSH outcomes. The hierarchy of safety control states that design decisions early in the construction supply chain have safety implications much later. The design for safety literature however says that one important issue that impacts the ability to implement the concept is the differing attitudes and motivations present in the process between designers and builders (Hecker and Gambatese 2003; Gambatese, Behm et al. 2005). The safety cultures therefore of these firms can diverge as they relate to the attitudes toward design for safety, and identifying mechanisms to close this gap could lead to OSH gains.

Safety climate is a concept that is routinely interchanged with safety culture. The key difference is that safety climate is the outcomes of an organization's safety culture at a particular point in time, and is displayed through outcomes such as safety documentation, rules, and attitudes of employees toward safety (Guldenmund 2000; Dingsdag, Biggs et al. 2008). This is an important distinction because these outcomes are measurable, and therefore safety climate has been used as a proxy to measure the strength of an organization's safety culture (Flin, Mearns et al. 2000). It can be thought of as measuring the "temperature" of a company's workers' actual attitudes toward safety at a given time (Gittleman, Gardner et al. 2010). Safety climate should measure a group or person's true priorities in regard to safety (Dov 2008), and could thus be useful in measuring the differences in attitudes between different firms and roles in the construction supply chain. The measurement of these attitudes could hopefully lead to knowledge as to where the gaps exist in safety attitudes between roles in the construction supply chain. This would be useful in developing educational programs aimed at creating better alignment between these roles, and the development of an improved overall safety culture for the entire construction supply chain.

More specifically, safety climate can be divided into discrete components to determine the strength of the different factors that influence safety attitudes. These factors could be very useful in determining the specific areas in which differences exist in the safety climate of different firms and roles in the construction supply chain. Flin, Mearns, et al. (2000) in a review of the safety climate literature found six emergent themes that were repeatedly found when trying to measure safety climate. These themes in order from most frequent were:

1. Management – The attitudes of a work force in relation to management's attitudes and behaviors in regard to safety
2. Safety Systems – A broad construct that describes an organization's safety management system (safety officers, committees, equipment, policies, etc.)
3. Risk – Attitudes of safety risk and hazards on the worksite and the related attitudes toward OSH risks
4. Work Pressure – Perception in regards to pressure placed by the organization on workload and productivity requirements
5. Competence – Perception of worker qualifications, skills, and knowledge on the technical skills required to safely perform the given set of tasks on a worksite
6. Procedures/Rules – Attitudes of the rules and procedures in place in regard to OSH and the related attitudes toward compliance or violation of these rules and procedures.

Mohamed (2002) used a similar set of constructs in his model describing the components of safety climate in the construction industry. The constructs in this model are similar to the ones above, but offer an even more specific set of factors that could be used to measure potential gaps in safety attitudes within the supply chain. This safety climate model consisted of the following constructs:

1. Management Commitment
2. Communication
3. Safety Rules and Procedures
4. Supportive Environment
5. Supervisory Environment
6. Worker's Involvement
7. Personal Risk Appreciation
8. Appraisal of Work Hazards
9. Work Pressure
10. Competence

As described previously, understanding differences in the role network of a work system can lead to insights that can be used to better structure the interactions and processes within that work system. In regards to construction OSH, understanding the differences in safety attitudes between the firms in the supply chain could be used to create a more uniform safety culture, as shared mental models are an important determinant of safety outcomes (Prussia, Brown et al. 2003). The differences in safety attitudes between specific roles in the supply chain such as architects, superintendents, and project managers could also be used to better structure the work system to improve the interactions in the role network of the construction supply chain. Safety climate is a means to determine where the differences in safety attitudes are located in the construction project work system.

Using safety climate as a tool to understand OSH attitude differences would also strengthen the work on a current NIOSH grant that the researcher is a member of. This project is cooperative agreement U60 OH009761, and the primary goal of the project is to research decision-making in the construction supply chain from planning through completion of a project and how it affects OSH. Specific Aim 2 of this project entails using a photograph sorting technique to identify perception differences between roles in the construction supply chain. The research in this dissertation will strengthen and complement the findings of the project's research by studying these perception differences using a different data collection tool that can be compared to the project's results.

1.7 Problem Statement

Identify if there are gaps in safety attitudes among the key safety roles in the construction supply chain, and whether there are differences in these gaps based on the type of supply chain a role operates within.

1.8 Research Purpose

The purpose of this research is to identify if safety attitudes differ between the key safety roles in the construction supply chain and whether these attitudes changes based on whether a role operates within a design-bid-build or design-build supply chain. Understanding safety climate differences between key safety roles and supply chain types can lead to improved OSH performance by using this understanding to foster more shared attitudes in regard to safety.

1.9 Research Hypotheses and Objectives

The research hypotheses and objectives for this study are:

Hypothesis 1: There will be a statistically significant difference in safety attitudes between key safety roles in the construction supply chain in one or more of the safety climate constructs in the Mohammed (2002) model.

The objective of this hypothesis is to determine the specific elements of safety in which safety perception differences occur between common roles in the construction supply chain. This data will be useful in determining the congruence level of safety attitudes within the role network of the construction project work system.

Hypothesis 2: The difference in safety attitudes between roles in the construction supply chain statistically differ depending on whether a key safety role operates in a Design-Build or Design-Bid-Build project delivery system supply chain.

This hypothesis will determine whether safety attitudes differ for a given key safety role based on the project delivery method. Design-Build supply chains typically involve fewer organizations than Design-Bid-Build, as the designer and constructor is generally the same firm. The analysis based on this hypothesis will help in testing whether more uniform safety attitudes are present when fewer firms are present in the supply chain.

Hypothesis 3: There is a difference in safety attitudes based on the organizational home of a key safety role (owner, designer, constructor, and sub-contractor) in one or more of the safety climate constructs in the Mohammed (2002) model.

The roles in the construction supply chain combine to form safety cultures at a higher level that can be described as the organizational home. Identifying the key differences in safety attitudes at this level could also be an important factor in creating a more uniform safety culture within the construction project work system.

Hypothesis 4: Demographic data such as the respondent's age, experience level, education level, safety training, typical project size, and typical project sector has an effect on safety attitudes overall and for each key safety role.

The demographic data will allow analysis of which of these factors are most important in creating a more positive safety climate. The effects of demographic factors on safety attitudes could also be useful in understanding how these attitudes are formed, such as how effective training or other factors are in creating positive safety attitudes.

Hypothesis 5: Educating roles on safety perception differences in the construction supply chain will have a positive effect on safety climate within the supply chain.

The analysis of the first four hypotheses will be used to develop an Attitude Congruence Training (ACT) mechanism to educate project personnel on safety perception differences between their role and others on a construction project and how they can improve their performance in regards to OSH. This tool will therefore be the mechanism that transforms the data obtained from earlier stages of the research into a practical tool that can be used by project personnel to create a more uniform safety culture in the construction supply chain. In addition, users will be asked to give feedback on the best platforms for communicating this type of information, so that later iterations of the training can be performed in a manner that increases the impact on participants.

1.10 Research Overview

As an overview, the following steps will be completed over the course of the research:

1. Develop a tool to identify gaps in safety attitudes among the key safety roles in the construction supply chain

2. Analyze these differences to develop a better understanding of the sources of fragmentation in the construction supply chain in regard to OSH
3. Develop a mechanism to educate roles in the construction work system based on the results

2 Chapter 2 - Literature Review

2.1 Safety Climate Definition

Organizational climate is defined as the workforce's attitudes of the atmosphere within an organization (González-Romá, Peiro et al. 1999). Building on this concept in regards to safety attitudes, Flin, Mearns, et al. (2000) define an organization's safety climate as "a snapshot of the state of safety providing an indicator of the underlying safety culture of a work group, plant, or organization". Safety climate is therefore the attitudes of employees in regard to the importance of safety in their organizational culture (Zohar 1980; Gittleman, Gardner et al. 2010), which makes its measurement a "useful diagnostic tool and method for measuring the safety culture" (Lingard, Cooke et al. 2009). Furthermore, as perceived safety climate improves the shared mental model of who is responsible for safety has been shown to converge (Prussia, Brown et al. 2003). Surveys tools are a method for the measurement of safety climate, as they are a good instrument to summarize an individual's attitudes regarding safety climate (Flin, Mearns et al. 2000; Guldenmund 2000). The following chapter will discuss the safety climate literature, and performance in assessing differences in safety attitudes between individuals and groups. It will also highlight the common constructs included in Mohammed's safety climate model for the construction industry, how each affects safety in the construction supply chain, and how attitudes within each are developed.

2.2 Safety Climate Constructs

2.2.1 Literature Reviews Prior to 2000

There have been several papers that have reviewed the safety climate literature to determine the most common constructs included in safety climate instruments. Table 2.1

details the common constructs that were found for several of these studies that reviewed the safety climate literature prior to 2000.

Table 2-1 Literature reviews of safety climate constructs

Study	Number of Instruments Reviewed	Common Constructs
Dedobbeleer and Béland (1998)	10	1. Management Commitment – measured by practices, safety management system, foreman impact, instructions, and equipment 2. Worker Involvement – measured by meetings, control, risk perception, and injuries
Flin, Mearns et al. (2000)	18	1. Management/ Supervision – attitudes of management attitudes and behaviors in relation to safety as well as to production and other issues such as selection, discipline, and planning 2. Safety System – construct that encompasses multiple aspects of an organization's safety management system such as safety officers, committees, policies, and equipment 3. Risk – includes self-reported risk taking, risk and hazard attitudes, and risk and safety attitudes 4. Work Pressure – factors that relate to work pace and workload that form the balance in the organization between pressure placed on production versus safety 5. Competence – attitudes of the level of workers' qualifications, skills, and knowledge in relation to safety issues and is generally tied to selection, training, and knowledge standards 6. Procedures/Rules – attitudes of the adequacy of safety rules and procedures within the organization and the attitude toward compliance or violation
Guldenmund (2000)	15	1. Management 2. Risk 3. Safety Arrangements 4. Procedures 5. Training 6. Work Pressure

Williamson, Feyer et al. (1997)	7	1. Safety Awareness – attitudes toward hazards, risks, and the possibility of injury in the workplace 2. Safety Responsibility – perception about whose role it is to ensure safety at the workplace 3. Safety Priority – attitudes about the importance placed on safety in the workplace 4. Management Commitment – attitudes regarding management commitment to safety related issues 5. Safety Control – attitudes toward how controllable accidents are in the workplace 6. Safety Motivation – attitudes related to the influences motivating safe or unsafe behavior in the workplace 7. Safety Activity – an individual's attitudes regarding their own safe work behavior 8. Safety Evaluation – an individual's attitudes regarding the safety of the own workplace

2.2.2 Group Differences in Safety Climate

Safety climate is generally not considered an individual predictor of safety attitudes, but does describe group level attitudes (Glick 1985; Pousette, Larsson et al. 2008). Zohar (2005) developed a multi-level model to describe how inter-group differences in safety climate can develop within one organizational climate. Several studies have thus used safety climate instruments to find significant differences in safety climate constructs between sub-groups within an organization and between organizations within an industry (Cox and Cheyne 2000; Lee and Harrison 2000; McDonald, Corrigan et al. 2000). These types of studies have also been used to determine why some groups within an industry such as road construction perform better on OHS as compared to others, and hypothesize that creating a positive macro group-level safety climate could benefit overall safety performance within the industry (Lingard, Cooke et al. 2009). Safety climate measurement tools have also been used to propose strategies to bridge gaps in safety culture based on inter-group differences in safety attitudes that were found using a safety climate measurement tool (Mason and Simpson 1995; Budworth 1997). Overall, there is sufficient literature to suggest that a safety climate survey instrument is a valid tool for measuring inter-group differences at a variety of levels.

2.2.3 Construction Industry Safety Climate Constructs

More recently, several studies have used safety climate instruments specifically within the construction to determine the constructs that most heavily influence safety attitudes and the differences in attitudes within sub-groups of personnel. The majority of safety climate survey instruments in the construction industry have targeted construction workers, safety managers, and upper management (Mohamed 2002) separately, and try to collect data at different organizations to analyze the safety climate of that specific role at the industry level (Gillen, Baltz et al. 2002; Siu, Phillips et al. 2004; Abudayyeh, Fredericks et al. 2006). This type of research illustrates that with an appropriate experimental design a safety climate survey instrument can be an appropriate tool to analyze groups of employees grouped by their role on a construction project at the industry level.

Safety climate questionnaires have also been used in construction to explore differences in attitudes between sub-groups of personnel. Glendon and Litherland (2001) used a modified version of a common safety climate questionnaire (Glendon, Stanton et al. 1994) and factor analysis to determine the six constructs that were most influential in shaping safety attitudes and to evaluate inter-group differences between construction and maintenance workers of a road construction organization. The six constructs that emerged from the study were:

1. Communication and Support
2. Adequacy of Procedures
3. Work Pressure
4. Personal Protective Equipment (PPE)
5. Relationships
6. Safety Rules

Another study conducted in the Hong Kong construction industry by Fang, Chen et al. (2006) combined existing safety climate questionnaires developed by Health and Safety Executive (HSE) of the United Kingdom and another by the government of Hong Kong into one 87 question tool. The researchers then conducted a factor analysis to also determine which constructs most heavily influenced safety attitudes of on-site construction employees within a large construction organization and its sub-contractors. The resulting 10 factors were the result:

1. Safety attitude and management commitment
2. Safety consultation and safety training
3. Supervisor's role and workmate's role
4. Risk taking behavior
5. Safety resources
6. Appraisal of safety procedure and work risk
7. Improper safety procedure
8. Worker's involvement
9. Workmate's influence
10. Competence

Mohamed's (2002) safety climate instrument uses a model developed by an extensive literature review, and whose constructs together broadly describe the safety climate of construction workers in a construction organization. The constructs used in this model also had a strong similarity to the factors identified by Fang, Chen et al. through statistical factor analysis (Fang, Chen et al. 2006). This study uses a survey with seven statements within each construct on a 5-point Likert scale as an indicator to measure the strength of that construct. The survey was also not within just one organization, and was administered to workers within 10 organizations at 6 different sites. The resulting constructs are shown in Figure 2.1 (Mohamed 2002), and are a good overview of the components of safety that could differ in attitudes between roles throughout the construction supply chain. Each of these constructs also has a body of literature supporting it that can be used to understand how OSH attitudes in construction are formed from a comprehensive viewpoint.

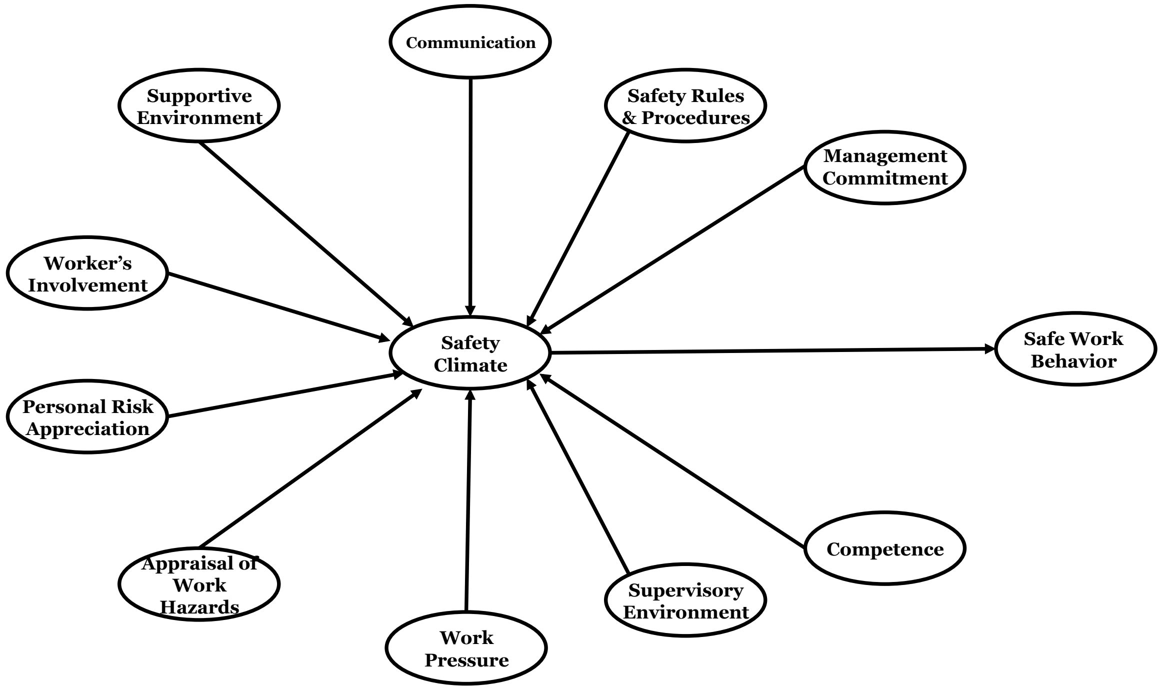


Figure 2-1 Construction Safety Climate Model (Mohammed 2002)

Mohammed (2002) uses three measurement properties from Fornell and Larcker (1981) to assess the reliability and validity of the items and constructs in the measurement model. The three properties and results for Mohammed's safety climate survey (2002) are as follows:

1. Individual Item Reliability – Simple correlations (loadings) of each item in the survey on their respective constructs are calculated using 0.70 as a cutoff point (Fornell and Larcker 1981). All ten constructs exhibited values for this value of greater than 0.70, which implies that less than half of the item's variance is due to error and thus acceptable levels of individual item reliability.
2. Convergent validity – Cronbach's alpha was calculated for each of the ten constructs in the model, and all were at least at the minimum acceptable value of

0.70 (Litwin 1995). This indicates that the items within each construct seem to measure a single construct, and thus show suitable levels of internal consistency.

3. Discriminant Validity – This is defined as the degree to which each of the ten constructs diverges from the other constructs in the model. The analysis used the *average variance extracted* (A_v) employed by Fornell and Larcker (1981) as the evaluation tool for this property. This value for a construct should be greater than the variance between the construct and other constructs in the model, and the analysis shows this to be the case for this measurement tool.

This analysis supports that the questionnaire used in this safety climate model shows satisfactory levels of reliability and validity. The purpose of the research outlined in Chapter 1 was to create a comprehensive safety climate instrument that could measure attitude differences between roles throughout the work system using the ten constructs listed in the model as a base. Mohammed's (2002) instrument was only applied on construction workers, and thus will have to be generalized for application on personnel throughout the construction supply chain. The analysis above does show however that the items included in the survey for each construct are a good foundation for a study within the construction industry if the survey is generalized properly.

Mohammed's (2002) safety climate model for the construction industry will be the base for the model discussed in this research. It shows strong similarity to Fang, Chen, et al. (2006), Glendon and Litherland (2001), as well as those presented in Table 2-1, and showed strong validity and reliability when used on an industry sample (Mohammed 2002). The focus of the research is to also determine differences between roles, and thus a model with a more specific set of latent variables offers more opportunity to identify more defined differences between roles.

2.3 Management Commitment

Numerous studies have found that management's commitment to a safety is the most important factor affecting the success of an organization's OSH program (Zohar 1980; Jeselskis, Anderson et al. 1996; Flin, Mearns et al. 2000), and that workers also view management positions as the most safety critical (Dingsdag, Biggs et al. 2008). Other work has shown that construction site safety initiatives that had more management support and commitment were more effectively implemented than ones with less management engagement (Duff, Robertson et al. 1994; Lingard and Rowlinson 1998). In addition, the inspection and enforcement of safety regulations by management has been shown to increase the perception of workers that safety is a high priority and increase the value of safety in the organization (Dingsdag, Biggs et al. 2008).

Management commitment to safety programs has been found to have the largest positive correlation to the success of the programs among the factors of management commitment, facilitator/observer quality, and goal-setting quality by management for safety performance (Marsh, Davies et al. 1998). Furthermore, the same study found that management commitment was actually an underlying factor that was positively correlated with the other two constructs. The study also discussed that the most important initiative that management can be committed to in order to improve the success of safety programs is increased communication in regards to OSH. This communication allowed management to learn what factors workers perceived to be the most important blockages to increased safety performance. Taking action on removing these blockages on a consistent basis has also been shown as a factor on the level of commitment that workers perceive (Hinze 1996; Gittleman, Gardner et al. 2010). Taking action shows that management is committed to improving OSH, and workers are more willing to support OSH programs when they perceive that management listens to their concerns and is genuinely concerned about their personal safety (Langford, Rowlinson et al. 1993).

Other studies have discussed mechanisms for organizations to improve the commitment level of management. The source of the commitment is not important and does not affect the results on safety climate among workers, as workers perceive the increased levels of management commitment regardless of why the commitment is present (Marsh, Davies et al. 1998). One such study of a UK construction project (Cameron and Duff 2007) studied the effects of goal setting and performance measurement for the management team of a construction project. It used outcomes in the following seven items to measure safety performance: induction training, toolbox talk training, safety committees, subcontractor safety meetings, maintenance of safety records, safety manager actions, and safety consideration (interaction, communication and worker engagement). The goal setting process for the management team consisted of participative team goal setting, self-reporting of results, and development of action plans. Using a pre-test/post-test experimental design, the study found that performance increased from 49% to 83% on the rating scale. This increase is attributed to the increased level of commitment that the managerial goal setting brought to the project.

As mentioned before, safety climate is a measurement of the attitudes of workers regarding safety that can be thought of as the surface features of an organization's safety culture. In relation to commitment, there are multiple factors that affect the attitudes of a workforce. These include “management practices, financial commitment, program design, implementation, and maintenance of the company OSH program” (Gilkey, Keefe et al. 2003). According to the U.S. Occupational Safety and Health Administration, evidence of management commitment to safety and health that workers can perceive are (Occupational Safety & Health Administration 1993):

1. A policy statement document in which the company’s OSH goals are established and communicated to all employees
2. Regular maintenance of the OSH program
3. Safety meetings, safety inspections, and safety agenda items in meetings
4. Commitment of financial resources
5. Safety rules and procedures
6. Observation of safety rules by management

Overall, managers are faced with multiple demands on their time and pressure to keep the project on schedule, but showing a time commitment to safety is imperative to showing the importance of OSH down the line to employees (Flin 2003; Gillen 2004).

2.4 Communication

Communication between parties involved on a construction project is a critical component of OSH performance. Data has shown that effective safety communication within an organization has led to an increase in perceived organizational support of OSH (Chyene, Cox et al. 1998; Hofmann and Morgeson 1999). Communication is top-down and bottom-up, as attitudes of communication are based on both management to employee communication and employee to management feedback (Mohamed 2002). Effective communication mechanisms increase the visibility of safety in the organization, and are an essential factor in distinguishing high performing OSH programs from low performing ones (Lingard, Cooke et al. 2009).

The general organizational climate in regards to open communication is important, as if employees perceive open communication as important within the organization then they will perceive safety communication as valued when it occurs (Neal, Griffin et al. 2000). Workers with a foreman or supervisor that never mentions safety will perceive that safety is unimportant, and consequently will be more likely to not place a strong emphasis on safety (Hofmann and Stetzer 1996). Written communication on safety related matters, written safety policies and procedures, discussing safety in the field, safety meetings, and site visits by management in which safety is discussed are all mechanisms by which safety communication can occur (Hinze 1996).

In assessing communication from the top down, effective communication by management in regards to safety programs shows a commitment to safety, and has been found to be the most important factor on improving attitudes on the importance of safety among workers (Sawacha, Naoum et al. 1999). One factor that has been found to increase the perception of workers in relation to safety communication from management is avoiding the assignment of blame when discussing issues, as this helps to foster an "us against them" mentality in the workforce. The same study also found that workers perceived better communication when management was able to adapt their communication style depending on the situation (Dingsdag, Biggs et al. 2010). Furthermore, other work has found that the attitudes of upper level management by the workforce in regards to safety commitment are strongly influenced by how they are portrayed by supervisors of the workforce (Meglino, Ravlin et al. 1989; Clarke 1999).

This highlights how communication from management to employees must be consistent through all levels in order to have the largest impact on safety attitudes, as supervisors and foreman are “the filter or lens through which management messages and attitudes are transmitted to the workforce and views and feedback from the shop-floor passed back up to line management” (Ward, Brazier et al. 2003).

Safety goal setting and performance feedback from management is another important communication tool. Studies have shown a significant increase in safety performance on sites that set goals for a safety metric and give employees feedback verbally and graphically on the group’s performance relative to goals (Cooper, Phillips et al. 1994; Austin, Kessler et al. 1996; Laitinen and Ruohomäki 1996). All of these studies observed and recorded safe work behaviors from a pre-existing list, and set a baseline measure for the percentage of observations that included safe work behavior. Goals were then set for the measure, and feedback was given through the use of charts showing progress toward the goal and verbally during meetings. All of the studies found an increase in the measured safe work behaviors after the feedback mechanisms were implemented.
From the bottom up safety communication is also important, as an improvement in safe work behavior has been found in workers that perceive that management listens to and takes into account their ideas in the decision-making process (Hinze 1981). One such mechanism for providing such an opportunity are “tailgate talks” in which safety issues are discussed in an informal setting that promotes two-way dialog. This is usually as part of a morning site safety cycle that can also include activities such as stretching and safety plans. Toolbox talks are an opportunity for supervisors or foremen to talk about lessons-learned from injuries and near-misses and various safety topics daily with workers, and

give workers an opportunity to discuss these topics with management (Choudhry and Fang 2008).

Communication in the supply chain is not just a construction management and worker issue. Communication on safety expectations from owner to contractor has been shown to improve safety performance. Techniques like discussing safety issues and performance at the beginning of each meeting will increase the contractor's commitment to safety (Huang 2003). Another interaction in which communication has been shown to increase worker safety is between the designer and the constructor (Hinze and Wiegand 1992; Weinstein, Gambatese et al. 2005). This interaction can help designers understand design principles that can increase worker safety, and increase the perception of the importance of OSH within the design firm (Leather 1987; Weinstein, Gambatese et al. 2005). Designers are a group within the construction supply chain that traditionally are not as heavily involved in the United States in safety decisions, but for which more knowledge and commitment of how their work affects OSH can lead to safer worksites (Gambatese, Behm et al. 2005).

Hispanic workers are an increasingly significant component of the construction industry. As of 2005, 21.9% of the construction workforce in the United States was foreign-born (2^{nd} most behind agriculture), and of these foreign born workers 84% were of Hispanic descent (Center for Construction Research and Training 2007). In addition, Hispanic workers in the construction industry have a higher percentage of fatal and non-fatal injuries compared to non-Hispanic workers. The data also reveals that the gap between both fatal and non-fatal injuries for both Hispanic and non-Hispanic workers have decreased over time from 1992-2005, but that an apparent gap still remains (Center for Construction Research and Training 2007).

These results underly the importance of effectively educating and communicating OSH topics to workers of Hispanic descent. It is important that the training and education is both linguistically and culturally apprpropriate for these workers in order to effectively commuicate safety information (National Research Council 2003). In order to achieve this goal, guidelines have been established to aid in the develoment of educational materials for Hispanic workers. One example of such guidelines are as follows, and can help in increasing the perception of safety among Hispanic workers in the construction industry through improved communication of safety issues (Brunette 2004):

1. Design materials that are linguistically and culturally appropriate
2. Use a language that is familiar to the workers
3. Avoid straight translation from English materials
4. Use a native-speaking Spanish translator who has in-depth knowledge of the topic
5. Keep materials at a limited literacy level (medium-to-low literacy level)
6. Use plenty of clear and realistic illustrations, graphics, or photographs
7. Use generic, "standard" Spanish, to provide equivalent Spanish versions of a given word or term, when appropriate
8. Conduct pilot tests with a subset of Hispanic workers
9. Have Hispanic trainers who are native speakers and provide the Spanish language training
10. Include basic education on OSHA laws and workers' rights to safe and healthy conditions of workers in the training program

11. Deliver educational and training program in a learner-centered environment
12. Provide an educational and training program that is culturally sensitive and is accompanied by an employer's true commitment to safety
13. Establish a continuous evaluation process

2.5 Safety Rules and Procedures

In construction, effective safety management programs have been shown to reduce accidents, and thus substantially reduce the large direct and indirect costs that result from these accidents (Levitt and Samelson 1993). Rules and procedures regarding safety onsite are a core piece of any safety management system, and from a safety climate perspective workers need to perceive they are held accountable to following them (Mohamed 2002). Most accidents that occur already have a rule or procedure in place that could have prevented the accident, thus improving construction safety is more related to effectively implementing a set of rules and procedures rather than writing new ones (Laurence 2005). While implementing rules and procedures as part of a safety system is an essential part of management showing a commitment to OHS, the accountability to following these rules needs to fall on supervisors to be the most effective. This means decentralization in terms of rule enforcement and decision-making that affects the safety of members of their workgroup (Simard and Marchand 1997). Care must be taken however that the implementation of rules and procedures is not done in an inconsistent manner that leads workers to develop a negative attitude toward them, or the organization risks a decrease in adherence to the rules and procedures and the associated risky behaviors that can follow such actions (Lingard 2002).

One study in the Australian mining industry (Laurence 2005) collected data from management and miners to determine how safety rules and procedures should be developed in order to be more effective. The results of the research were the following:

1. Management and regulatory authorities should not continue to develop more rules and procedures to cover every aspect of the job, as workers can neither neither keep up with nor comprehend such a large level of detail. In addition, workers should be involved in the process of developing safety rules and procedures in order to improve safety commitment and develop a more positive safety culture within the organization.
2. The goal of rules and procedures should be to "operate with a framework of fewer rules but of the highest quality." This is because detailed prescriptive regulations, work rules and procedures, and large safety site management plans will not connect with the average worker.
3. More emphasis should be placed on the process of working safe while using rules and procedures instead of just focusing on the content of the regulations themselves.
4. Communication channels between management and workers in regards to rules and procedures need to be open and effective in order to ensure a positive safety culture.
5. The main causal factors of accidents and incidents, risk-taking, and safety errors on-site were found to be problems of implementation, communication, and learning of safety rules and procedures instead of the content of the actual rules themselves.

Another study of rules and procedures specifically within the Australian construction industry (Dingsdag, Biggs et al. 2008) supports the finding of Australian mining one above. It found that understanding the purpose of OHS rules and regulations was more commonly mentioned as important to a safety culture than following rules and regulations. It also found that workers found more value in training and education that focused on understanding the reason for certain OHS activities and skills-based education instead of content based training.

One commonly used technique for documenting safety rules using a process-based format is developing standard operating procedures (SOP's). SOP's are documents that can walk the worker through the necessary steps to complete a task, and many times include a checklist for workers to complete (Reese and Eidson 2006). These documents should also be easily accessible for workers in locations such as on a piece of equipment and in an electronic database that is kept current, and include information such as the steps in the sequence of the activity, instructions for completing each step safely, and key points of emphasis (Reese and Eidson 2006). Well written SOP's are a communication tool for safety information, can reduce training time of new employees during the hiring process and existing employees on new or updated work activities, and reduce variation in work processes by improving the consistency of employee jobs (Stup 2001). In addition to the above benefits, SOP's are useful for auditing work procedures to ensure regulatory compliance, maintaining a safety management quality system, and as a mechanism for increasing the visibility of safety information within an organization (Environmental Protection Agency 2007).

2.6 Supportive Environment

This dimension refers to the general morale of the work force in regard to safety, and the trust, support, and confidence in relationships within a work group (Mohamed 2002). Goldberg's (1991) study in manufacturing found that a supportive environment led workers to take a more active role in safety instead of acceptance of existing situations that might be unsafe. The study found that an organizational climate in which the workforce agrees on the importance of safety (and thus a feeling of support within work groups) leads individual workers to take on a more activist behavior in participating in OSH activities. The authors also note that activities such as training that can help reduce pessimism toward safety and lead to an increase in co-worker support can be a mechanism to lead workers to be more involved in efforts aimed at increasing the level of safety at work sites.

The basis for a supportive environment influencing safety climate is that workers interact on a daily basis and rely on their co-workers daily to provide a safe work environment. Thus, workers with more positive relationships with co-workers, supervisors, and management in turn promote a more positive safety climate (Rowlinson 2004). Further underlying the importance of working environment as important to safety attitudes, other work has shown that "respondents perceived that shared responsibilities and harmonious working relationships as a pre-requisite for a safe workplace environment" (Mohamed, Ali et al. 2009). The critical factor why a supportive environment among workers is key is that while individual accountability for safety is important, workers must also be confident that their fellow workers are also responsible and supportive of OSH (Teo 2006).

2.7 Supervisory Environment

Management commitment has been shown to be a key factor in worker safety, but the effective implementation of the safety program on the actual worksite on a daily basis falls on frontline supervisors (Agrilla 1999; Mohamed 2003). Supervisors are in a unique position, as they are the group that carries out the safety program developed by management on a daily basis with frontline workers. They are a critical bridge between management and workers, and must ensure that management remains engaged and informed and worker needs are met in regards to safety (Agrilla 1999). Organizations need to ensure supervisors receive the necessary OSH training as part of an overall worker education program so that they have the skills sets required to properly communicate and administer a safety management program (Ringen 1996; Sawacha, Naoum et al. 1999). Workers also look to their supervisors as an example, as safe work behavior by supervisors has been found to be an important factor on safe worker behavior by workers (Sawacha, Naoum et al. 1999; Gillen, Baltz et al. 2002). For example, in a study in the use of trench boxes it was found that 74% of respondents designated the foreman/supervisor as the competent trenching person required by OSHA and who has the most responsibility for safety (Hinze 2005).

Studies have also found a higher level of safe work behavior as supervisors become more relationship oriented with their employees (Langford, Rowlinson et al. 1993). The same study also detailed two key findings with regards to how the environment fostered by supervisors affects safety climate.

1. Supervisors can also influence the safety attitudes of employees by exhibiting a high level of positive safety behavior and attitudes, as it shows employees that safety is an important issue.
2. Supervisors that engage in frequent communication on safety can expect better safety performance by workers

Conversely, other work has shown that supervisors have the ability to undermine the importance placed on safety by management if they do not show support for safety programs with employees (Gillen 2004). In this regard, supervisors must not allow workers to take shortcuts to save time that increase safety risks, and also not overlook safety even when focusing on productivity and meeting schedule demands (Mitropoulos 2005). The focus on safety by supervisors during the “indoctrination period” for new employees also is crucial to the attitudes of new workers in regard to OSH (Goldenhar, Moran et al. 2001).

2.8 Worker Involvement

Workers being participants in the safety management process instead of just recipients of the outputs of the program is another important factor in the perception of safety within an organization (Williamson, Feyer et al. 1997). It is important that workers perceive that they are able to effectively and easily address safety issues that concern them, and be a contributor in the OSH decision-making process (Donald 1996; Milgate 2002). Benefits of employee involvement in OSH issues include:

1. Timely resolution of OSH issues when they occur on the frontline (Milgate 2002)

2. Compliance with regulatory requirements in some countries concerning health and safety participation by employees (specifically unions) (James and Walters 1994)
3. Increased worker knowledge and awareness of OSH matters (Milgate 2002)
4. Decreased resistance to the implementation of safety management programs due to involvement in the decision-making process (Adams, Hede et al.)
5. Increased two-way communication between management and workers, which is a tool management can use to collect ideas from those with the most intimate knowledge of workplace conditions and for employees to be involved in the safety management process by communicating their ideas (Worker's Compensation Board of Prince Edward Worker's Compensation Board of Prince Edward Island 2009)

Safety committees/teams that include representation from the workforce across functions have been used as one mechanism for increasing worker involvement in OSH (Donald 1996), and have been shown to be an important factor in safety performance (Sawacha, Naoum et al. 1999). Workers are on the worksite daily, and thus are usually more aware of hazards at the workplace. Safety committees consisting of managers, workers, and potentially subcontractors are a way to foster interaction between all of the relevant parties involved in a safety management system and foster buy-in from the parties (Lin 2001). The Australian government requires safety committees with employee representation in all territories except the Northern province (Milgate 2002), and has defined some of the primary responsibilities of these committees as follows:

1. Assist in the development, implementation, and review of OHS policies and procedures
2. Analyze and have relevant discussions on reports by OHS representatives
3. Facilitate a cooperative interaction and communication between management and employees regarding safety issues
4. Aid in the open distribution of OHS material and communications (Australian Workplace Relations Minister'sAustralian Workplace Relations Minister's Council 1999)

Another means to involve workers in safety management systems is the process and procedures used to report injuries, near-misses, and potential hazards (Mohamed 2002). Programs such as the Safety Training Observation Program (STOP) pioneered by the DuPont Corporation have been shown to increase safety performance. STOP is a program that teaches workplace safety by giving employees tools to recognize potential hazards, relies on employees auditing each other for safe and unsafe work practices, and teaches steps to reinforce safe work practices and rectify unsafe acts and working situations (Noria Corporation 2010). Observation cards are common tool used by organizations to engage employees in safety by observing work sites, and reporting safe or unsafe behavior that they witness. These cards can be used to find trends on potential safety hazards, and as a measure to determine participation in a safety management program (Boyce 2009). Newer generations of the STOP program have integrated more peer-to-peer techniques to increase worker communication about safety issues. The goal of the program is to engage the employee in participating in a company's safety management system by making safety second nature to the individual and an integrated element of organizational culture (DuPont DuPont Corporation 2010).

2.9 Personal Appreciation of Risk

Studies have been conducted to determine if risk perception should be included as a construct of safety climate (Dedobbeleer and Béland 1998). No direct evidence in Dedobbeleer and Beland's was found to conclude that risk perception is not linked to safety outcomes. A review of safety climate studies does show that multiple studies on safety climate have included it as a factor (Flin, Mearns et al. 2000), and that the dimension does influence attitudes on safety (Cox and Cox 1991).

Risk perception is an important component of a safe working environment, as how workers perceive the risks they are exposed to while carrying out their tasks can contribute to how they manage those risks. Risk perception can be defined as a subjective perception of the chance of an accident or injury occurring when a source of risk is encountered (Rundmo 2000). Risk perception has not been shown to be associated with risk behavior however, but the same predictor variables do affect both. Thus, the factors that cause variations in these two variables such as management and employee commitment to safety are the key to improving risk perception and as a result safe working behavior (Rundmo 1997). Furthermore, attitudes toward safety have been shown to be associated with risk perception, and a person's assessment of safety climate has been shown to be a predictor of rational risk-taking decisions (Rundmo 2000). The willingness to take risks varies by an individual, and improving the perception of risk within the organization can work to lower where the center of the distribution for risk-taking is located (March and Shapira 1992).

2.10 Appraisal of Physical Work Environment and Work Hazards

Prior to the construction phase, a job hazard analysis can significantly eliminate or reduce worker exposure. This analysis should be supplemented by training to help workers recognize hazards on the job site and how to safely control them (Hinze 1996). This construct however does not just encompass construction workers having the appropriate training to recognize potential work hazards on the job site. The process of controlling hazards at the work site begins with the planning and design process, and owners and designers must also be aware of potential hazards in order to control for them in the design. Mohamed (2002) defines this construct as integrating safety into planning the site layout and working environment by identifying safety hazards. Activities that are used for this purpose can include site selection, the construction design, traffic control, material lay-down areas, location and layout of job site offices, and enclosure of the construction site.

Safety in construction design is a growing concept in the construction safety field, and can have a significant effect on the hazards that are present on a construction site. One project found that 42% of fatalities in a study were linked to decisions made during the design phase (Behm 2005). Research collecting data from designers and contractors has detailed numerous examples of decisions made during the design phase of a project that positively impacted construction worker safety through site layout, access points for work, design changes, stairways, location of material, walkways, fall protection, guardrail height and locations, and utility locations (Hinze and Wiegand 1992; Gambatese, Behm et al. 2005; Weinstein, Gambatese et al. 2005). Implementing these design modifications and tools through education, training, and legislation can increase safety visibility throughout the entire supply chain of a project, and ultimately lead to safer working environments for construction workers (Hecker and Gambatese 2003).

The time/safety influence curve is shown in Figure 2.3, and illustrates the impact that design can have on safety compared to other supply chain phases (Szymberski 1997). Construction worker safety is primarily left to the constructor in the United States in order to avoid the liability that can be associated with dictating "means and methods" (Hecker and Gambatese 2003). Identification of hazards earlier in the supply chain however can have a greater impact, because the hazards can possibly be eliminated or controlled more effectively than using PPE and other methods that are usually utilized at the construction phase (Behm 2005). Significant safety improvements gained from focusing on safety earlier in the supply chain will not only increase the perception of safety in these stages, but also in the construction phase with the partnerships that these initiatives create (Hecker and Gambatese 2003).

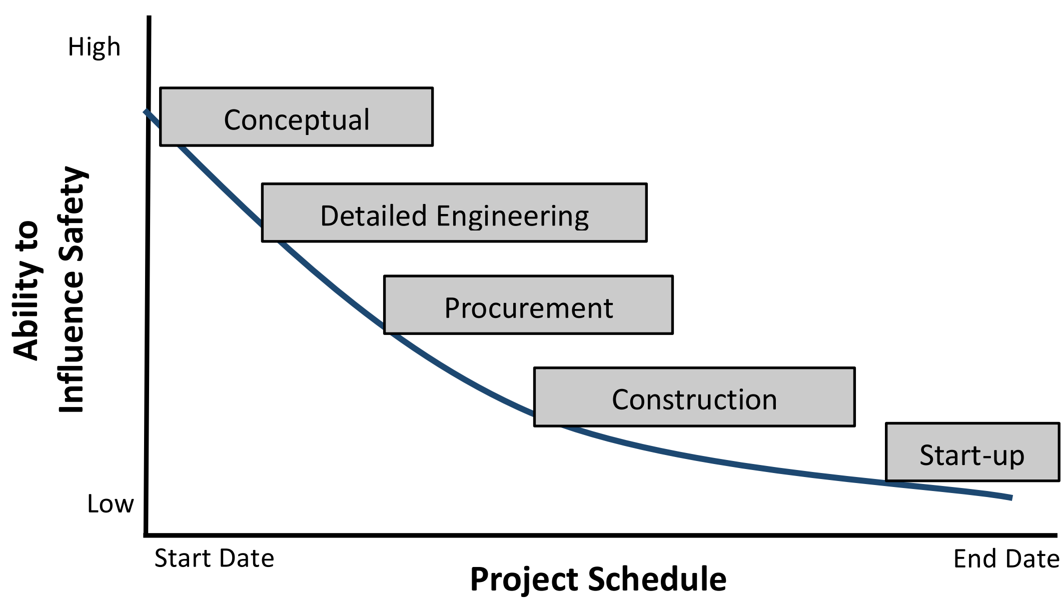


Figure 2-2 Time/Safety Influence Curve (Szymberski 1997)

Tools such as "Total-Safety" have been developed that allow designers to input a construction method, and then determine what the common hazards associated with that method and their probability of occurring. This allows designers to improve their knowledge of potential hazards, and eliminate or account for potential hazards in their design (Carter and Smith 2006). Figure 2.4 illustrates the differentiation of control of hazards through preventative methods such as design changes and precautionary methods such as the use of PPE when they are present. Preventative measures are designed to limit the probability of a hazard entering the triangle (and thus the potential for an accident occurring), while precautionary measures are aimed at limiting the severity of a hazard if an accident does occur (Carter and Smith 2006). This is another illustration of how hazard identification early in the supply chain can improve overall safety performance.

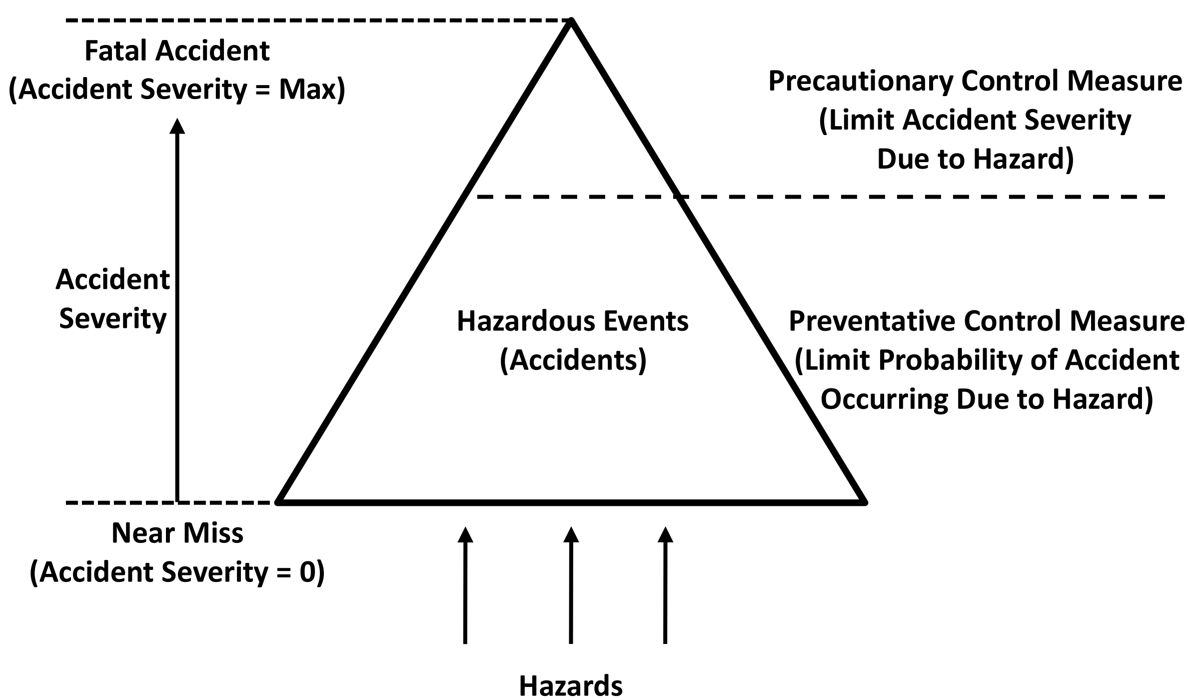


Figure 2-3 Hazardous Event Triangle and Control Methods (Carter and Smith 2006)

While hazards can be controlled effectively early in the design phase, there will still be hazards on the job site that workers must be trained to recognize and control before they occur (Hinze 1996). Tools such as a job hazard analysis are commonly used to teach workers to look for hazards before starting a new job or when working conditions change. They focus on the "relationship between the worker, the task, the tools, and the work environment." This tool is usually a form in which the worker must identify the steps involved in completing a job, potential hazards that might be present for each step, and the recommended action or procedure for controlling each hazard to a level of acceptable risk (Occupational Safety & Health Administration 2002).

2.11 Work Pressure

Balancing productivity versus safety is a large OSH issue on construction sites, and the pressure placed on productivity can have an effect on safety performance especially when resources and schedule are tight (Flin, Mearns et al. 2000). The work pressure placed on production has been shown to influence the level of unsafe acts by workers (Mearns, Whitaker et al. 2003). In addition to being a factor in unsafe acts, the conflict between production and safety has been shown to be a significant effect on the attitudes of workers, and is influenced by the pressure placed on it by management (Clarke 2006).

One area that has been shown to have a significant impact on safety attitudes is bonus systems that reward productivity and can thus encourage shortcuts and risk-taking (Peckitt, Glendon et al. 2004; Rowlinson 2004). One study found that productivity bonuses without accounting for safety performance have a significant adverse affect on safety performance by increasing risky behavior (Sawacha, Naoum et al. 1999). The most important economical factor that was found to have an impact on construction site safety were incentive bonus systems intended to increase productivity that also increased risk-taking by construction workers. For this reason, productivity bonus systems must be devised so that they do not entice supervisors, managers, and workers to overlook safety for the sake of productivity. These reward systems must compensate for reaching desired productivity levels while maintaining a safe working environment (Langford, Rowlinson et al. 1993). Conversely, safety incentive programs must not place too much pressure on having a low number of incidents that require first aid, near-misses, and accidents in order to not entice workers to under-report these incidents (Hinze and Godfrey 2003).

2.12 Competence

The competence construct is related to the perception of personnel as to the skills, knowledge, and qualifications of worker's in regard to OSH. This construct is connected to selection of workers and their training, which has also been mentioned as an important factor within previous constructs that were discussed (Sawacha, Naoum et al. 1999; Mohamed 2002). The hiring process of an organization must be effective in hiring competent employees, and then successfully training these new employees once they are hired. Training is one of the fundamental methods that organizations use to promote safety, and thus has an important impact of the perception of safety and reduction of skepticism in safety initiatives within the workforce (Goldberg, Dar-El et al. 1991; Gyekye 2005). Legislation in some countries has also made certain types of training mandatory, and certifications from organizations such as OSHA are tracked and used as an example of safety competence (Ringen 1995).

The impact of safety training on actual performance is important, as safety training has been shown to be significantly associated with safe work behavior and OSH outcomes

(Cooper and Phillips 2004). The results of this study found that of the safety climate constructs studied that the link between safety climate and safe work behavior was impacted most significantly by the perception of the importance of safety training. Training also has been mentioned as a key component in many of the other constructs discussed, such as management commitment, supervisory environment, communication (including Hispanics), and appraisal of work hazards. This specific construct thus is important to safety climate because it involves the perception as to how the selection and training processes affect the perception of safety skills, knowledge, and qualification of multiple constructs within an organization or work group (Flin, Mearns et al. 2000).

OSHA requires that when performing work such as excavation or working with respirators that a "qualified" and "competent" person must be assigned to the job. OSHA certification is not only a regulation, but is a tool to allow employees to perceive the level of training within the organization. OSHA has developed a set of guidelines and training model for organizations to use to aid in determining what employees need to be trained, in what areas the training is required, and what information should be included in the training (Occupational Safety and Health Administration 1996). The model is designed to ensure that organizations meet the training needs of their employees and communicate the importance of the training. The model is as follows:

1. *Determine if training is needed* – The first step in the training model is to determine if something can be solved through training, and to recognize the need for training before accidents occur. This step also involves identifying activities performed on a construction site that require training because of legislation.

2. *Identify Training Needs* - OSHA guidelines have a comprehensive list of activities that require training before a person can perform a task. Training needs do not just stop with required training, and OSHA recommends that organizations assess the specific needs and potential hazards of a job site and perform training to teach employees how to control these hazards. Other methods to determine training needs are to look at accident records to look for trends, gather input from employees, observing employees on the job site, and benchmarking.
3. *Identify Goals and Objectives* – Effective training involves determining the goals and the desired results of the training before it begins. This should include employers identifying what they want their employees to do better, how employees will demonstrate what they have learned, and that they have reached the desired level of competence.
4. *Develop Learning Activities* – Learning activities are the mechanisms that are used within the training for employees to demonstrate that they have met the learning objectives, and should meet actual conditions as closely as possible.
5. *Conduct the Training* – Training is most effective when the goals and relevance are clear to participants. Relating the training to actual conditions and how the training will benefit the employees can do this. The organization of the training should also be made clear to employees beforehand, and the main points emphasized on multiple occasions throughout.
6. *Evaluate Program Effectiveness* – This step is to ensure that the training is meeting its goals in the actual workplace. Student opinions, supervisor

observations, and workplace improvements as a result of the training should be gathered and analyzed.

7. *Improve the Program* – The data gathered in the previous step should be used to determine if the training is meeting its goals. This should be a continuous improvement process that allows the training to be improved to better prepare employees for job site safety.

2.13 Literature Review Conclusion

This chapter has given an overview of safety climate as a tool to measure differences in safety attitudes between groups. More specifically, a model for describing safety climate in construction environments was presented that breaks down safety into the components that influence safety attitudes (Mohamed 2002). These components can be measured, and understanding where significant differences in the model exist between roles within the construction supply chain can give insights into where to focus improvement efforts at reducing fragmentation in the supply chain. This model has been verified by comparison with other safety climate instruments, and seems to have similar constructs to those both intended for inside and outside the construction industry. It also offers the most defined set of constructs of the ones developed for the construction industry, which is ideal for identifying specific differences in attitudes between subgroups (roles). Understanding how each construct in the model affects safety attitudes is also a base for developing improvement options once differences are identified.

3 Chapter 3 - Research Methodology

3.1 Introduction

One of the key goals of this research is to quantitatively measure the components of safety that together form the attitudes toward OSH of key roles throughout the construction project work system. The researcher has been on numerous construction sites as part of a NIOSH funded research project, and differences in safety attitudes are apparent qualitatively from just interviewing personnel on a construction project. They must however be measured quantitatively in order to more specifically determine the strength and location of these differences. For example, it could help bridge OSH perception gaps between designers and constructor project managers if it could be shown that the most statistically significant difference in those roles' attitudes toward OSH was management commitment toward safety. This knowledge could be used to develop targeted training or other improvement mechanisms to bridge this gap, and hopefully create a more uniform safety culture in the construction supply chain.

Another hypothesis is that safety attitudes differ based on whether a role is operating within a design-bid-build or design-build supply chain. Measuring this quantitatively and more specifically what components of safety show the most significant differences would also be valuable in reducing fragmentation in the supply chain. Design-build supply chains involve design and construction within the same firm with constructor involvement typically very early in the design process, while design-bid-build projects involve different firms for these functions. Differentiation in the supply chain between groups has been shown to be a "marked barrier" to reducing accident rates (Richter and Koch 2004). Thus, if design-build supply chains show more uniform safety attitudes between roles then it could suggest that creation of more familiarity in the supply chain could lead to a more shared safety culture.

The hypotheses for the proposed research are listed below, and the rest of the chapter discusses the methodology that is proposed to test them.

Hypothesis 1: There will be a statistically significant difference in safety attitudes between key safety roles in the construction supply chain in one or more of the safety climate constructs in the Mohammed (2002) model.

Hypothesis 2: The difference in safety attitudes between roles in the construction supply chain statistically differ depending on whether a key safety role operates in a Design-Build or Design-Bid-Build project delivery supply chain

Hypothesis 3: There is a difference in safety attitudes based on the organizational home of a key safety role (owner, designer, constructor, and sub-contractor) in one or more of the safety climate constructs in the Mohammed (2002) model

Hypothesis 4: Demographic data such as age, experience level, native language, and OSHA training has an effect on safety attitudes overall and for each key safety role

Hypothesis 5: Educating roles on safety perception differences in the construction supply chain will have a positive effect on safety climate within the supply chain.

3.2 Research Design

3.2.1 Overview of Research Design

Based on the literature review and pilot field studies at construction sites, there is an opportunity to better understand the differences in safety attitudes among key safety roles in the construction supply chain. Literature has shown that shared mental models in construction are key to OSH safety and culture, as many of the conflicts that arise in regard to safety occur because of differences in attitudes between roles (Prussia, Brown et al. 2003). Accordingly, the research methods discussed in the rest of this chapter are organized in two phases. The first phase's objective is to develop a survey instrument to quantitatively determine the exact constructs of safety in which attitudes differ most significantly among roles. The second phase's objective is to use the results of the first phase to develop a tool to educate users on important gaps in safety attitudes between their role and others on a project, and then determine if using this tool results in knowledge for the user that helps create a more uniform safety culture on a project as well as the best platform for this type of education.

3.2.2 Research Goals

The goals for this research include:

1. Adapt the safety climate questionnaire developed by Mohammed (2002) specifically for construction workers into a general survey that can be used to collect data from key safety roles throughout the construction supply chain
2. Identify the key roles in the construction supply chain that affect OSH and that data should be collected on safety attitudes
3. Determine the significant differences in safety attitudes between key safety roles in the construction supply chain
4. Determine if design-build supply chains result in more uniform safety attitudes between key roles than design-bid-build supply chains

5. Determine the key differences in safety attitudes between the common organizational homes (i.e. design, constructor) of the key roles in the construction supply chain
6. Use the results of the research to develop an educational tool in to educate users on safety attitude differences that could inhibit a shared OSH mental model between roles
7. Validate the information included in the tool using industry participants to provide a higher degree of external validity
8. Analyze the portrayal of information in the tool by using the industry participants to collect data on the effectiveness of the tool in portraying information to the user that can be applied to bridge gaps in safety attitudes between roles on a construction project, barriers to implementing the concepts discussed in the training, and the best platform for communicating the type of information included in the training tool

The rest of this chapter presents the methods used to collect this data, and the results are then discussed in Chapter 4.

3.3 Research Model

The constructs in Mohammed's (2002) safety climate model for a construction environment was used to evaluate safety climate differences between key roles. As mentioned in the literature review, the constructs in this model had a strong similarity to ones identified by (Fang, Chen et al. 2006) through a statistical factor analysis, and seem to be a well-founded base for measuring safety attitudes in the construction industry. This fact that this model has been validated for construction was the main factor that it was chosen over other safety climate tools (Geller, Roberts et al. 1996; Cox and Cheyne 2000; Cooper and Phillips 2004) that have shown consistent results in environments such as manufacturing and offshore drilling.   The constructs included in Mohammed's (2002) model are:

1. Management Commitment
2. Communication
3. Safety Rules and Procedures
4. Supportive Environment
5. Supervisory Environment
6. Worker's Involvement
7. Personal Risk Appreciation
8. Appraisal of Work Hazards
9. Work Pressure
10. Competence

Figure 3.1 presents the model for collecting data for phase one. A generalized safety climate survey based on Mohammed's (2002) model was given to participants in industry using contacts from within Virginia Tech's Occupational Safety and Health Research Center (OSHRC) and Myers-Lawson School of Construction (MLSoC). The primary factor of analysis was differences in safety climate between key roles identified in the construction supply chain. The supply chain type that the participant's firm generally operates within was also captured to use as a blocking variable. It was hypothesized that roles will exhibit differences in safety attitudes between supply chain types, and adding it as a blocking variable allowed this analysis. Finally, the organizational home of each participant was collected so that roles could be grouped at this level in order to perform a secondary analysis on key perception differences between roles within the same organizational home and between organizational homes when aggregating roles within each one.

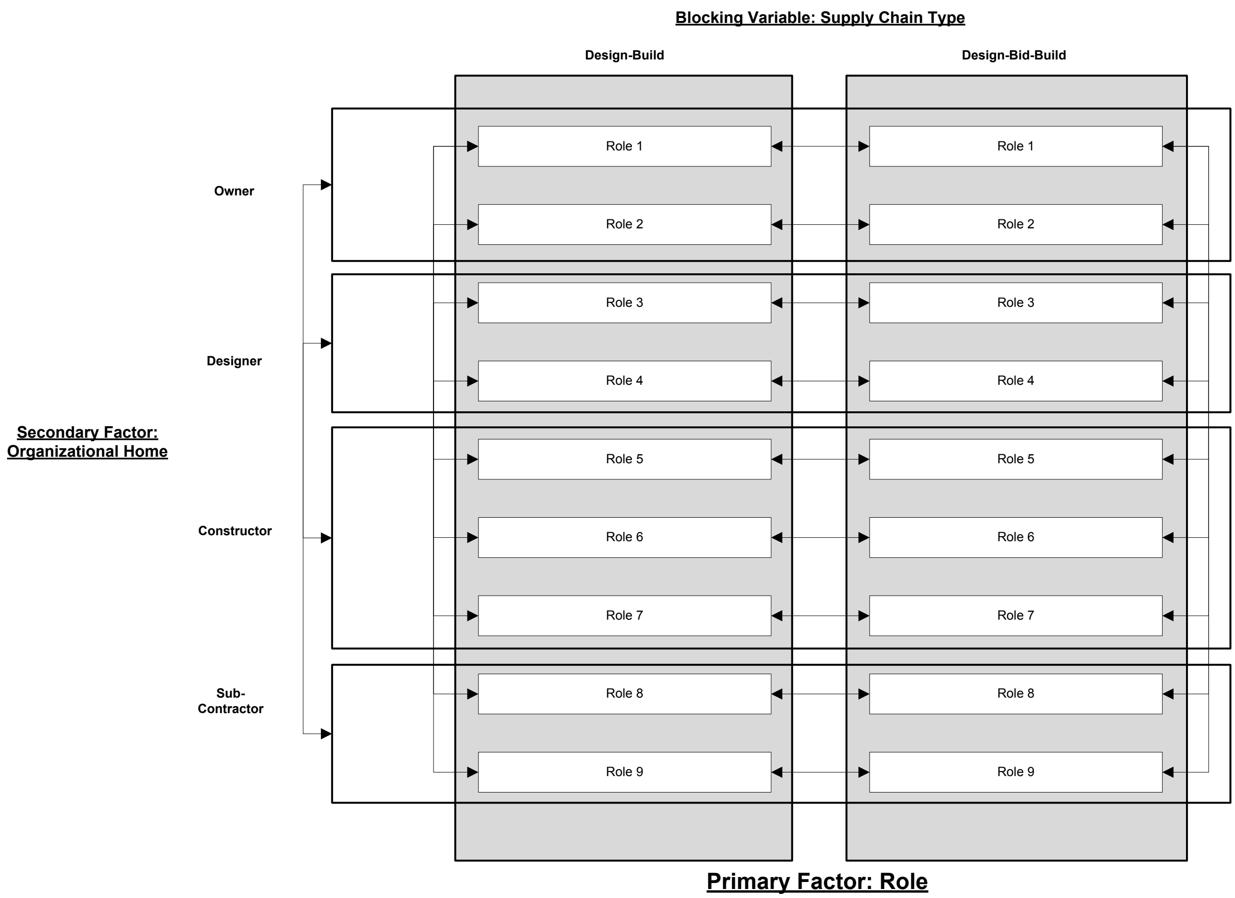


Figure 3-1 Phase One Research Model

Phase two of the research involves developing an Attitude Congruence Training (ACT) tool for safety to educate project personnel on safety perception differences between their roles and others in the supply chain. This part of the research also utilizes industry participants using contacts from the OSHRC and MLSoC to validate the data from phase one that is included in the tool. This gives the results a higher degree of external validity, and this data was collected using a survey that asks the experts to agree with statements based on the results of phase one. Participants were also asked to provide information on the ACT tool determine if the data included is portrayed in a manner that effectively educates the user on potential gaps in the construction supply chain, and the best platform for communicating this type of data.

3.4 Phase I Overview

3.4.1 Identification of Key Safety Roles

The first step that needs to be completed before collecting data on safety attitude differences is to determine the roles throughout the construction supply chain that the safety climate survey is targeted. One key goal of research is to determine safety perception differences of key safety roles throughout the supply chain, and thus developing a relevant list of these roles is a prerequisite to targeting participants for data collection. Targeting every common role on a construction project would have proved burdensome in terms of data collection, as the size of the construction role network can be somewhat large. Thus the target list for the research had to be narrowed down to those that have the most impact on construction worker safety based on expert opinion and relevant literature.

Table 3.1 is based on literature and is a list of common roles present on a construction project (Fisk and Reynolds 2003; Dingsdag, Biggs et al. 2008). This list was the starting point for narrowing down to the key roles that impact safety in the construction supply chain.

Table 3-1 Construction Project Job Positions (Fisk and Reynolds 2003)

Level	Owner or Architect/Engineer	Contractor
Project Level Management	Project Manager	Project Manager
	Project Engineer	General Superintendent
	Project Architect	Construction Management
	Project Director	
	Contracting Officer	
Construction Management Level	Construction Manager	Construction Manager
	Resident Engineer	Project Engineer
	Resident Architect	Superintendent
	Construction Coordinator	Estimator
	Resident Manager	
Functional Management Level	Resident Project Representative	Project Engineer
	Project Representative	Superintendent
	Resident Engineer	Foreman
	Resident Inspector	Contractor's Quality Control Representative
	Inspector	Union Representative/Steward
	Quality Control Supervisor	

The power of a study has been shown to considerably decrease when the ratio of the size of each subgroup to overall sample size falls below a level of 0.10 (Aguinis and Stone-Romero 1997). Thus assuming equal sample sizes, this suggests that when developing the number of roles to include in the study that at a maximum of 10 subgroups should be included, and a goal of six to seven groups was set to allow for some variance in the sample size of subgroups. If ten groups had been considered, it would have introduced the additional constraint of having to keep subgroup sizes relatively equal, which would be difficult when targeting large groups of participants.

A group of industry and academic experts was identified in order to narrow down Table 3-1 to a manageable number of roles for data collection. Each of the experts was asked to rate the most important roles that impact OSH in the construction supply chain. The average ranking of each role was then calculated, and the group of roles with the highest average ranking was included in the survey along with other roles that literature has identified as important. The result was a group of roles that the final survey instrument would be sent out to.

3.4.2 Survey Instrument Development

As discussed in Section 2.2.3, a generalized questionnaire need to be developed in order to applicable to roles that typically participate in different stages of a construction project. The same 5-point Likert scale (1= strongly disagree; 3 = neither disagree or agree; 5 = strongly agree) with seven items included for each construct as in the original measurement tool was used as a starting point for development. The items in Mohammed's instrument were based on statements used in other safety climate research (Cox and Cox 1991; Tomás and Oliver 1995; Glazner, Borgerding et al. 1999; Cox and Cheyne 2000; Lee and Harrison 2000), and modified when necessary to fit the construction industry. Some examples of items in the survey that had to be generalized for application on roles throughout the construction supply chain include:

- 'Safety Rules and Procedures' construct – "Current safety rules and procedures are made available to protect us from accidents"
- 'Supportive Environment' construct – "As a group, we adopt a no-blame approach to highlight unsafe work behavior"
- 'Personal Appreciation of Risk' construct – "I am sure it is only a matter of time before I am involved in an accident"

The overall safety climate scale within Mohammed's instrument was generalized in order to capture overall safety attitudes in addition to by construct. This latent variable is a good indicator if the measurement model is reliable, as differences between constructs should also lead to differences in overall safety climate according to Mohammed's (2002) model and results. This scale asks the respondent to rate their level of endorsement on a 1-9 scale (9 = very strong endorsement) for 10 items related to overall safety climate in the work environment, but this was changed to a 5-point scale in order to align with the other items in the instrument.

3.4.3 Survey Instrument Review

After the instrument was generalized, the first step in evaluating was to test it for content validity. Content validity is the "degree to which elements of an assessment instrument are relevant to and representative of the targeted construct for a particular assessment purpose" (Haynes, Richard et al. 1995). One detail that supports the content validity of the instrument is that the items in Mohammed's survey were drawn from existing safety climate literature (Carmines and Zeller 1986). Even though the items had to be generalized, their basis is at least relevant to their associated construct based on previous research.

Care had to be taken during the generalization process to ensure that it was applicable to workers with varying educational levels. One mechanism to do this is the Flesch-Kincaid Grade Level scores that can be calculated using Microsoft Word. The Flesch-Kincaid Grade Level score rates a given text on a United States education level using the following formula (Microsoft Corporation 2007):

$$Flesch - Kincaid\ Grade\ Level = (0.39 \times AWL) + (11.8 \times ASL) - 15.59$$

This is an important evaluation for the survey, because according to recent data only 77.4% of all employees in the construction industry had a high school diploma and only 45% of construction workers (Center for Construction Research and Training 2007). The survey instrument needs to be easy to read in order to accommodate the wide range of participants in the research, and thus less than a high school reading level was chosen. The next step in determining content validity was to have experts familiar with construction safety review the instrument. A total of five experts were identified and asked to review the survey for both clarity and relevance of content using a Content Validity Index (CVI) (Lynn 1986). This index uses a 4-point Likert scale for each reviewer to rate each item for relevance (1=not relevant, 2=somewhat relevant, 3=quite relevant, 4=very relevant). The purpose of using this procedure is to allow multiple raters to review a survey separately and evaluate the relevance of items to the domain of content that the item is supposed to represent (Wynd, Schmidt et al. 2003), and then to calculate a proportion agreement when ratings of 1 or 2 are deemed content invalid and ratings of 3 or 4 are considered content valid (Lynn 1986). Research has shown that chance agreement of relevance among raters is a limitation of the CVI procedure. Thus, evaluation guidelines based on the use of a 'kappa designated agreement statistic' that is calculated using a binomial probability of chance occurrence were used to evaluate the results of the CVI study (Polit, Beck et al. 2007). Table 3.2 shows the evaluation guidelines using this evaluation procedure, and it differs from Lynn's guidelines because Lynn suggested that all reviewers should be in agreement when using 5 or less reviewers.

Table 3-2 Evaluation Criterion for CVI Proportions

Number of Experts (N)	Experts Giving Rating of 3 or 4 (A)	CVI	p_c	k^*	Evaluation
5	5	1	0.041	1	Excellent
5	4	0.8	0.156	0.76	Excellent

p_c = probability of chance occurrence for a binomial random variable = [N!A!(N-A)!] * 5^N
k^* = kappa designated agreement on relevance = (CVI-p_c) / (1-p_c)

After this exercise was completed and the survey was updated, then a pilot study was conducted by sampling personnel throughout the supply chain to further test the content of the questionnaire before sending it out for widespread data collection. Simple correlations were calculated within each construct to test individual item reliability, and the internal consistency for each construct was tested using Cronbach's Alpha (Fornell and Larcker 1981). These results were important for updating the survey before final data collection.

A demographics section was added to the survey after the pilot to collect information that is required to perform the research. The information that was collected in this section included the primary role that the subject serves in the construction supply chain and what type of supply chain (design-build or design-bid-build) the subject is primarily involved in. It is possible that subjects could have served multiple roles or been involved in design-bid-build and design-build projects, and thus the participant's current information was collected in order to group the subject in the correct classification(s) and prevent some possible confounding influences. Other information that was captured in this section is experience level, education level, OSHA training completed (OSHA 10 or 30), and the origin of a participant's attitudes toward safety.

3.4.4 Participants

Participants for Phase I were recruited by researching the world wide web for construction personnel in appropriate organizations that fit into one of the role groups. After contact was initiated and permission received, a link to the survey included in the email was used by the participant to access the survey (or a hard copy was mailed if needed).

Research has shown that confirmatory factor analysis should be used cautiously with samples less than 200 (Boomsma and Hoogland 2001), but that sample size effects can still be statistically significant for samples up to 400 (Marsh, Balla et al. 1988). Thus, 200 participants was the minimum sample that was considered, with 400 being the goal. The power of this sample size was also calculated using the pilot survey standard deviation and the identified number of key roles. If the power is found to be less than the generally accepted value of 0.80 (Cohen 1988), then the sample size required for the questionnaire should be increased to provide an acceptable power.

The questionnaire was available in both electronic and paper and pencil format. The electronic version was web-based, and a link with instructions was emailed to participants that would rather take this version of the survey and have access to a computer. The paper and pencil format was intended for construction workers and others that might not have easy access to a computer or be proficient on a computer. The two main guidelines that were used on the survey is that participants had to be at least 18 years old and be proficient in English since the survey was not translated. The survey was not administered below the supervisor/foreman level, and thus an adequate number of English-speaking participants were available.

3.4.5 Data Analysis of Survey Results

The scores for each of the seven items in each of the ten constructs was assigned values ranging from 1 to 5 to indicate level of agreement by the participant. The scores within each construct were then summed in order to determine the strength of each construct within the safety climate model. The demographic information included the primary role of the participant, supply chain type of their firm, and the organizational home of the participant in the construction supply chain. This data allowed aggregation and analysis of the data so that the hypotheses of the proposed research could be tested.

A JMP data file was created with the results from the surveys. Some of the surveys were adminstered with paper and pencil, and had to be converted into an electronic format by manually inputting the results the online sample. There were only approximately 30 of these type of surveys completed, and they were 100% sampled for accuracy after they were input into the online system.

The largest portion of the surveys was adminstered electroncially using an online survey tool. These results were exported into an Excel spreadsheet and combined with the manual survey spreadsheet to form a master spreadsheet of all of the survey results that ccould be imported into JMP as a data file.

The primary variable of interest in this study is at the role level, and thus data collected by individuals was aggregated by their primary role. Data was aggregated for each item by averaging the score for each role of every participant that completed the survey. Theoretically, the scores within each construct represent the perceived effectiveness of the conditions and procedures supporting that construct. Safety climate scores are additive and higher scores indicate “more favorable conditions and procedures” in regard to OSH (Zohar 1980). For the original study (Mohammed 2002), there are seven items within each construct scored on a 1 to 5 scale, and thus the highest possible score within each construct was 35 and the lowest possible score was 7. There was also an overall safety climate score that was used to obtain the overall strength of each role in terms of safety attitudes.

The reliability and validity of the data were assesed using the procedures outlined by Fornell and Larker (1981), and discussed in Section 2.2.3 for evaluating Mohammed's (2002) instrument. The reliability and internal consistency of the measurement instrument must be evaluated. Simple correlations were calculated within each construct to test individual item reliability. Cronbach's alpha coeficient (Cronbach 1951) was used to determine that the set of questions in the measurement tool result in a stable response, as it is a reliability measure that determines the amount of variation accounted for by the scores of the underlying construct (Santos 1999). In other words, this statistic will support that a given set of questions measure a single construct, which in this prosposed research are the safety climate constructs discussed previously. Values for Cronbach's alpha are reccommended to be at least 0.7 for a construct for it to have an acceptable level of internal consistency (Nunnally, Bernstein et al. 1967; Gliem and Gliem 2003; Reader, Flin et al. 2007). If any constructs are found to have a value of less than 0.7, then the variable will be evaluated to see if it should be removed prior to analysis due to the items within that construct having a low correlation as to the variable they are measuring. There is justification for including some scales with questionable levels of internal consistency (Cronbach's alpha of 0.6 – 0.7) since the survey instrument will be a modified version of an existing questionnaire and could be classified as a new instrument. If a construct that has been adjusted a large amount from Mohammed's survey has a questionable score then the construct might still be included in the analysis if the scale is deemed 'new' (Nunnally, Bernstein et al. 1967; Flynn, Schroeder et al. 1994).

The content validity of the constructs used in the model was evaluated to assure that the constructs found through factor analysis in Mohammed's (2002) for construction workers hold up for all roles throughout the supply chain. This was assessed through a confirmatory factor analysis (CFA), which allows testing the relationship between the variables observed in the data and underlying latent constructs that are hypothesized beforehand using prior knowledge such as literature (Suhr 2006). In CFA, a fitted population covariance matrix formed from factor loadings, factor variances, covariances, and residual variances is compared to a sample covariance matrix for similarity. If the two matrices are found to be sufficiently similar then then the model adequately fits a particular set of data (Marsh, Balla et al. 1988). The CFA analysis was performed by creating the hypothesized measurement model in JMP and performing the analysis in SAS. This procedure was used versus an Exploratory Factory Analysis because a measurement model was already hypothesized with a given set of latent constructs and their associated items.

If the CFA did not support the use of the 10 constructs from Mohammed's (2002) model then an exploratory factor analysis (EFA) would have been performed in JMP using principal component analysis (PCA) with varimax rotation. This is a technique to reduce the dimensionality of a data set while still keeping as much variation as possible from the orginal data set. The "principal components" of the data set are computed using a "eigenvalue-eigenvector problem for a positive-semidefinite symmetric matrix" (Jolliffe 2005). The Kaiser criterion of an eigen value of 1 should be the cut-off used to determine which factors emerge from the analysis (Straub, Boudreau et al. 2004; Costello and Osborne 2005). If the orginal set of factors do not emerge from the analysis then the orginal set of factors can be reduced to look for differences between key safety roles. If differences are found between the new factors, then a secondary analysis using the orginal factors can then be evaluated using a secondary analysis. Again, since there was already a hypothesized measurement model CFA was chosen to validate the measurement model, and an exploratory analysis would have been performed only if the analysis did not support the model.

The aim for hypothesis one of the proposed research is to find differences in the ten safety climate constructs for the primamry variable of key safety roles. The analysis of variance (ANOVA) model can be used to explore these differences, but first the appropriateness of this model must be determined. ANOVA is a robust model that does not assume a relationship between the independent and dependent variables as in linear regression, but serious departures from the assumptions of the model must be evaluated and remedial measures taken if any required. The departures from the model that were used to determine if the ANOVA model is appropriate for each safety climate construct are listed below along with possible tests that can be used for this analysis (Neter, Wasserman et al. 1996).

1. Nonconstancy of error variance – Hartley Test or Brown-Forsythe Test
2. Nonindependence of error terms
3. Outliers
4. Omission of important explanatory variables
5. Nonnormality of error terms – Shapiro-Wilk Test

Before this analysis can be performed, the key assumption of the ANOVA model was tested, which is that the results follow a normal distribution. This assumption can be tested using residual analysis, formal lack of fit test for nonnormality such as the Shapiro-

Wilk test, and normal probability plots of the error terms for normality assumption (Neter, Wasserman et al. 1996). Remedial measures such as transforms were be considered when the assumptions were violated, but the best action for ordinal data such as this is to consider nonparametric statistics to test for differences (Kitchenham and Pfleeger 2003). The data proved to not be normal, and the remedial measures taken are discussed in Chapter 4 after the normality testing procedure.

Multicollinearity is another violation of the model that occurs when two or more of the independent variables are highly correlated. Correlations for the predictor variables were be calculated in JMP to determine to what extent (if any) multicollinearity exists (Neter, Wasserman et al. 1996). As in the previous analysis, this condition was checked and remedial measures taken such as ridge regression considered if needed.

As stated, the results did not support normality, which indicates that ANOVA based on the mean is not an appropriate test procedure. An ANOVA type process using median statistics (nonparametric tests) can be used instead. In order to determine if there are differences in safety climate among the roles, an initial nonparametric Multivariate Analysis of Variance (MANOVA) was performed before any nonparametric ANOVA models are run between roles for individual constructs. The dependent variables in this analysis are the safety climate constructs ($Y_1 \ldots Y_{10}$) discussed in hypothesis 1, and the independent variables ($X_1 \ldots X_n$) are the key safety roles identified in prior analysis. MANOVA takes into account the intercorrelations among the dependent variables, and reduce the chance of Type I error that can occur with multiple analysis of variance tests (ANOVA) on the independent variables. The result of the MANOVA should be whether or not there are differences in any of the safety climate constructs in the survey instrument for the roles that are defined as the independent variables. ANOVA's are then used to investigate the differences for each of the dependent variables once the MANOVA has been run on all of the independent variables at once.

Hypothesis two and three concerns safety climate differences at the project delivery and organizational level. The project delivery type and organizational home of each key safety role was defined, and then an ANOVA-type procedure completed using project delivery and organizational home as the independent variable, overall safety climate (using the new safety climate scale from Mohammed's model) as the dependent variable, and supply chain type as a blocking variable. This analysis gives insight into the width of the gap, if any, between organizations in regard to safety attitudes, and whether the supply chain type has an effect on shared safety attitudes.

The demographics collected in the survey were also used to determine their effect, if any, on safety attitudes. Understanding how other factors affect attitudes outside of roles and supply chain type could also be valuable in understanding how safety attitudes are formed. Analysis of these variables was be used to determine if independent variables such as age, experience level, education level, OSHA 10 or 30 training certification, affect safety attitudes, and what levels within these variables seem to show the effects.. This information is classified as hypothesis four in Chapter 1

Table 3.3 gives an overview of each hypothesis studied in Phase I, and the associated dependent and independent variables that will be used to test the hypothesis using the methods (tests) listed. The tests listed in the third column assume that the violations of the ANOVA procedure are not violated by the results. For this data, the assumption was violated and the nonparametric version of the test listed was performed. These tests follow the same process as the ANOVA except that they use the median instead of the mean. The test listed is meant to suggest that this process will be used, no the specific test.

Table 3-3 Phase I Hypothesis with associated variables and methods overview

Hypothesis	**Variables**	**Tests**
Hypothesis 1: There will be no differences between the 10 constructs of safety climate between key safety roles	IV: Role DV: Safety Climate Constructs	MANOVA
Hypothesis 1a and 2a: There will be no differences in management commitment detected between any key safety roles or supply chain type	IV: Role BV: Supply Chain Type DV: Management Commitment	ANOVA
Hypothesis 1b and 2b: There will be no differences in communication detected between any key safety roles or supply chain type	IV: Role BV: Supply Chain Type DV: Communication	ANOVA
Hypothesis 1c and 2c: There will be no differences in safety rules and procedures detected between any key safety roles or supply chain type	IV: Role BV: Supply Chain Type DV: Safety Rules and Procedures	ANOVA
Hypothesis 1d and 2d: There will be no differences in supportive environment detected between any key safety roles or supply chain type	IV: Role BV: Supply Chain Type DV: Supportive Environment	ANOVA
Hypothesis 1e and 2e: There will be no differences in supervisory environment detected between any key safety roles or supply chain type	IV: Role BV: Supply Chain Type DV: Supervisory Environment	ANOVA
Hypothesis 1f and 2f: There will be no differences in worker involvement detected between any key safety roles or supply chain type	IV: Role BV: Supply Chain Type DV: Work Involvement	ANOVA
Hypothesis 1g and 2g: There will be no differences in personal appreciation of risk detected between any key safety roles or supply chain type	IV: Role BV: Supply Chain Type DV: Personal Appreciation of Risk	ANOVA
Hypothesis 1h and 2h: There will be no differences in appraisal of work	IV: Role BV: Supply Chain Type	ANOVA

hazards detected between any key safety roles or supply chain type	DV: Appraisal of Work Hazards	
Hypothesis 1i and 2i: There will be no differences in work pressure detected between any key safety roles or supply chain type	IV: Role BV: Supply Chain Type DV: Work Pressure	ANOVA
Hypothesis 1j and 2j: There will be no differences in competence detected between any key safety roles or supply chain type	IV: Role BV: Supply Chain Type DV: Competence	ANOVA
Hypothesis 1k and 2k: There will be no differences in overall safety climate detected between any key safety roles or supply chain type	IV: Role BV: Supply Chain Type DV: Overall Safety Climate	ANOVA
Hypothesis 3: There will be no differences between organizational homes and supply chain types for overall safety climate	IV: Organizational Home BV: Supply Chain Type DV: Safety Climate	ANOVA
Hypothesis 3a-3i: There will be no differences in the safety climate constructs between each type of organizational home	IV: Organizational Home BV: Supply Chain Type DV: Safety Climate Constructs	MANOVA
Hypothesis 4: There will be no difference in safety attitudes based on the demographic data collected in the safety climate survey	IV: Demographic Factors (age, experience level, training level) DV: Safety climate scores	ANOVA

3.4.6 Phase I Assumptions, Delimitations, and Limitations

The following are assumptions, delimitations, and limitations of the proposed research that should be considered when evaluating the results.

- *Safety Climate as Proxy Measure* – Safety climate is an appropriate measure for measuring safety attitudes, and high safety climate scores have been shown to be an antecedent for safe work behavior (Flin, Mearns et al. 2000; Guldenmund 2000; Neal and Griffin 2002; Lingard, Cooke et al. 2009). Thus, understanding safety attitude differences can be assumed to have the potential to positively affect OSH outcomes on construction projects.

- *Project Size* – There are a wide range of projects in the construction industry from small projects that involve very small firms to large projects that involve multiple, corporate firms. The Mohammed (2002) study in which the measurement model is based targeted medium to large projects in order to collect the most data possible at each location. This research also targets organizations that typically work on medium to large projects (> $1 million) in which the project lifecyle and safety considerations are usually more complex. The external validity of the results are not applicable to the entire construction industry, but it is focused on the type of projects with supply chains that typically have the roles of interest and that the researcher had the most access.
- *Industry Sector* – One important difference between the residential construction industry and others is the typical size of projects. Residential projects are usually smaller than commercial projects, and thus are excluded from the study (Costantino, Pietroforte et al. 2001). Additionally, OSHA has separate standards for residential construction than other industry sectors, and thus this could effect the attitudes of the respondents. This will limit the external validity of the project, but several of the roles in the study are not directly comparable regardless such as Upper Management and others are not typically seen on residential projects such as Project Engineers.
- *Multiple Project Roles* – The study makes the assumption that even though personnel can potentially serve as multiple roles on projects that for data collection purposes they will be grouped into their primary role. Attitudes obtained from serving in these multiple roles could be a confounding influence

on their safety attitudes, but this influence is minimized by only targeting organizations that work on large, non-residential projects in which this situation should not be an issue.

- *Multiple Roles in Career* – Some personnel will have also served in multiple roles throughout their careers, but in this study will be grouped into their current role. Past experiences outside of their current role could also have a confounding influence on a person's safety attitudes. One way that this is tested is by also asking for experience in the current role and in the construction industry to determine if experience level has an effect on safety attitudes.
- *Hispanic Aspects* – The study does not include any analysis on how integration of Hispanic concepts into safety management programs affects safety climate throughout the supply chain. Hispanics are an important group in the U.S. construction industry that future research might address.
- *Project Delivery Mechanism* - The demographic question on project delivery type is limited to design-bid-build and design-build supply chains because they are the two most common delivery methods (Ling, Chan et al. 2004) and easily accessible for data collection. This does not include other supply chain types such as accelerated or collaborative that would increase the external validity of the results.
- *Experience on Project Delivery Type* – Some firms and personnel will have experience on both design-bid-build and design-build, but will be grouped into their current project for data collection purposes. This could be a confounding influence on safety attitudes by delivery mechanisms. This is addressed in the

survey by giving the respondent a text option in which they can list their typicaly project delivery type if they feel design-bid-build or design-build do not adequately describe them. Other forms of data collection might prove more appropriate for testing this variable, as reducing this to a survey question might be difficult for the particpant.

- *Design Firm Definition* – The training was targeted to design firms, which included both architects and structural engineers. Collecting infromation on differences, if any, between these groups could be a future research opportunity

3.5 Phase II Overview

3.5.1 Educational Tool Need

Phase II of the project involves developing an training tool to educate construction personnel on safety attitude differences among personnel on a construction project that can impede a unified safety culture. Results from Phase I of the proposed research served as a needs assessment in terms of developing the tool. The end goal of this phase of the research is to determine the value of the information in terms of improving educating construction personnel on how they can improve OSH practices and the best medium for communicating this type of information to construction personnel. The attitude congruence training (ACT) tool was critiqued by construction industry experts to provide feedback on their level of agreement on results of the safety climate survey from Phase I, and thus provide a higher degree of external validity to the information included in training tool.

3.5.2 Training Tool Development

There are numerous platforms that can be used for training, all of which could be tested to develop a training tool that can be used to take the research from Phase I to practice in industry (r2p). Based on industry and training literature, some common formats include:

- Onsite classroom training with participants,
- Instructor-led online training,
- Self-guided website,
- Reference materials such as articles, case studies, and handouts, and
- Pre-recorded video courses/presentation (Dimeff, Koerner et al. 2009; Citrix Education 2012; Oracle University 2012).

A self-directed training tool was developed as a web-based tool, as this medium is a good mechanism to expose the tool to a wide range of participants and confounding influences of training differing between partipant classes is eliminated. The tool gives the particpant background information tailored to their role about how construction worker safety is affected by their work. The material in the ACT training also aligns where applicable with current NIOSH goals, and is based on construction safety literature. Results of the Phase 1 of the research were the basis for choosing the areas of focus for a particular role, as they should give insights to what areas have the largest need for improvement. The end result should be to address gaps in the current system in order to create a more unified safety culture between the stakeholders involved on the project.

3.5.2.1 Training System Development Model

The development of the ACT training system should be methodological, and ensure that the training tool meets the objectives of educating personnel within the construction supply chain on differences in safety attitudes. Figure 3.2 is adapted from Goldstein (2002), and was used as the model that will be used for developing the training system.

Figure 3-2 Training system development model (adapted from Goldstein 2002)

A brief overview of each of the steps is given below.

1. Needs Assessment – This phase involves development of the instructional objectives by understanding the organizations and personnel that the training is targeted for. This stage also involves determining the knowledge, skills, and abilities that trainees should acquire as a result of the training.
2. Training and Development – This stage of the training development involves designing the learning environment to achieve the objectives of the needs assessment phase. The learning principles, motivations and characteristics of trainees, and what types of training techniques best meet the learning objectives must all be considered.
3. Evaluation – This phase centers around defining a measure of success for the ACT training program, and evaluating how well the training programs meets these goals based on testing the training system. The evaluation phase also should assess the training validity of the training system in terms of whether trainees learned during the training, whether the material learned can be transferred to the work environment, and intraorganizational and interorganizational applicability.

3.5.2.2 Training Needs Assessment

The data from Phase I regarding differences in safety attitudes between key roles in the construction supply chain was the basis of the needs assessment for the content included in the attitude congruence training. This data reveals what aspects of the safety climate model are lower compared to others for a particular role, as well as what areas for that role are significantly lower than other comparable roles. From a training environment perspective, this information needs to include the skills, concepts, and attitudes that must be transferred to the job setting as new knowledge, skills, and abilities (Goldstein 2002).

Techniques for improving safety climate within each construct that are based on safety literature were included in the ACT tool. For example, if a signifcant difference in hazard appraisal was identified between designers and construction managers, then safety in design techniques could be used from literature (Hinze and Wiegand 1992; Gambatese, Hinze et al. 1997; Gambatese and Hinze 1999; Hecker and Gambatese 2003) to increase the awareness of how safety hazards can be addressed in the design phase.

In addition to using the data from Phase I of the proposed research, the training tool also draws from literature to educate trainees on the construction supply chain. Information was included on the primary steps of the construction supply chain from concept through completion of a project, and how roles involved with each of the steps can impact safety at the construction stage. The literature can be used to educate on how the different pieces of the supply chain are supposed to fit together, and the knowledge from Phase I can then be used to display the obstacles to this happening in an efficient manner. The reason this material was included is to at least give particpants a base knowledge of the cosntruction supply chain, how decisions made early in the supply chain can affect OSH outcomes on the construction site, and examples of how safety attitudes can differ between roles in the supply chain. This base will improve the results of the training by ensuring that each particpant at least has a minimum amount of knowledge prior to being exposed to the information on safety attitude differences and understands why this information is impactful.

3.5.2.3 Training Development

When developing the educational tool, the learning outcomes of the user must be identified in order to develop training methods that best stimulate the desired type of learning (Goldstein 2002). Gagne, et al. (1992) described five learning outcomes that can be used to guide development of a training system. They are intellectual skills, cognitive skills, verbal information, attitudes, and motor skills. The key desired outcomes of the ACT training is cognitive strategies in which users understand how and when to use the information they learn in the training and attitudes in which the training shapes trainee preferences for different actions. Training methods for reaching these outcomes are also described, and a common theme in these methods is presenting real scenarios and examples in which the user understands why the information is important and how it should affect choices in practice (Gagne, Briggs et al. 1992).

The target training groups must also be identified in order to properly design the training system. The training system will not be designed for just one organization within the construction supply chain. Thus, it must be flexible enough to fulfill the learning objectives to a wide range of user backgrounds and educational levels that might work in a given role.

Based on this information the training has the following sections:

1. Introduction to emphasize the importance of construction worker safety to the user
2. Background on how the user's role affects construction workers safety
3. Results of the Phase 1 safety climate survey revealing areas in the safety climate model that the user's role typically can improve on to reduce fragmentation in safety attitudes
4. Literature based educational information pertaining to how the user can improve in their day to day role in terms of OSH performance

3.5.2.4 Evaluation of Training System

The research seeks to determine if there is support for a cause and effect relationship of the use of the training tool creating a more positive safety environment on a construction project. The data included in the tool was be reviewed by experts to assess the applicability of the material to industry. This expert validation was conducted with two goals. The first is to determine the portrayal of the information and usability of the training tool. The second is to determine not only the applicability of the information, but if there is more relevant information that should be included in the training before sending to a larger sample.

This served as an initial means of ensuring that the tool is designed in a manner that is conducive to meeting its learning objectives and allows users to efficiently and easily learn and use the tool. Doing this testing prior to exposing potential users to the training system allowed obvious areas for improvement to be identified and addressed prior to the particpants that provided the most important validation being exposed (Battleson, Booth et al. 2001). The experts were asked to step through the website as a user, and provide feedback via a survey on their opinions on how well the training met its goals and ways that it can be improved.

After the experts have evaluated the tool, it was sent to industry participants to gain feedback on its effectiveness. Information portrayal was of particular interest, as there are multiple mediums to communicate the information contained in the initial website training. These can differ based on the role, but besides web-based platforms could include proffesional development training, conference presentations, university curriclum, and other communication methods. Determining the best location to train construction industry personnel on these issues is an important facet of the research that can eventually increase the impact of the training. The website is just the initial platform to introduce the information to potential users, and understanding what information and in what form will "hook" particpants is an important step in meeting the goals of this type of training.

Each particpant was also be asked to complete a short survey to give feedback on how well the ACT tool performs in terms of meeting its learning objectives. As outlined previously these included educating the user on how they fit into the construction supply chain in terms of impacting OSH, giving the user an understanding of key safety attitude differences between their role and others, and giving the user knowledge on techniques for improving attitude congruence. Interactive elements in the instrument were be based on previous items in usability research for ease of use/learnability and information portrayal that have been used and validated (Lewis 1995; Muench and Mahoney 2004). A question was also be added to determine the particpants's level of agreement with the results of Phase 1, thereby improving external validity as well identifying what items should be emphasized in future training. Other items addressed the best platform for portraying the type of information included in the tool, and barriers the particpant sees in implementing the concepts referenced in the training.

3.5.3 Particpants

Two industry experts were recruited through contacts of the MLSoC to pilot test the ACT training and provide usability feedback of Phase II. These experts were given an overview of the goal of the training, and were asked to provide feedback on a prototype website to determine how it could be improved before sending to industry particpants. After the tool wass updated based on expert feedback, particpants were recruited from industry to use the tool, and give feedback on the ease-of-use, information portrayal, and validity of the information included in the ACT tool. This required them to use the website and fill out a survey, and thus at least 15-20 minutes were required with each particpant. This was communicated to each participant, and they were recruited using contacts from the MLSoC and research on the world wide web.

3.5.4 Data Analysis of Phase II Data

The survey that particpants were asked to fill out was an important source of information on how well participants feel the training tool achieves its learning objectives. This was an indicator of how well the tool performs in turning information from Phase I of the research into knowledge that can be used to reduce fragmentation in the construction supply chain in terms of safety attitudes. Data was also valuable for determining the best methods for portraying this type of information moving forward, and barriers to implementation in industry. The means for each question were tabulated in order to understand how well the tool performs within each area in terms of information portrayal, and confidence intervals calculated when relevant to determine if the choices overlapped for a given question in order to test for differences. Revisions were considered for the tool based on the results of the survey.

3.5.5 Phase II Assumptions, Delimitations, and Limitations

- The participants came from different organizations, and thus the base safety cultures and resulting attitudes of the particpants will differ. These nonequivalent groups could be a confounding influence on the effect of the training since it was a realtively small sample size (less than 30).
- A quasi-experiment experiment that applies the training on one construction project and compares pre and post-test measurements in safety climate scores versus another comparison construction project that does not receive the training would improve the validity of supporting a cause and effect relationship between the training tool and improved safety attitudes. This could be an extension of this proposed research, but will not be conducted due to time and accessibility constraints.
- The training was only targeted toward designers, as this group was found to have lower attitudes than the other groups in the sample (discussed in Chapter 4). The validity of the finding will be valuable in better integrating an important group into the safety planning process, but future research should involve using the Phase I results for educating other roles.
- The training was tested using a web-based approach because it provided a good platform for easily having a wide-reaching sample in an electronic format. Initially portraying this information in another manner could have possibly led to

different results, and thus the initial platform could be a possible confounding influence.

- The training was targeted to design firms, which included both architects and structural engineers. Future research could possibly educating these roles separately if it is not assumed there are differences between the groups.

3.6 Research Methodology Conclusions

The research seeks to address an important area in construction safety by exploring how the safety attitudes of different key roles in the supply chain differ. Safety attitudes were broken down into ten constructs using Mohammed's (Mohamed 2002) safety climate model, and a survey was developed that generalizes his questionnaire so that it is applicable to all roles throughout the construction supply chain. Statistical techniques such as ANOVA, MANOVA, and regression were be used explore these differences using the survey data, and determine if there is evidence to support these differences. The results of this analysis was then used to develop a training tool to educate construction project personnel on differences in safety attitudes between them and other roles in the supply chain, and whose goal is to reduce gaps in safety attitudes and create a more unified safety culture. The tool then underwent usability testing by construction industry personnel to provide feedback on how well the tool turns the data from Phase I into knowledge that can be used to reduce gaps in safety attitudes in the construction supply chain.

4 Chapter 4 – Data Results and Analysis

This chapter will give the results of the process discussed in Chapter 3 that was used to develop the final survey instrument. It will then discuss the results of a sample of 433 responses from the U.S. construction industry by comparing safety attitude differences between roles and within each role, as well as the effect of demographic factors that were collected. Phase II results will also be presented to analyze how the data can be used to reduce fragmentation in the construction supply chain.

4.1 Role Identification for Final Survey Instrument

In order to narrow the roles to include in the final questionnaire, a short survey instrument was developed to have experts rank the roles they felt were the most impactful in influencing risk control and safety on a construction project. The survey was based on Table 3.1, and simply asked respondents to rank from highest to lowest the roles they felt impacted risk control and construction worker safety on construction projects. Some of the terminology was changed (e.g. Project Director to Project Executive, Contracting Office to Contract Specialist) to be more in line with job titles generally seen in the construction industry (based on the author's experience). Upper management was added based on construction safety literature to encompass all senior level management such as the CEO, CFO, COO, etc. This data collection mechanism was chosen instead of a method such as a structured interview with each expert in order to ensure that each expert was given the same frame of reference and to minimize the time required for each expert in order to improve the response rate.

The results of this survey instrument are shown in Table 4-1. The survey was sent to 14 experts in industry and academia, and 4 industry and 4 academia responses were received. The mean is the average ranking from 1 to 15 of each role in terms of perceived importance to impacting safety and risk control on a construction project (with 1 being most impactful). Items not connected by the same letter in the last column were found to be significantly different in the analysis. For example, the superintendent role is only significantly different than the top for rows based on the analysis.

Table 4-1: Average ranking from expert role survey

Position	Mean	Tukey-Kramer Mean Comparison
Quality Control Representative	12.625	A
Estimator	10.500	AB
Designer	10.250	AB
Contract Specialist	10.125	AB
Union Representative/Steward	9.375	ABC
Project Engineer	9.000	ABC
Construction Coordinator	8.500	ABC
Project Executive	8.375	ABC
Safety Representative	7.500	ABC
Safety Manager	7.125	ABC
Upper Management	7.000	ABC
Project Manager	6.625	ABC
Construction Manager	5.625	BC
Foreman	4.250	BC
Superintendent	3.125	C

The goal of the final survey instrument is to collect data on safety attitudes from roles throughout the construction supply chain. An initial ANOVA test on all of the roles resulted in an F-ratio of 3.43 and a p-value of 0.0001, which implies that there is a significant difference between at least two of the roles. The letters in the third column are a result of a Tukey-Kramer means comparison test that administered post-hoc in which roles not connected by the same letter are significantly different. The results indicate that many of the roles listed as the most impactful tend to be more centered on the construction phase. Thus, the designer and project engineer roles were added to the final instrument based on their impact on design decisions and safety in design literature (Manuele 2003; Behm 2005; Gambatese, Behm et al. 2005).

Additionally, based on feedback from participants it was difficult to differentiate the construction manager role from the project manager except for projects in which the construction management firm self-performs work. Also, according to the Bureau of Labor Statistics (2011) construction managers "are often called project managers, constructors, construction superintendents, project engineers, construction supervisors, or general contractors." Thus, the construction manager role was included in the project manager role for survey purposes. Also, the safety manager and safety representative are very close in rank, and feedback indicated that it was difficult to differentiate the two roles. These two roles were also consolidated for purposes of the final survey.

Chapter 3 stated that the goal was to include seven roles in the final instrument unless there was a very close ranking. A significant statistical difference cannot be found between most of the roles, so the top five roles in the rankings and the designer and project engineer roles were included. The roles that were included in the final instrument are as follows:

1. Superintendent
2. Foreman
3. Project Manager
4. Upper Management
5. Safety Manager

6. Project Engineer
7. Designer

4.2 Survey Generalization Process

Some of questions in Mohammed's (Mohamed 2002) survey needed to be generalized in order to make them meaningful to personnel that are not generally performing construction operations. The main concern during this process was framing questions so that they included a focus on risk/hazard control in addition to being focused on safety at the construction stage. Table 4.2 lists the original question from the Management Commitment construct and the generalized question as an example of this process.

Table 4-2: Generalized questions for management commitment construct

Original Question (Mohamed 2002)	Generalized Question
Management clearly considers safety to be equally as important as production,	My company's management clearly thinks safety is as important as other factors on a project.
Management expresses concern if safety procedures are not adhered to	My company's management shows concern if employees do not think about safety and potential risks in their work
Management acts decisively when a safety concern is raised	My company's management acts decisively when a potential safety risk or concern is raised
Management acts quickly to correct safety problems	My company's management acts quickly to correct potential safety risks and problems
Management acts only after accidents have occurred	My company's management stresses safety only after an incident occurs on one of our projects
Management praises site employees for working safely	My company's management praises employees for thinking about safety and potential risks in their work
Management disciplines site employees for working unsafely	My company's management disciplines employees for not thinking about safety and potential risks in their work

Once the questions were generalized, the first step was to check the content validity of each question using a content validity index (CVI) procedure. The experts ranked each question on a 4-point relevancy scale, and questions with at least four experts giving the question a rating of 3 or 4 were considered content valid. Seventy of the eighty questions in the generalized survey met the criteria of being content valid. The remaining ten questions were further reviewed to consider why the experts did not consider each question valid. One important piece of data for this process was comments left by the experts. These comments when available were used to understand the train of thought of why the question was not considered content valid, and to adjust accordingly where necessary.

Another concern for the survey instrument is that the likely educational level range was potentially from high (graduate degree) for some respondents to low (high school or lower) for others. For this reason, great care was taken to ensure that the grade level scores (calculated using Flesch-Kincaid Grade Level score from Microsoft Word) were high school or lower. The average grade level score for each construct is given in Table 4.3. None of the constructs have an average score above a 10th grade level, and no individual question was above a 12th grade level.

Table 4-3: Grade-level average for questions in each construct

Construct	Grade Level Score
Management Commitment	8.9
Communication	9.9
Safety Rules and Procedures	7.7
Supportive Environment	7.8
Supervisory Environment	9.0
Workers’ Involvement	9.5
Personal Appreciation of Risk	9.2
Work Hazard Appraisal	8.0
Work Pressure	8.7
Competence	8.6
Overall Safety Climate Scale	6.0

4.3 Pilot Survey

4.3.1 Pilot Survey Demographics

The processes used to generalize the survey were important because it minimized the risk that there were obvious issues that could affect reliability in a pilot study. The survey instrument was sent via email to a wide range of construction personnel using an internet-based search. Feedback from the pilot study indicated that the 90-question survey was too long (it took 12-15 minutes to complete based on data), and this resulted in a response rate of less than 10%. This is considerably less than other similar survey research that resulted in a 16.33% response rate on the first contact with other cited rates as high as 25% (Munoz-Leiva, Sanchez-Fernandez et al. 2010).

One important takeaway from this process was the need to cut the length of the survey by approximately half in order to make the average time to take the survey in the five to ten minute range that might not seem as cumbersome. Research shows a thirteen minute or less length as the ideal length for obtaining good response rates (Fan and Yan 2010), but in this case it appears the population in questions requires a shorter survey.

The distribution of roles for the 19 respondents of the pilot study is shown in Table 4-4, and displays how results were spread across the targeted roles. There were not enough responses in each sub-group to test potential differences, but the data was useful in testing the internal consistency of the survey instrument.

Table 4-4: Role distribution of pilot survey respondents

Role	Number of Responses
Designer	1
Foreman	5
Project Engineer	2
Project Manager	3
Safety Manager	1
Superintendent	2
Upper Management	5

4.3.2 Pilot Survey Results

A pilot study of a survey on a relatively small sample is a tool to analyze how well the questions in a section are measuring the same construct before data is collected on a large population. It can also be used to test the questions in a construct that seem to be the most reliable, and thus can be used as a tool for the reducing the total length of a survey instrument while still evaluating the internal consistency.

The process for reducing the total length of the survey was to first calculate the Cronbach's Alpha score for all seven items in each construct. Some survey generation literature advises four to six items per construct in order to adequately test the homogeneity of items within each construct, but internal consistency must also be balanced against biases that result from boredom and fatigue of too many items (Hinkin 1998). Some research does show however that a minimum of three items per construct can still result in adequate internal consistency between items within a construct (Cook and Heptworth 1981). A decision was made based on the pilot results in which respondents stated the survey was considerably too long to leave three items in each construct. The response rate for the pilot survey was very low, and thus priority was given to reducing the overall length (but still leaving enough questions within each construct to be a reliable).

Items were removed based on improving the Cronbach's Alpha score for each item. If this score was maximized and more than three items were still left in the construct, then items were then removed based on reducing the overall Cronbach's Alpha score for the construct the least amount. This method was chosen in order to maximize the internal consistency of the items within each construct while minimizing the number of items as much as possible. Table 4-5 gives the results of which items were kept for the final survey instrument after completing the outlined process. The Cronbach's Alpha score for each construct is for the final question set in the third column. The lowest value for any construct is 0.67, which is very close to the general level of acceptability of 0.70 (Nunnally, Bernstein et al. 1967). All of the other constructs are approximately 0.80 or higher, which indicates a very good internal consistency for the survey instrument. The constructs are ordered according to how Mohammed's (2002) survey instrument, and this order will be used throughout the results chapter for consistency.

Table 4-5: Final survey instrument and associated construct reliability

Construct	Items Included	Cronbach's Alpha
1. Management Commitment	• My company's management clearly thinks safety is as important as other factors on a project (time, cost, quality, etc.). • My company's management shows concern if employees do not think about safety and potential risks in their work. • My company's management disciplines employees when they do not consider safety and potential risks in their work.	0.8301
2. Communication	• My company's management clearly communicates safety and risk control issues. • My company's management regularly brings safety and risk control info to the attention of employees. • My company's management has campaigns to promote considering safety and potential risks in their work.	0.8732

3. Rules and Procedures	• Current safety rules and procedures are made available to prevent and protect us from accidents. • Current safety rules and procedures meet my needs as a source of information on safety and risk control. • Current safety rules and procedures are not enforced by my company.	0.7863
4. Supportive Environment	• My company always offers help when needed to create a safe work environment. • My company tries to ensure that construction workers do not work alone in hazardous situations. • My company tries to make sure that the workload is reasonably balanced among all members.	0.8829
5. Supervisory Environment	• My supervisor (person I report to) does not think safety and risk control are important parts of the construction process. • My supervisor (person I report to) is a good resource for solving safety and risk control problems. • My supervisor (person I report to) values my ideas on how to improve safety and prevent hazards even if major changes to work methods are proposed.	0.8007
6. Workers' Involvement	• Everyone at my company reports potential hazards, incidents, and accidents no matter how severe they are. • Everyone at my company is part of safety planning for a project. • Everyone at my company contributes to a job safety/hazard analysis if they are asked.	0.8093
7. Personal Appreciation of Risk	• I understand how I can affect safety on a construction project. • I understand what my responsibilities are for safety and risk control on a construction project. • I am aware that safety/risk control should be the number one priority in my mind while working.	0.8516
8. Work Hazard Identification	• On my company's projects identifying potential hazards is not a major aim of the design process. • On my company's projects working with defective equipment is not allowed at any time. • On my company's projects potential risks and outcomes are identified prior to the start of construction work.	0.6718
9. Work Pressure	• Under pressure I at times need to depart from normal safety and risk control procedures in order to get the job done. • Under pressure it is normal for me to take shortcuts at the expense of safety. • Under pressure I tolerate minor potentially unsafe conditions on the project site.	0.8201
10. Competence	• I received adequate training on how to consider safety in my job. • I am aware of relevant safety and risk control procedures. • I fully understand current and relevant laws on occupational safety and health	0.8517

11. Overall Safety Climate	• The focus in my company on construction worker safety and the prevention and control of potential risks plays an effective role in preventing accidents. • The focus in my company on construction worker safety and the prevention and control of potential risks reduces risk for construction workers • The focus in my company on construction worker safety and the prevention and control of potential risks is not restrictive or superficial. • The focus in my company on construction worker safety and the prevention and control of potential risks helps increase output on the construction site. • The focus in my company on construction worker safety and the prevention and control of potential risks contributes to my work satisfaction. • The focus in my company on construction worker safety and the prevention and control of potential risks has a positive influence on morale.	0.8633

4.4 Final Sample Size Determination

The pilot data was used to determine the sample size required to provide a significant result while still maintaining an acceptable level of power in the test. There were 19 subjects in the sample data, and the largest role subgroup was five responses (Foreman and Upper Management). A very conservative approach was thus taken with the data because of the low sample size. Descriptive statistics of each construct were calculated using only the questions to be included in the final instrument. The largest standard deviation of any construct in this data was the Workers' Involvement construct, which had a standard deviation 0.8719 for all 19 respondents, and thus this standard deviation was used for the sample size calculations. The effect size was estimated using JMP for the foreman and upper management roles that had the most responses in the pilot data. The effect size was 0.4801 for Foremen 0.3987 for Upper Management, and thus a conservative estimate of the effect size of 0.20 was used to calculate the least standard number required for a level of significance of 0.05 and power of 0.80. The result using these parameters was a least significant number of 105 responses (approximately 15 responses per role).

4.5 Final Survey Administration

The primary contact for respondents was via email. An online version of the survey was created using the Qualtrics website, and a print version was created in Microsoft Excel. Thirteen surveys were completed manually, and these results were entered and checked for accuracy according to the sample plan in Chapter 3. None of the entered surveys had any errors (100% correct), and thus the sample was accepted. The final survey with instructions is shown in Appendix A.

Just over 3,300 people were contacted by researching the internet for contacts at organizations that fit the survey criteria. The criteria (as discussed in Chapter 3) used were organizations that primarily seemed to participate on large commercial, industrial, and heavy engineering projects based on the organization's web site. 575 (17.4%) people started the survey and 433 (13.1%) people completed it, which is just below levels cited in similar research (Munoz-Leiva, Sanchez-Fernandez et al. 2010). This was a 75.1% percent completion rate, which was probably due to the relatively high number of questions in the survey even though the median response time was just 10 minutes. The response rate could have been improved by using follow-up emails, but since the results were completely anonymous the author did not want to bother participants that had already taken the survey. Additionally, the follow-up email could be seen as harassing to those that chose not to participate, and might represent the researcher's university in a negative manner.

The breakdown by company type and role is shown in Table 4-6. The totals do not add up for every category, as some respondents left the organization type or role blank, and thus these results were not used in the relevant analysis.

Table 4-6: Breakdown of final survey respondents

Role	Firm Type				Total
	Owner	Designer	Construction Manager	Sub-contractor	
Designer	1	39	1	1	42
Foreman	2	0	11	17	30
Project Engineer	3	6	26	5	40
Project Manager	34	5	59	16	114
Safety Manager	0	0	48	10	58
Superintendent	2	0	54	11	67
Upper Management	7	10	44	17	79
Total	49	60	248	73	

4.6 Confirmatory Factor Analysis

4.6.1 Measurement Model

A confirmatory factor analysis (CFA) was performed using path modeling to determine how well the hypothesized model fits the data obtained from the survey responses. CFA can be used as a tool to assess the construct validity of a survey to determine how well individual items measure the independent factors of interest (Hinkin 1998). It is hypothesized that a set of items measure a given construct or latent variable. Figure 4-1 is as an illustration of the relationships in a hypothetical path model and can be used as an example of how the structural equation model used to test the hypothesized relationships are developed. In the model L_j represent the hypothesized latent variables, X_i represent the observed variables (items in survey instrument), f_{ij} represent the factor loadings (effect or regression slope of the latent variable on the observed variables, e_i represent the variance (including measurement error) not captured by the latent variables, and the c_{12} variable represents the co-variance between latent variables 1 and 2.

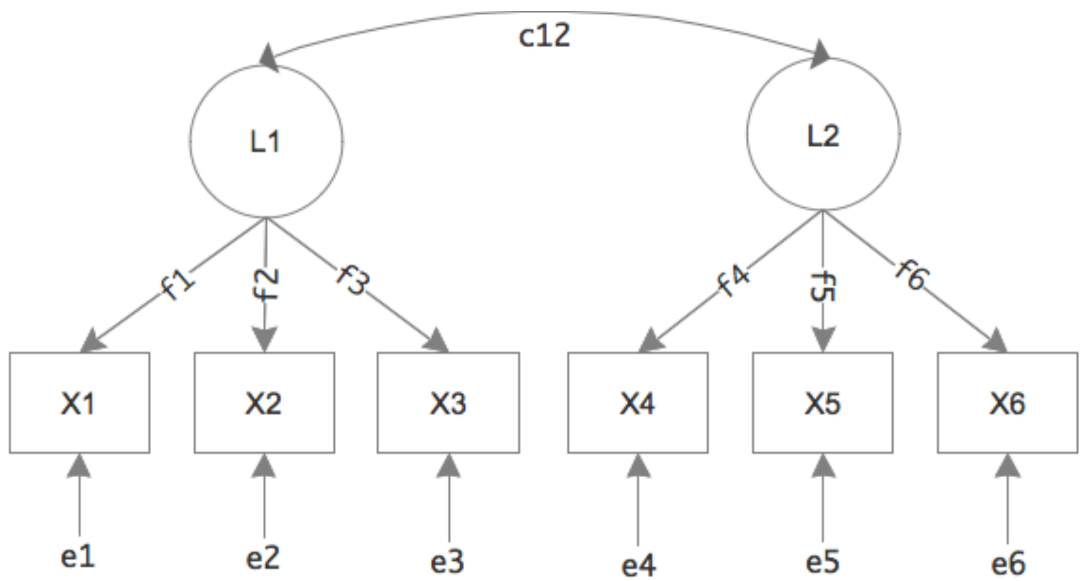


Figure 4-1: CFA measurement model example

Assuming that the deviation for each observed and latent variable is centered around each respective mean, the equation for each observed variable is summarized below and is the basis for developing the CFA population and observed covariance matrices for the survey instrument in this analysis.

$$X_i = f_{ij}L_j + e_i$$

The structural model shown in Figure 4-2 was developed based by the format used by Hatcher (1994) for Confirmatory Factor Analysis using structural equations modeling to test how constructs are related and the direction of these relationships. It is based on Mohammed's model (2002) except it does not include the 'safe work behavior' portion of the model. The intent of this research is to measure differences in safety attitudes between roles on a construction project, and not determine if those attitudes lead to safe work behavior. The measurement model is illustrated using the management commitment construct, and all constructs are measured in an identical manner as management commitment with three items (survey questions) forming the measure for each latent construct. The overall safety climate construct is also measured with survey items, but it is measured using six items.

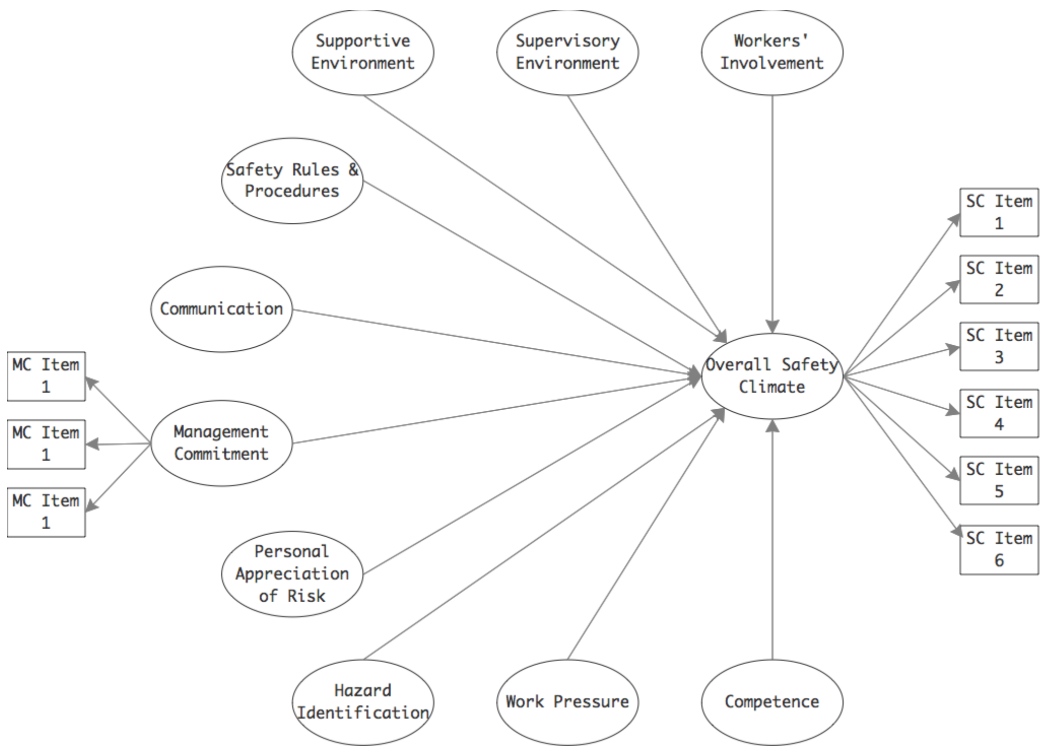


Figure 4-2: Measurement model for CFA analysis

The model was input into SAS using a structural equation model to represent the relationships between variables. The model identified a residual term for each exogenous manifest variable (square boxes), stated the variance of these residual terms should be estimated by the model, fixed the variances of the latent variables (ovals) at 1, and assumed that latent variables could co-vary and these values should be estimated. Also, the model was analyzed using means and covariances using a full information maximum likelihood estimation method instead of maximum likelihood estimation method because approximately 25% of the surveys had at least one missing item. This type of method for estimating the model has been shown to be efficient and unbiased as well as having near optimal Type I error rates for applied data sets such as the one in this research (Enders and Bandalos 2001; Raykov 2005).

4.6.2 Multicollinearity and Normality Tests

The foundation of a CFA is beginning with a model that predicts the existence of latent variables and a set of indicator variables that load on each latent variable. The model is then tested using actual data to determine whether the model does a good job of approximating the actual relationships. Hatcher (1994) describes a set of conditions that should be met in order for CFA to be a good analysis tool for determining if a structural model is an appropriate for a given set of data. The model does not meet two of these conditions, as the data appears to have multicollinearity and not be normally distributed. Multicollinearity was assessed by testing whether the regression coefficient for a given construct changed when others were added or taken out of the model. Normality was tested using the Shapiro-Wilk goodness-of-fit test, and the null hypothesis that the data is normal was rejected for all of the variables in the model.

Multicollinearity and nonnormality could be expected however for this data. Multicollinearity could be expected because all of the latent variables are indicators of the same dependent variable, and as one increases or decreases others should be correlated in the same direction. The multicollinearity problem is not severe however, as no latent constructs have extremely high correlations with another construct (see Table 4-12) at levels that have been shown to bias CFA results (Grewal, Cote et al. 2004).

Nonnormality could be expected because the survey captures ordinal data from a Likert-type scale, and respondents choosing to complete a safety survey could be expected to care about safety and potentially skew toward the top end of the scale. Nonnormality in ordinal survey data has been addressed, and with moderate skewness and kurtosis (most values less than 2.0) the maximum-likelihood method has been shown to be robust against departures from normality and the factor loadings are even less affected than the goodness of fit indices (Muthen and Kaplan 1985; Flora and Curran 2004). These values are shown in Table 4-7, and it does appear that the data displays low to moderate levels of skewness and kurtosis that suggests using a maximum likelihood method is reasonable for this data.

Table 4-7: Nonnormality data

Construct	Skewness	Kurtosis
Management Commitment	-1.64	4.04
Communication	-1.15	2.02
Safety Rules & Procedures	0.34	-0.89
Supportive Environment	-0.77	1.06
Supervisory Environment	-0.66	0.08
Worker Involvement	-0.31	-0.38
Personal Appreciation of Risk	-0.70	-0.48
Work Hazard Identification	-0.62	0.24
Work Pressure	-0.72	0
Competence	-0.64	1.08

4.6.3 Goodness of Fit Indices

A group of goodness of fit indices was used as an initial assessment of the model fit, and then a more detailed analysis of factor loadings and other indices were used to make a final determination of whether the model should be used to analyze differences in the latent factors. No one index can determine the model fit, but understanding the information each conveys and assessing them as a whole will allow an informed decision to be reached on appropriateness of the factor structure (Hatcher 1994).

Table 4-8 is an overview of the results of the model output from SAS and what each result means in terms of model fit. Overall, these fit indices indicate that the model provides an adequate fit. Some of the values are close to the rejection criteria, but are within accepted rules of thumb (Hoyle 1995; Hu and Bentler 1999; Vandenberg and Lance 2000; Chen, Sousa et al. 2005; Schreiber, Nora et al. 2006). Hu and Bentler (1999) examined these indices further, and developed a set of conditions aimed at reducing the sum of Type I and II error when evaluating CFA models. These conditions were to reject if one of the parts of the following combinations were not met:

1. CFI < 0.96, SRMSR > 0.09
2. RMSEA > 0.06, SRMSR > 0.06 (Hu and Bentler 1999).

The model in this research only meets rule 2, but overall there is enough evidence that the model provides a reasonable fit for the data.

Table 4-8: Goodness-of-fit indices overview

Description	Value from Model	Rejection Criterion	Interpretation
Chi-Square / Degrees of Freedom	2.4 (1287.13/535)	> 2.0 – 3.0	This is a rule of thumb, and there is debate as to where the cutoff for this test should be (Hatcher 1994). This test is also dependent on the sample size, and studies have shown that the same model can give different results with small versus large samples (Marsh, Balla et al. 1988). Overall models that are less than 3.0 are generally considered acceptable.
Standardized Root Mean Square Residual (SRMSR)	0.0544	> 0.08	The model is below the rejection point of 0.08
Adjusted Goodness of Fit Index (AGFI)	0.9524	< 0.95	The model is above the 0.95 rejection number, but this index has performed poorly in simulation studies and should thus be scrutinized heavily (Schreiber, Nora et al. 2006)
Root Mean Square Error of Approximation (RMSEA)	0.0576 with an upper 90% confidence interval of 0.0616	> 0.06 – 0.08 with upper confidence interval	The upper confidence interval is just above the most conservative criterion of 0.06 and below 0.08
Bentler Comparative Fit Index (CFI)	0.9020	< 0.90	The Bentler CFI indicates an acceptable fit based on general rule of thumb

The indices described above show that there is reasonable evidence that the model fits the data. These indices however are for an overall fit, and more detailed assessment of the performance of individual items in measuring each associated individual construct should be performed (Hatcher 1994; Hinkin 1998). The first analysis that was performed was on the factor loadings that are the path coefficients from the latent variables to their indicator variables in the model. The factor loading of each indicator variable needs to be assessed in order to determine how well each individual indicator is measuring its construct of interest.

4.6.4 Tests on Individual Variables

The unstandardized and standardized factor loadings along with their standard errors and t-values are shown in Table 4-9 and Table 4-10 respectively. There are no near zero standard errors such as 0.0003 for either the unstandardized or standardized results, which indicates that there is not an obvious estimation problem (Hatcher 1994). All of the t-values for both sets of results are larger than 3.291, which imply the null hypothesis for each item (that each factor loading is zero) is rejected with a p-value of less than 0.001. Additionally, all of the standardized factor loadings are greater than 0.50. In fact, 31 of the 36 items have a standardized factor loading above the 0.6 value that is considered a strong indicator (Cabrera-Nguyen 2010). All standardized factor loadings are also above a conservative cutoff of 0.5 that would define an item as a weak indicator for a latent variable when performing applied analytic research using questionnaires in which individual items are used as indicator variables (Hair, Anderson et al. 1998; Brown 2006; Cabrera-Nguyen 2010). These results indicate more evidence that the items are doing a reasonable job of measuring the latent variable they are assigned to.

Table 4-9: Unstandardized Factor Loadings

Latent Variable	Factor Loading	Estimate	Standard Error	t-value
Management Commitment	MC Item 1	1.15802	0.19887	5.82286
Management Commitment	MC Item 2	1.11023	0.18461	6.01392
Management Commitment	MC Item 3	1.16435	0.20408	5.70542
Communication	Communication Item 1	1.00529	0.14589	6.89085
Communication	Communication Item 2	1.10868	0.16008	6.92578
Communication	Communication Item 3	1.09931	0.16532	6.64951
Safety Rules & Procedures	Safety Rules Item 1	1.08586	0.14139	7.68004
Safety Rules & Procedures	Safety Rules Item 2	1.05572	0.13927	7.58033
Safety Rules & Procedures	Safety Rules Item 3	0.92314	0.13675	6.75083
Supportive Environment	Supportive Env Item 1	1.01897	0.09413	7.94318
Supportive Environment	Supportive Env Item 2	1.39005	0.12021	11.5632
Supportive Environment	Supportive Env Item 3	0.94709	0.10722	8.83356
Supervisory Environment	Supervisory Env Item 1	1.02787	0.13759	7.47029
Supervisory Environment	Supervisory Env Item 2	1.5757	0.19837	7.94318
Supervisory Environment	Supervisory Env Item 3	1.68881	0.20263	8.3344
Workers' Involvement	WI Item 1	0.94889	0.08606	11.0255
Workers' Involvement	WI Item 2	1.1574	0.09829	11.7758
Workers' Involvement	WI Item 3	0.7778	0.07367	10.5577
Personal Appreciation of Risk	Risk App Item 1	1.06426	0.14293	7.44598
Personal Appreciation of Risk	Risk App Item 2	1.05099	0.14229	7.3861
Personal Appreciation of Risk	Risk App Item 3	1.00047	0.14287	7.00264
Work Hazard Identification	Hazard ID Item 1	0.95116	0.11535	8.24563
Work Hazard Identification	Hazard ID Item 2	1.07717	0.11016	9.77863
Work Hazard Identification	Hazard ID Item 3	1.02943	0.10459	9.84209
Work Pressure	Pressure Item 1	1.04299	0.12173	8.5681
Work Pressure	Pressure Item 2	0.85968	0.10229	8.40398
Work Pressure	Pressure Item 3	1.00766	0.12161	8.28577
Competence	Competence Item 1	1.00387	0.12641	7.94147
Competence	Competence Item 2	0.83729	0.10376	8.06954
Competence	Competence Item 3	0.88531	0.12015	7.36843
Overall Safety Climate	SC Item 1	0.91163	0.09524	9.5724
Overall Safety Climate	SC Item 2	0.95452	0.09559	9.98533
Overall Safety Climate	SC Item 3	0.87063	0.09904	8.79063
Overall Safety Climate	SC Item 4	0.86687	0.10154	8.53701
Overall Safety Climate	SC Item 5	1.05633	0.10734	9.84075
Overall Safety Climate	SC Item 6	1.01193	0.10482	9.65439

Table 4-10: Standardized Factor Loadings

Latent Variable	Factor Loading	Estimate	Standard Error	t-value
Management Commitment	MC Item 1	0.68952	0.03263	21.1328
Management Commitment	MC Item 2	0.80415	0.02788	28.8464
Management Commitment	MC Item 3	0.62778	0.03576	17.5561
Communication	Comm Item 1	0.84353	0.01772	47.5931
Communication	Comm Item 2	0.86698	0.01627	53.279
Communication	Comm Item 3	0.70591	0.02328	26.1074
Safety Rules & Procedures	Rules Item 1	0.77497	0.02534	30.5887
Safety Rules & Procedures	Rules Item 2	0.74129	0.02706	27.3966
Safety Rules & Procedures	Rules Item 3	0.5341	0.03834	13.9296
Supportive Environment	Supportive Env Item 1	0.65849	0.03179	20.714
Supportive Environment	Supportive Env Item 2	0.72505	0.02865	25.3029
Supportive Environment	Supportive Env Item 3	0.50123	0.003922	12.7805
Supervisory Environment	Supervisory Env Item 1	0.57021	0.03603	14.3743
Supervisory Environment	Supervisory Env Item 2	0.64838	0.03312	17.9961
Supervisory Environment	Supervisory Env Item 3	0.71976	0.03312	21.7303
Workers' Involvement	WI Item 1	0.71888	0.02954	24.3381
Workers' Involvement	WI Item 2	0.7897	0.0259	30.4855
Workers' Involvement	WI Item 3	0.67427	0.03203	21.0499
Personal Appreciation of Risk	Risk App Item 1	0.8769	0.01906	45.9965
Personal Appreciation of Risk	Risk App Item 2	0.85084	0.02021	42.1007
Personal Appreciation of Risk	Risk App Item 3	0.6746	0.03003	22.4605
Work Hazard Identification	Hazard ID Item 1	0.51049	0.03942	12.9504
Work Hazard Identification	Hazard ID Item 2	0.67249	0.032	21.0158
Work Hazard Identification	Hazard ID Item 3	0.68072	0.03165	21.5046
Work Pressure	Pressure Item 1	0.83379	0.02319	35.9608
Work Pressure	Pressure Item 2	0.82936	0.02452	33.8215
Work Pressure	Pressure Item 3	0.75186	0.02701	27.8341
Competence	Competence Item 1	0.80771	0.02328	34.6988
Competence	Competence Item 2	0.85001	0.02132	39.8704
Competence	Competence Item 3	0.63435	0.3324	19.0824
Overall Safety Climate	SC Item 1	0.73886	0.09524	9.5724
Overall Safety Climate	SC Item 2	0.8207	0.02467	9.98533
Overall Safety Climate	SC Item 3	0.61845	0.01898	8.79063
Overall Safety Climate	SC Item 4	0.58535	0.10154	8.53701
Overall Safety Climate	SC Item 5	0.79119	0.10734	9.84075
Overall Safety Climate	SC Item 6	0.7556	0.10482	9.65439

The R^2 values for each item are a measure of association of each item to its underlying dimension. None of the items had a R^2 value lower than 0.25 and 30 of the 36 items had a value of 0.4 or greater. The values are given in Table 4-11 below, and there are no extremely low values that would suggest an item is not at least explaining a moderate portion of its construct's measured variance.

Table 4-11: R^2 values and correlation with construct for each survey item

Latent Variable	R^2	R	Correlation with Associated Construct
Management Commitment Item 1	0.47544	0.6895	0.7944
Management Commitment Item 2	0.64666	0.8042	0.8399
Management Commitment Item 3	0.39411	0.6278	0.7863
Communication Item 1	0.71154	0.8435	0.8571
Communication Item 2	0.75165	0.8671	0.8935
Communication Item 3	0.49831	0.7059	0.8635
Safety Rules & Procedures Item 1	0.60058	0.7750	0.806
Safety Rules & Procedures Item 2	0.54951	0.7413	0.8081
Safety Rules & Procedures Item 3	0.28526	0.5341	0.755
Supportive Environment Item 1	0.4336	0.6584	0.7559
Supportive Environment Item 2	0.5257	0.7251	0.8067
Supportive Environment Item 3	0.25123	0.5012	0.7353
Supervisory Environment Item 1	0.32513	0.5702	0.7038
Supervisory Environment Item 2	0.4204	0.6484	0.8189
Supervisory Environment Item 3	0.51805	0.7198	0.8142
Workers' Involvement Item 1	0.51679	0.7189	0.8247
Workers' Involvement Item 2	0.62363	0.7897	0.8771
Workers' Involvement Item 3	0.45464	0.6743	0.7731
Personal Appreciation of Risk Item 1	0.76895	0.8769	0.8886
Personal Appreciation of Risk Item 2	0.72392	0.8508	0.8692
Personal Appreciation of Risk Item 3	0.45509	0.6746	0.8436
Work Hazard Identification Item 1	0.2606	0.5105	0.7576
Work Hazard Identification Item 2	0.45224	0.6725	0.7507
Work Hazard Identification Item 3	0.46338	0.6807	0.7821
Work Pressure Item 1	0.69521	0.8338	0.889
Work Pressure Item 2	0.68783	0.8294	0.8545
Work Pressure Item 3	0.56539	0.7519	0.8822
Competence Item 1	0.6524	0.8077	0.8522
Competence Item 2	0.72251	0.8500	0.8545
Competence Item 3	0.40239	0.6343	0.8218
Overall Safety Climate Item 1	0.54592	0.7389	0.7401
Overall Safety Climate Item 2	0.67356	0.8207	0.7995
Overall Safety Climate Item 3	0.38248	0.6184	0.7074
Overall Safety Climate Item 4	0.34264	0.5854	0.726
Overall Safety Climate Item 5	0.62598	0.7912	0.8415
Overall Safety Climate Item 6	0.57093	0.7556	0.8166

The residuals can also be analyzed to assess the fit of the model, and if the model provides a good fit for the data the residuals should be zero or near zero (Hatcher 1994). The distribution of the residuals should initially be evaluated to determine if it is centered on zero, symmetrical, and contain no or few large residuals. Figure 4-3 displays the distribution of the residuals, and it does appear that it meets the three criteria outlined above. The average standardized residual of the model was 0.0345, and the largest individual residual was 0.17123. Hatcher (1994) states that standardized residuals over 2.00 are considered problematic, and all of the residuals are well below this value. The residuals also support that the proposed model does a sufficient job of representing the data.

Range ID	Range		Frequency	Percent of Total
1	-0.155	-0.103	1	0.14%
2	-0.103	-0.052	64	9.12%
3	-0.052	0	254	36.18%
4	0	0.0515	273	38.89%
5	0.0515	0.1031	98	13.96%
6	0.1031	0.1546	11	1.57%
7	0.1546	0.2061	1	0.14%

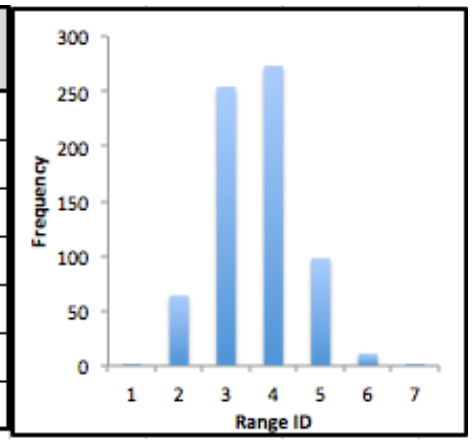


Figure 4-2: Residual analysis

4.6.5 Reliability and Validity of Measurement Model

In addition to analyzing the significance of the individual factor loadings and residuals, tests should also be run to assess the reliability and validity of the measurement model. The three-step process suggested by Fornell and Larcker (1981) and followed by Mohamed (2002) to assess individual item reliability, convergent validity, and discriminant validity of the independent constructs will be used.

1. *Individual Item Reliability* – Individual item reliability was evaluated by using the simple correlation between each item and its associated construct. 0.70 was used as the cutoff value, and the lowest individual correlation between an item and its construct for this data was 0.7038 for supervisory environment item 1. A value greater than 0.70 suggests that less than half of an items variance is due to error (Fornell and Larcker 1981). These values are given in Table 4-11 above.
2. *Convergent Validity* – Convergent validity will be evaluated using Cronbach's Alpha to determine the homogeneity of the set of items that are supposed to be measuring a given construct. The Cronbach's Alpha for each construct is shown in Table 4-12 and seven of the ten constructs have a value above the 0.70 value generally found in the literature as an acceptable cutoff (Nunnally, Bernstein et al. 1967). None of the remaining three are below 0.6418, and there is literature that suggests 0.60 is an acceptable value for newly developed scales such as the one in this research with a relatively few number of items measuring each construct (Churchill Jr 1979; Litwin 1995; Hair, Anderson et al. 1998). Overall, the data shows an acceptable level of internal consistency when evaluating new items being used to measure existing constructs.

3. *Discriminant Validity* – The average variance extracted will be used to measure how each construct differs from other constructs in the model. The individual factor loadings and error variances were used to calculate the average variance extracted using the following formula (A_v=average variance extracted, L_i=factor loading, var(e_i)= error variance associated with item):

$$A_v = \frac{\sum L_i^2}{\sum L_i^2 + \sum var(e_i)}$$

The average variance extracted measures the amount of variance due to the underlying factor of interest in relation to the amount of variance attributed to measurement error, and is shown in Table 4-12. All of the A_v values are well above the minimum value of 0.5 suggested by Fornell and Larcker (1981). Additionally, the square root of average variance extracted is also greater than the largest correlation between the construct and another construct (the variance shared between two constructs), which also implies significant discriminant validity (Mohamed 2002).

Table 4-12 follows, and summarizes these values for each construct.

Table 4-12: Reliability and validity measures of independent constructs

Construct	Cronbach's Alpha	Average Variance Extracted	Square Root of Average Variance Extracted	Highest Correlation with Another Construct
Management Commitment	0.7157	0.7855	0.8863	0.5996 (Communication)
Communication	0.8322	0.8167	0.9037	0.6728 (Safety Rules & Procedures)
Safety Rules & Procedures	0.6856	0.7745	0.8801	0.6728 (Communication)
Supportive Environment	0.6418	0.7728	0.8791	0.6459 (Communication)
Supervisory Environment	0.6769	0.8572	0.9259	0.5606 (Supportive Environment)
Worker Involvement	0.7658	0.7052	0.8398	0.6192 (Work Hazard Identification)
Personal Appreciation of Risk	0.8267	0.8833	0.9398	0.5172 (Competence)
Work Hazard Identification	0.8267	0.6829	0.8264	0.6192 (Worker Involvement)
Work Pressure	0.8393	0.7549	0.8688	0.4312 (Work Hazard Identification)
Competence	0.7787	0.7617	0.8728	0.5557 (Safety Rules & Procedures)

Overall, the model appears to be a good fit with for the data based on analysis of overall goodness-of-fit indices and examination of individual item performance. This suggests that the measurement model can be used to test for differences between latent variables (constructs), and that the items are doing a reasonable job in measuring these constructs.

4.7 Phase I Results

4.7.1 Overview

As stated, the measurement model appears to be a good fit with the data and can be used to test for differences between latent variables. Figure 4-4 presents the average score for each construct from the sample. While there does appear to be differences in the data, more analysis needs to be performed in order to identify the appropriate tests that need to be performed in order to identify potential differences. The following section discusses the processes and tests used to identify the appropriate analysis that should be performed on the sample.

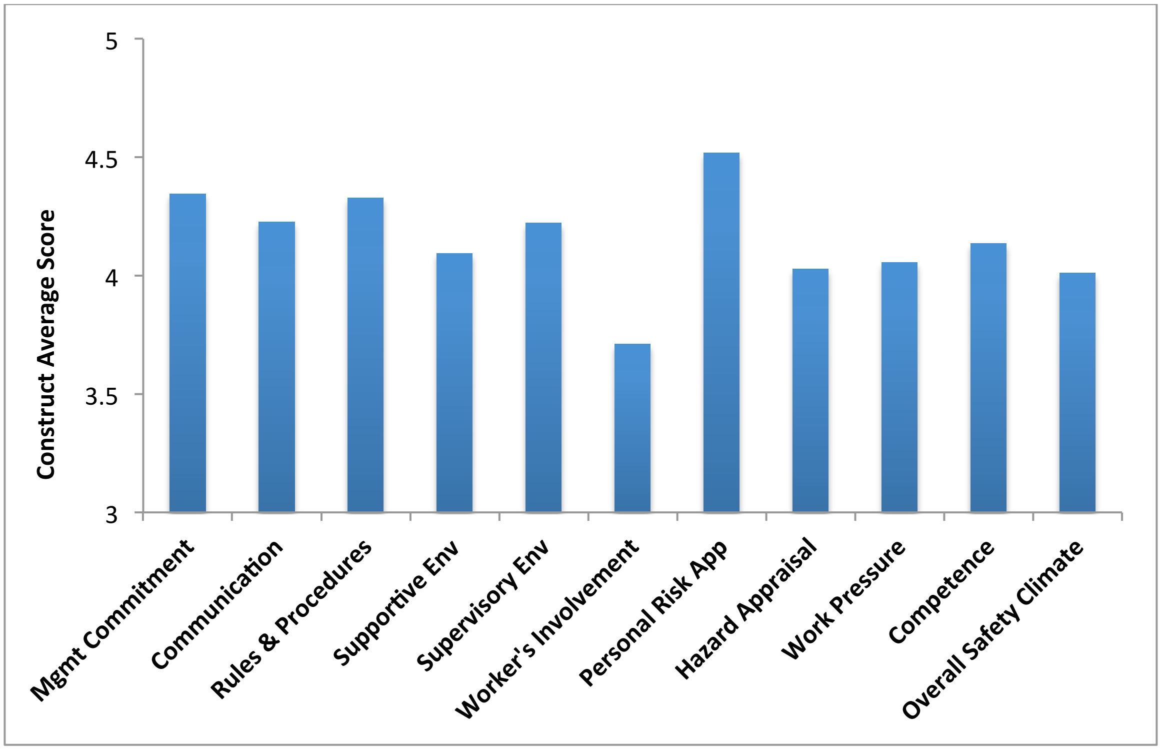


Figure 4-3: Average Score by Construct

One of the main goals of this research is to use a survey instrument to collect data that can be used to look for differences between groups. A common method to accomplish this task is to use an ANOVA procedure to test for differences between subgroups. While ANOVA does not make any assumptions on the relationship between the independent and dependent variable, it does however depend on the distribution of the responses to be approximately normal since it is based on the mean statistic. Serious departures from this assumption can mean that the ANOVA procedure is not an appropriate measure, and that other tests such as nonparametric ones based on the median and rank statistics might be more appropriate. The data could be transformed in some cases, but with ordinal survey data converting from an ordinal to a numerical scale risks giving misleading results (Kitchenham and Pfleeger 2003).

To test the normality of the results, the distribution of each scale (ten constructs and overall safety climate) using the sum of the three questions that comprise each construct (six for overall safety climate). A normal curve was fit to the data, and then a Shapiro-Wilk test was used to test whether the data was normal. The null hypothesis for this test is that the data is from a normal distribution, and thus rejecting the null hypothesis is analogous to saying the data does not appear normal. The test statistic for each construct is shown in Table 4-13, and it does not appear that the sampling distribution of any of the constructs appears to be normal. The p-value of all of the constructs is actually less than 0.0001, which is well below any threshold that could be used to state that the results are normally distributed.

Table 4-13: Shapiro-Wilk normality results

Construct	Shapiro-Wilk W Statistic	p-Value
Management Commitment	0.823	< 0.0001
Communication	0.874	< 0.0001
Safety Rules & Procedures	0.898	< 0.0001
Supportive Environment	0.933	< 0.0001
Supervisory Environment	0.923	< 0.0001
Worker Involvement	0.964	< 0.0001
Personal Appreciation of Risk	0.815	< 0.0001
Work Hazard Identification	0.942	< 0.0001
Work Pressure	0.912	< 0.0001
Competence	0.918	< 0.0001
Overall Safety Climate	0.968	< 0.0001

As shown in Table 4-6 previously, the sample size for each of the roles are not equal. Unequal sample sizes could also lead to misleading results if the variances for any of the constructs are drastically different. Thus, tests for unequal variances were run in JMP to determine whether there was evidence that the variances between roles differed. The Brown-Forsythe test was used, because it is based on the median and is robust against non-normal data (Neter, Wasserman et al. 1996; Vargha and Delaney 1998; Grissom 2000). The null hypothesis for this test is that the variances are equal, and thus rejecting the null hypothesis at a given confidence level implies there is evidence of unequal variances. These results are in Table 4-14, and show that all of the constructs except communication and personal appreciation of risk appear to have equal variances at a confidence level of $\alpha = 0.05$.

Table 4-14: Brown-Forsythe test results

Construct	F Ratio	p-Value
Management Commitment	0.8088	0.5635
Communication	2.62	0.0166*
Safety Rules & Procedures	1.8342	0.0910
Supportive Environment	0.7355	0.6229
Supervisory Environment	1.0356	0.4014
Worker Involvement	0.9372	0.4679
Personal Appreciation of Risk	3.6380	0.0016*
Work Hazard Identification	0.5503	0.7697
Work Pressure	0.5042	0.8053
Competence	0.3776	0.8933
Overall Safety Climate	1.0053	0.7697

A post-hoc analysis was conducted on the Communication and Personal Appreciation of Risk constructs to study the differences more in-depth. Figure 4-5 shows the results of an Analysis of Means for the Variances for Communication and Personal Appreciation of Risk respectively. It shows that that role 6 (superintendent) in communication and role 5 (safety manager) in personal appreciation of risk appear to be the only roles outside the determination limits. Remedial actions were taken for these constructs when appropriate to account for these results.

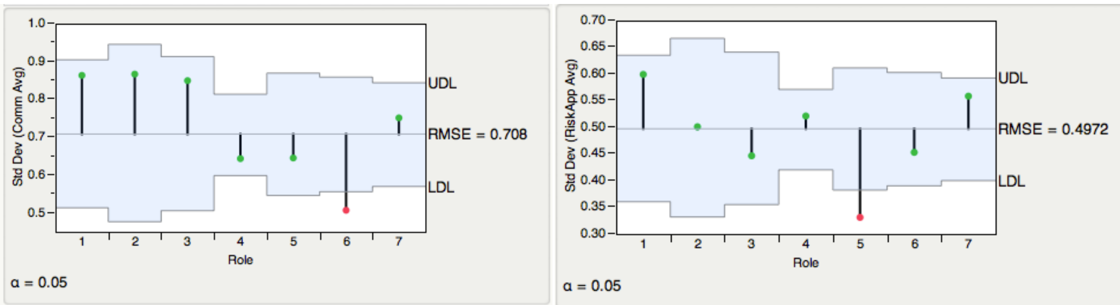


Figure 4-4: Analysis of Means for Variances of Communication and Personal Appreciation of Risk constructs

4.7.2 Differences Between Roles

Nonparametric equivalence tests can be used to determine if there are differences between the roles for each construct from the survey. These tests are based on the median, and thus are robust against departures from normality by ranking all groups (role) together (Neter, Wasserman et al. 1996; Chan and Walmsley 1997). As shown above, the survey data does not appear to be normal and transformations were not an option with the ordinal data. The first test that was performed was the Kruskal-Wallis one-way analysis of variance by ranks, which is equivalent to a one-way ANOVA for parametric, normal data. This test assumes identically shaped distributions and variances for the data, and tests for a difference in medians. All of the distributions for each construct are shown in Appendix B, and when broken down by role each construct also seems to be distributed similarly.

The Welch test was performed on the communication and appreciation of risk constructs. The Welch test uses a t-test process, but does not use a pooled variance estimate in order to allow for unequal variances between groups. This test is recommended when samples have unequal variances, and has been shown to minimize Type 1 and II errors as compared to other alternative tests (Tomarken and Serlin 1986; Schneider and Penfield 1997; Fagerland and Sandvik 2009).

The chi-squared test statistic and associated p-value of the Kruskal-Wallis tests are in Table 4-15, and each test had 6 degrees of freedom (7 roles in analysis - 1). The test statistic for the communication and personal appreciation of risk constructs are the F-ratio from the Welch test. All of the constructs except management commitment, worker involvement, and work hazard identification have a p-value less than 0.05. This means that there is at least one significant difference between a pair of roles within each construct at a 95% level of confidence. There is also evidence of a difference within worker involvement, as its p-value of 0.0799 is close to the threshold value. The next step in the analysis is post-hoc tests to determine the location of the differences identified in Table 1.

Table 4-15: Results of Kruskal-Wallis analysis of variance by ranks test of differences between roles

Construct	Test Statistic	p-Value
Management Commitment	4.6817	0.5852
Communication	2.6509 (F-test)	0.0180
Safety Rules & Procedures	26.2107	0.0002
Supportive Environment	13.8235	0.0317
Supervisory Environment	14.8324	0.0216
Worker Involvement	11.2880	0.0799
Personal Appreciation of Risk	10.70 (F-test)	< 0.0001
Work Hazard Identification	7.2551	0.2979
Work Pressure	13.1791	0.0403
Competence	43.4661	< 0.0001
Overall Safety Climate	33.8691	< 0.0001

Note – gray cells have p-value greater than 0.10

Post-hoc nonparametric comparisons were run using the Steel-Dwass method to determine the location of the differences identified in Table 4-15. This test was run on all possible comparisons within each construct, and controls for the overall level of significance of the tests by accounting for multiple comparisons being performed. This test is the nonparametric version of the Tukey-Kramer test, and is conservative when there is a difference in sample size between groups such as the case with this data (Hayter 1984). The results are summarized in Table 4-16, and all differences with a p-value less than 0.10 are reported.

Table 4-16: Results of Steel-Dwass Test

Construct	Role 1 (Higher Median Rank)	Role 2 (Lower Median Rank)	Z-score	p-value
Communication	Project Engineer	Designer	3.08	0.0342
	Project Manager	Designer	2.94	0.0512
	Safety Manager	Designer	3.09	0.0329
	Superintendent	Designer	3.62	0.0055
	Upper Management	Designer	3.12	0.0303
Safety Rules and Procedures	Foreman	Designer	3.19	0.0237
	Project Engineer	Designer	3.38	0.0127
	Project Manager	Designer	4.34	0.0003
	Safety Manager	Designer	4.60	< 0.0001
	Superintendent	Designer	4.07	0.0009
	Upper Management	Designer	3.85	0.0022
Supportive Environment	Project Engineer	Designer	2.77	0.0812
	Safety Manager	Designer	2.88	0.0610
	Upper Management	Designer	3.21	0.0226
Supervisory Environment	Safety Manager	Project Manager	2.93	0.0534
Workers' Involvement	Upper Management	Designer	3.07	0.0345
Personal Appreciation of Risk	Foreman	Designer	2.77	0.0808
	Project Engineer	Designer	3.24	0.0207
	Project Manager	Designer	3.65	0.0049
	Safety Manager	Designer	6.13	< 0.0001
	Superintendent	Designer	4.51	0.0001
	Upper Management	Designer	3.88	0.0020
	Safety Manager	Foreman	3.08	0.0341
	Safety Manager	Project Engineer	3.57	0.0066
	Safety Manager	Project Manager	4.07	0.0009
	Safety Manager	Upper Management	-2.86	0.0641
Work Pressure	Safety Manager	Superintendent	-3.04	0.0380
Competence	Safety Manager	Designer	5.59	< 0.0001
	Safety Manager	Project Engineer	4.08	0.0009
	Safety Manager	Project Manager	4.85	< 0.0001
	Safety Manager	Superintendent	-3.47	0.0095
	Safety Manager	Upper Management	-3.18	0.0250
	Foreman	Designer	2.80	0.0764
	Superintendent	Designer	3.05	0.0374
	Upper Management	Designer	3.68	0.0044
Overall Safety Climate	Project Manager	Designer	2.80	0.0757
	Safety Manager	Designer	4.66	< 0.0001
	Superintendent	Designer	3.16	0.0267
	Upper Management	Designer	3.33	0.0155
	Safety Manager	Project Engineer	3.69	0.0042
	Safety Manager	Project Manager	3.96	0.0014
	Safety Manager	Superintendent	-3.21	0.0228

The main trends in the results of this test are that designers seem to have lower attitudes toward safety in several constructs, while safety managers have higher attitudes in several constructs. Designers have lower attitudes than multiple other roles in communication, safety rules and procedures, supportive environment, personal appreciation of risk, competence, and overall safety climate. Safety Managers on the other hand have higher attitudes than multiple other roles in personal appreciation of risk, competence, and overall safety climate.

The results for designers are interesting because they align with safety in design literature discussed previously that states designers can have an important impact on safety but few in the U.S. consider safety. The results are useful because they show what areas might need to be focused on to improve designers' safety attitudes. For example, designers do not perceive as much communication or as much of a supportive environment in regards to safety as other roles in the construction supply chain. These two areas as well as safety rules and procedures could be two mechanisms to improve safety competence for designers. They also do not appreciate risk as much as other roles, which might explain some of the reasons safety is not always considered in the design phase.

As for safety managers, it can be expected that they have higher safety attitudes than other roles based on their job description. It could be expected that they have a higher personal appreciation of risk since their roles involves risk control on construction projects. This could also be a training opportunity on construction projects, as other roles do not seem to have as much regard for risk on the construction site. It could also be expected that safety managers have a higher competence in regards to safety, as it would be expected they have had a great deal of safety training. One potential takeaway from this result is that safety managers need to ensure that they are not over-estimating competence in regards to construction for those they work with.

4.7.3 Differences within Roles

The results between roles are useful in comparing how roles compare to others in terms of strength of attitudes within each construct. Similarly, roles can be analyzed in isolation to determine the strength of attitudes within one construct compared to other constructs for each role separately. These differences can be assessed using a matched pairs procedure if it is assumed that each respondent is an independent rater/judge. The first step in this process is to conduct a Friedman test to determine if there are any significant differences between constructs within each role. This is similar to an ANOVA for parametric data, and if significant differences are found then post-hoc tests can be run to locate the differences. Each construct had a p-value of less than 0.001, indicating that post-hoc tests can be run.

In order to determine the location of significant differences within each role, a nonparametric version of the paired t-test can be performed. A Wilcoxon Signed Rank Test is the equivalent of a paired t-test for nonparametric data, and tests whether there is a difference between two groups by testing whether the median difference between two groups is zero. The main assumption in this test is that the distribution of the difference between the two groups is symmetric, which was tested by calculating each paired difference and plotting the distribution. There are 45 paired differences for this data (10 constructs), and the distributions for these differences appeared to be normal in the plots.

Additionally, since there are 45 differences to be compared a Bonferroni adjustment should be made to establish a level of significance for the overall family of tests in order to account for an increased likelihood of Type I error in individual tests. This can be made by dividing the level of significance for individual tests by the number of tests being performed. In this case we want to determine what constructs seem to be rated less than others by respondents, and thus a somewhat liberal level of significance of 0.10 can be used for each test given the goal. After making the Bonferroni adjustment the level of significance to reject the null hypothesis that there is not a difference between the groups is 0.10/45 = 0.00222. The result of the Wilcoxon Signed Rank Test for each role with an overall significance of 0.10 is shown below in Tables 4-17 through 4-23 below.

Table 4-17: Wilcoxon Signed Ranked Test for Designer subgroup

Designer (n=42)		Mgt Commit	Comm	Safety Rules & Proc	Support Env	Super Env	Worker Inv	App of Risk	Work Haz ID	Work Pressure	Comp	Count of p-value < 0.00222
	Overall Avg	4.21	3.82	3.92	3.8	4.1	3.5	4.08	3.84	3.97	3.77	
Management Commitment	4.21											0
Communication	3.82	0.0001										1
Safety Rules & Procedures	3.92	0.0006	0.7495									1
Supportive Environment	3.8	0.0002	0.5596	0.4404								2
Supervisory Environment	4.1	0.092	0.9946	0.9912	0.9983							0
Worker Involvement	3.5	< 0.0001	0.0153	0.0003	0.0004	< 0.0001						7
Personal Appreciation of Risk	4.08	0.1396	0.9832	0.965	0.9976	0.4894	0.9999					0
Work Hazard Identification	3.84	0.0004	0.5983	0.2914	0.5607	0.0061	0.9989	0.002				2
Work Pressure	3.97	0.0222	0.878	0.6091	0.9043	0.1486	0.9999	0.1463	0.8807			0
Competence	3.77	< 0.0001	0.4543	0.0688	0.2856	0.0033	0.9924	0.0008	0.2717	0.0875		2

Table 4-18: Wilcoxon Signed Ranked Test for Foreman subgroup

Foreman (n=30)		Mgt Commit	Comm	Safety Rules & Proc	Support Env	Super Env	Worker Inv	App of Risk	Work Haz ID	Work Pressure	Comp	Count of p-value < 0.00222
	Overall Avg	4.39	4.26	4.37	4.13	4.41	3.71	4.5	4.1	4.18	4.18	
Management Commitment	4.39											0
Communication	4.26	0.091										0
Safety Rules & Procedures	4.37	0.4416	0.8709									0
Supportive Environment	4.13	0.0179	0.1228	0.0079								1
Supervisory Environment	4.41	0.4931	0.9472	0.572	0.9985							0
Worker Involvement	3.71	< 0.0001	0.0001	< 0.0001	0.0001	< 0.0001						8
Personal Appreciation of Risk	4.5	0.6033	0.8681	0.7834	0.9971	0.5861	0.9999					0
Work Hazard Identification	4.1	0.0108	0.1589	0.0096	0.4971	0.003	0.9999	0.0052				0
Work Pressure	4.18	0.0929	0.1788	0.1341	0.3939	0.0299	0.9926	0.0165	0.5603			0
Competence	4.18	0.0279	0.2581	0.0066	0.6578	0.0037	0.9998	0.0019	0.7372	0.6272		1

Table 4-19: Wilcoxon Signed Ranked Test for Project Engineer subgroup

Project Engineer (n=40)		Mgt Commit	Comm	Safety Rules & Proc	Support Env	Super Env	Worker Inv	App of Risk	Work Haz ID	Work Pressure	Comp	Count of p-value < 0.00222
	Overall Avg	4.41	4.33	4.35	4.14	4.19	3.58	4.5	4.1	4.18	4.18	
Management Commitment	4.41											0
Communication	4.33	0.2354										0
Safety Rules & Procedures	4.35	0.217	0.5									0
Supportive Environment	4.14	0.0006	0.0164	0.0014								3
Supervisory Environment	4.19	0.0035	0.0523	0.0397	0.6444							1
Worker Involvement	3.58	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001						9
Personal Appreciation of Risk	4.5	0.8247	0.8018	0.9134	0.9994	0.9997	0.9999					0
Work Hazard Identification	4.1	< 0.0001	0.0007	0.0001	0.1014	0.0404	0.9999	< 0.0001				4
Work Pressure	4.18	0.0004	0.0139	0.0019	0.1913	0.0377	0.9983	< 0.0001	0.3869			3
Competence	4.18	< 0.0001	0.0026	0.0024	0.1295	0.053	0.9998	< 0.0001	0.6398	0.6857		2

Table 4-20: Wilcoxon Signed Ranked Test for Project Manager subgroup

Project Manager (n=114)		Mgt Commit	Comm	Safety Rules & Proc	Support Env	Super Env	Worker Inv	App of Risk	Work Haz ID	Work Pressure	Comp	Count of p-value < 0.00222
	Overall Avg	4.38	4.23	4.38	4.08	4.13	3.78	4.49	4.1	4.04	4.06	
Management Commitment	4.38											0
Communication	4.23	0.0023										2
Safety Rules & Procedures	4.38	0.4168	0.9999									0
Supportive Environment	4.08	< 0.0001	0.0033	< 0.0001								3
Supervisory Environment	4.13	< 0.0001	0.1089	< 0.0001	0.7791							3
Worker Involvement	3.78	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001						9
Personal Appreciation of Risk	4.49	0.984	0.9999	0.9861	0.9999	0.9999	0.9999					0
Work Hazard Identification	4.1	< 0.0001	0.0124	< 0.0001	0.535	0.2544	0.9999	< 0.0001				3
Work Pressure	4.04	< 0.0001	0.0253	< 0.0001	0.4683	0.3799	0.9993	< 0.0001	0.4102			3
Competence	4.06	< 0.0001	0.0029	< 0.0001	0.3184	0.1072	0.9999	< 0.0001	0.1872	0.3539		3

Table 4-21: Wilcoxon Signed Ranked Test for Safety Manager subgroup

Safety Manager (n=58)		Mgt Commit	Comm	Safety Rules & Proc	Support Env	Super Env	Worker Inv	App of Risk	Work Haz ID	Work Pressure	Comp	Count of p-value < 0.00222
	Overall Avg	4.39	4.25	4.48	4.13	4.42	3.6	4.8	4.03	4.26	4.49	
Management Commitment	4.39											1
Communication	4.25	0.0066										3
Safety Rules & Procedures	4.48	0.7631	0.9999									1
Supportive Environment	4.13	< 0.0001	0.0113	< 0.0001								5
Supervisory Environment	4.42	0.508	0.9551	0.1281	0.9996							1
Worker Involvement	3.6	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001						9
Personal Appreciation of Risk	4.8	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999					0
Work Hazard Identification	4.03	< 0.0001	0.0013	< 0.0001	0.0274	< 0.0001	0.9999	< 0.0001				6
Work Pressure	4.26	0.1075	0.5709	0.0415	0.9173	0.0826	0.9999	< 0.0001	0.9974			1
Competence	4.49	0.9121	0.9995	0.6506	0.9999	0.7647	0.9999	< 0.0001	0.9999	0.9874		1

Table 4-22: Wilcoxon Signed Ranked Test for Superintendent subgroup

Superintendent (n=67)		Mgt Commit	Comm	Safety Rules & Proc	Support Env	Super Env	Worker Inv	App of Risk	Work Haz ID	Work Pressure	Comp	Count of p-value < 0.00222
	Overall Avg	4.33	4.36	4.39	4.12	4.23	3.74	4.62	4.04	3.84	4.14	
Management Commitment	4.33											1
Communication	4.36	0.3604										1
Safety Rules & Procedures	4.39	0.4786	0.7525									1
Supportive Environment	4.12	0.0007	< 0.0001	< 0.0001								4
Supervisory Environment	4.23	0.5631	0.0247	0.0376	0.926							1
Worker Involvement	3.74	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001						8
Personal Appreciation of Risk	4.62	0.9998	0.9999	0.9999	0.9999	0.9999	0.9999					0
Work Hazard Identification	4.04	0.0002	< 0.0001	< 0.0001	0.1753	0.0057	0.9999	< 0.0001				4
Work Pressure	3.84	< 0.0001	< 0.0001	< 0.0001	0.0068	0.0002	0.917	< 0.0001	0.0316			5
Competence	4.14	0.0047	0.005	0.0005	0.6414	0.1319	0.9999	< 0.0001	0.8519	0.9953		2

Table 4-23: Wilcoxon Signed Ranked Test for Upper Management subgroup

Upper Management (n=79)		Mgt Commit	Comm	Safety Rules & Proc	Support Env	Super Env	Worker Inv	App of Risk	Work Haz ID	Work Pressure	Comp	Count of p-value < 0.00222
	Overall Avg	4.32	4.28	4.36	4.19	4.24	3.87	4.54	4.03	4.15	4.21	
Management Commitment	4.32											0
Communication	4.28	0.0332										1
Safety Rules & Procedures	4.36	0.2013	0.83									0
Supportive Environment	4.19	0.0019	0.0234	0.0013								3
Supervisory Environment	4.24	0.0104	0.1393	0.0092	0.8997							1
Worker Involvement	3.87	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001						7
Personal Appreciation of Risk	4.54	0.8772	0.9995	0.9959	0.9999	0.9999	0.9999					0
Work Hazard Identification	4.03	< 0.0001	< 0.0001	< 0.0001	0.01	0.0005	0.9856	< 0.0001				6
Work Pressure	4.15	0.0089	0.0575	0.0069	0.3208	0.1621	0.9966	< 0.0001	0.9427			1
Competence	4.21	0.0032	0.0174	0.0011	0.5878	0.2833	0.9999	< 0.0001	0.9982	0.7287		2

The results of the post-hoc Wilcoxon Signed Rank Tests reveal some interesting results. The most obvious result is that the Worker Involvement construct was significantly lower than at least seven of the other nine constructs within all seven roles. Thus, every role surveyed had statistically significant lower attitudes toward how everyone at their company is involved in the safety process than at least 78% of the other constructs measured. This highlights that personnel throughout the construction project lifecycle view safety as something that not everyone is involved in, and is an opportunity for improvement.

Some other key results from the post-hoc tests are summarized as follows:

1. The attitudes toward safety seem to be level for designers and foremen (outside of the Worker Involvement construct), as no other construct is significantly lower than 2 other constructs
2. Work Hazard Identification is significantly lower than four other constructs for the Project Engineer role, and Work Pressure and Supportive Environment are both significantly lower than 3 other constructs
3. Management Commitment, Safety Rules and Procedures, and Personal Appreciation of Risk are clustered in the Project Manager role, and are significantly higher than the rest of the constructs within the role

4. Supportive Environment and Work Hazard Identification were significantly ranked lower than at least five of the other nine constructs for the Safety Manager role
5. Supportive Environment, Work Hazard Identification, and Work Pressure were significantly lower than at least four of the nine other constructs for the Superintendent role
6. Work Hazard Identification was significantly lower than six of the other nine constructs within the Upper Management role

Overall, these results reveal opportunities to improve attitudes of certain constructs within each role. This information could be useful in developing training or improvement mechanisms aimed at improving safety attitudes of roles throughout the construction supply chain.

4.7.4 Differences Between Firm Types

The same process was that used to analyze difference between roles was used to determine if there were differences in the data between types of firms (owner, designer, constructor, sub-contractor). The first step was to determine if the variances differed between groups using the Brown-Forsythe test. These results are in Table 4-24, and show that the Management Commitment and Personal Appreciation of Risk constructs do show evidence of unequal variances between firm types.

Table 4-24: Brown-Forsythe Test results for firm differences

Construct	F Ratio	p-Value
Management Commitment	2.7824	0.0406*
Communication	2.3472	0.0721
Safety Rules & Procedures	1.49	0.2166
Supportive Environment	0.9240	0.4291
Supervisory Environment	0.2364	0.8710
Worker Involvement	1.5632	0.1976
Personal Appreciation of Risk	3.1358	0.0254*
Work Hazard Identification	0.1383	0.9371
Work Pressure	1.5247	0.2074
Competence	0.5051	0.6789
Overall Safety Climate	0.7860	0.5022

The results in Table 4-25 show the results of the appropriate test to determine if there is a significant difference between firm types within each construct. A Welch's F-test was performed on constructs that showed evidence of unequal variances, and a Kruskal-Wallis test was performed on the remaining constructs. The results show that all of the constructs have a p-value far less than 0.05 with the exception of Work Pressure, and that post-hoc tests should be performed to locate these differences.

Table 4-25: Results of Kruskal-Wallis or Welch test of differences between firm types

Construct	Test Statistic	p-Value
Management Commitment	4.9017 (F-test)	0.0029
Communication	49.9077	< 0.0001
Safety Rules & Procedures	51.7245	< 0.0001
Supportive Environment	34.5862	< 0.0001
Supervisory Environment	18.3536	0.0004
Worker Involvement	17.9957	0.0004
Personal Appreciation of Risk	18.41 (F-test)	< 0.0001
Work Hazard Identification	16.7452	0.0008
Work Pressure	2.8793	0.4106
Competence	52.9861	< 0.0001
Overall Safety Climate	47.4774	< 0.0001

Note – gray cells have p-value greater than 0.10

The results of the post-hoc Steel-Dwass tests for all pairs (to adjust for a 0.5 overall level of significance) showed some clear trends. These results are summarized in Table 4-26, and show that Construction Manager and Subcontractor firms consistently rank higher in attitudes toward safety than Owner and Designer firms. Additionally, the Construction Manager firm is ranks significantly higher than the Subcontractor firm in multiple categories.

Table 4-26: Summarized p-values of Steel-Dwass tests for all pairs of firms

Construct	CM > Owner	Sub > Owner	CM > Designer	Sub > Designer	CM > Sub
Management Commitment	0.0120		0.0052		
Communication	< .0001	0.0055	< .0001	0.0038	
Safety Rules & Procedures	< .0001	0.0008	< .0001		
Supportive Environment	< .0001	0.0185	< .0001	0.0406	
Supervisory Environment	0.0065	0.0776	0.0068		
Worker Involvement	0.0341		0.0018		
Personal Appreciation of Risk	0.0003		< .0001	0.0162	0.0336
Work Hazard Identification	0.0619		0.0017	0.0575	
Work Pressure					
Competence	< .0001	0.10	< .0001	0.0296	0.0285
Overall Safety Climate	< .0001		< .0001	0.0111	0.0273

Note – gray cells have p-value greater than 0.10

4.7.5 Differences within Firm Types

The same procedures used to test for differences within roles were again used to analyze within firm types. The Friedman test was used to test if there was a significant difference within each firm type, and the results again suggested post-hoc test could be run with a p-value of less than 0.01 for each type. In order to investigate these differences, a Wilcoxon Signed Rank test was performed for each firm type. These results are shown in Tables 4-27 through 4-30, and again a Bonferroni adjustment was made so that the level of significance on each test was 0.0022 in order to adjust for an overall level of significance of 0.10.

Table 4-27: Wilcoxon Signed Ranked Test for Owner firm subgroup

Owner (n=50)		Mgt Commit	Comm	Safety Rules & Proc	Support Env	Super Env	Worker Inv	App of Risk	Work Haz ID	Work Pressure	Comp	Count of p-value < 0.00222
	Overall Avg	4.21	3.89	4.15	3.82	4.00	3.52	4.34	3.87	4.01	3.83	
Management Commitment	4.21											0
Communication	3.89	0.0002										3
Safety Rules & Procedures	4.15	0.1488	0.9995									0
Supportive Environment	3.82	< 0.0001	0.2594	< 0.0001								3
Supervisory Environment	4.00	0.0162	0.9351	0.0476	0.9806							1
Worker Involvement	3.52	< 0.0001	0.0006	< 0.0001	0.0008	< 0.0001						8
Personal Appreciation of Risk	4.34	0.9117	0.9999	0.9893	0.9999	0.9996	0.9999					0
Work Hazard Identification	3.87	0.0001	0.3348	0.0034	0.516	0.0423	0.9999	< 0.0001				2
Work Pressure	4.01	0.0494	0.9349	0.2228	0.9696	0.7205	0.9999	0.0022	0.9307			1
Competence	3.83	0.001	0.3079	0.0008	0.593	0.0512	0.9971	< 0.0001	0.4265	0.0292		3

Table 4-28: Wilcoxon Signed Ranked Test for Designer firm subgroup

Designer (n=60)		Mgt Commit	Comm	Safety Rules & Proc	Support Env	Super Env	Worker Inv	App of Risk	Work Haz ID	Work Pressure	Comp	Count of p-value < 0.00222
	Overall Avg	4.21	3.82	3.92	3.8	4.1	3.5	4.08	3.84	3.97	3.77	
Management Commitment	4.19											0
Communication	3.83	0.0002										2
Safety Rules & Procedures	3.96	0.0043	0.892									0
Supportive Environment	3.83	< 0.0001	0.4954	0.0215								3
Supervisory Environment	4.04	0.0366	0.9766	0.9041	0.9995							0
Worker Involvement	3.48	< 0.0001	0.0006	< 0.0001	< 0.0001	< 0.0001						9
Personal Appreciation of Risk	4.16	0.4416	0.9989	0.9965	0.9999	0.8888	0.9999					0
Work Hazard Identification	3.81	< 0.0001	0.3488	0.0267	0.4442	0.003	0.9999	< 0.0001				2
Work Pressure	4.02	0.0247	0.921	0.6419	0.9709	0.3184	0.9999	0.0628	0.9779			0
Competence	3.79	< 0.0001	0.24	0.0009	0.1799	0.0008	0.9997	< 0.0001	0.3417	0.0239		4

Table 4-29: Wilcoxon Signed Ranked Test for Construction Manager firm subgroup

Construction Manager (n=249)		Mgt Commit	Comm	Safety Rules & Proc	Support Env	Super Env	Worker Inv	App of Risk	Work Haz ID	Work Pressure	Comp	Count of p-value < 0.00222
	Overall Avg	4.45	4.39	4.48	4.21	4.31	3.82	4.66	4.13	4.10	4.30	
Management Commitment	4.45											1
Communication	4.39	0.0037										1
Safety Rules & Procedures	4.48	0.3793	0.9923									1
Supportive Environment	4.21	< 0.0001	< 0.0001	< 0.0001								4
Supervisory Environment	4.31	< 0.0001	0.0047	< 0.0001	0.9928							3
Worker Involvement	3.82	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001						9
Personal Appreciation of Risk	4.66	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999					0
Work Hazard Identification	4.13	< 0.0001	< 0.0001	< 0.0001	0.0064	< 0.0001	0.9999	< 0.0001				6
Work Pressure	4.10	< 0.0001	< 0.0001	< 0.0001	0.0327	0.0001	0.9999	< 0.0001	0.4075			6
Competence	4.30	< 0.0001	0.0057	< 0.0001	0.9933	0.3504	0.9999	< 0.0001	0.9999	0.9997		3

Table 4-30: Wilcoxon Signed Ranked Test for Subcontractor firm subgroup

Subcontractor (n=73)		Mgt Commit	Comm	Safety Rules & Proc	Support Env	Super Env	Worker Inv	App of Risk	Work Haz ID	Work Pressure	Comp	Count of p-value < 0.00222
	Overall Avg	4.22	4.26	4.33	4.1	4.24	3.69	4.47	4.03	3.99	4.06	
Management Commitment	4.22											0
Communication	4.26	0.2274										0
Safety Rules & Procedures	4.33	0.6263	0.9126									0
Supportive Environment	4.10	0.0086	0.008	0.0002								2
Supervisory Environment	4.24	0.2556	0.3779	0.0315	0.9879							0
Worker Involvement	3.69	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001						8
Personal Appreciation of Risk	4.47	0.9535	0.9803	0.9226	0.9999	0.9919	0.9999					0
Work Hazard Identification	4.03	0.0012	0.0009	< 0.0001	0.2608	0.0011	0.9999	< 0.0001				5
Work Pressure	3.99	0.019	0.0032	0.0004	0.0925	0.0044	0.9914	< 0.0001	0.3635			2
Competence	4.06	0.0054	0.0015	< 0.0001	0.3844	0.0026	0.9999	< 0.0001	0.7282	0.8268		3

One result that was similar to the within roles analysis was that all four firm types ranked Workers' Involvement as lower than at least eight of the other nine constructs. This reinforces a key result of the roles analysis in that Workers' Involvement is an opportunity for improvement throughout the construction supply chain. Some of the other key results from this analysis are below.

1. Personnel within the Owner firm type view Communication and Competence as lower than three of the other nine constructs.
2. Competence is also lower than four of the other nine constructs within the Designer firm subgroup, and Supportive Environment is lower than three of the other nine constructs.
3. Construction Managers rank Work Hazard Identification and Work Pressure as lower than six of the other nine constructs and there is another cluster of Supportive Environment, Supervisory Environment, and Competence that are lower than at least three of the other four constructs.
4. The subcontractor subgroup rates Work Hazard Identification as lower than five of the other nine constructs, and Competence as lower than three of the other nine constructs.

4.7.6 Differences between Industry Sectors

Respondents were asked the industry sector of projects that they typically worked on. The response levels were Level 1 = Commercial (317 responses), Level 2 = Industrial (45 responses), Level 3 = Heavy Engineering (59 responses), and Level 4 = residential (15 responses). Residential respondents were not targeted for the survey because of differences in the type of work, and as can be seen above the majority of the responses were for commercial projects. There were some differences identified as shown in Table 4-31, and almost all of the significant differences were between the commercial and industrial industry sectors. In fact, no significant differences were detected between the residential sector and the others or between the heavy engineering and industrial sectors, which could be due to the low sample size. In fact, some of the higher ratings in the industrial and heavy engineering as compared to commercial could be due to the fact that respondents in these sectors primarily chose to take the survey on their own while there was a larger group in the commercial sector that was forwarded the survey through their company.

Table 4-31: Differences between industry sectors

Construct	Welch or Kruskal-Wallis	Industrial > Commercial	Heavy Eng > Commercial
Management Commitment	0.0043	0.0048	
Communication	< 0.0001	0.0041	
Safety Rules & Procedures	0.0650	0.0531	
Supportive Environment	0.0450	0.0743	
Supervisory Environment	0.1715		
Worker Involvement	0.0836	0.0691	
Personal Appreciation of Risk	0.0131	0.0601	
Work Hazard Identification	0.0055	0.0026	0.0196
Work Pressure	0.1087		
Competence	0.1468		
Overall Safety Climate	0.0040	0.0045	0.0643

Note – gray cells have p-value greater than 0.10

4.7.7 Differences between Project Delivery Types

Respondents were asked the project delivery method of the projects they typically worked on. The intent of this question was to determine if there were any differences in safety attitudes between personnel in the project lifecycle of design-bid-build projects where design and construction are different firms and design-build projects in which one entity is responsible for design and construction. The hypothesis behind this question was that design-build projects foster more collaboration earlier in the project lifecycle, and that safety would improve as a result of the collaboration. 286 respondents said they typically worked on design-bid-build project, 63 on design-build projects, and 86 listed "other" for this question.

The results do not show much evidence of differing safety attitudes between the design-bid-build and design-build project delivery mechanisms in terms of safety attitudes. All of the constructs with the exception of Management Commitment and Overall Safety Climate do not show evidence of Unequal Variances according to the Brown-Forsythe test. As Table 4-32 displays, all of the p-values for the nonparametric tests are well above any appropriate cut-off with the exception of the Management Commitment and Work Pressure construct. The post-hoc tests for Management Commitment provided minimal evidence that design-build was ranked higher than design-bid-build with a p-value of 0.1317 for the pair on the Steel-Dwass test. The Work Pressure construct showed a little stronger evidence of design-build projects ranking the construct higher than design-bid-build projects with a p-value of 0.0929. Overall, the results seem to indicate that two common project delivery mechanisms employed in the United States within the project lifecycle have little effect on the safety attitudes of personnel on the project.

Table 4-32: Brown-Forsythe unequal variance and Kruskal-Wallis analysis of variance by ranks test p-values

Construct	Brown-Forsythe	Kruskal-Wallis
Management Commitment	0.0635	0.0518 (Welch)
Communication	0.7172	0.5101
Safety Rules & Procedures	0.6645	0.6781
Supportive Environment	0.9069	0.9609
Supervisory Environment	0.4508	0.6639
Worker Involvement	0.4059	0.3086
Personal Appreciation of Risk	0.8182	0.3526
Work Hazard Identification	0.1303	0.6552
Work Pressure	0.2042	0.0882
Competence	0.9787	0.1658
Overall Safety Climate	0.0174	0.6692 (Welch)

Note – gray cells have p-value greater than 0.10

4.7.8 Differences within Project Delivery Types

Although there did not appear to be much evidence of significant differences between the design-bid-build and design-build subgroups, there are some differences when analyzing within group differences. The Friedman test indicated at least one significant difference between matched pairs. Post-hoc tests were performed using a Wilcoxon Signed Rank Test to determine the location of these differences. The results in the form of a p-value for each pairs are shown in Table 4-33 and Table 4-34. The first result that matched prior analysis is that both subgroups ranked the Worker Involvement construct lower than others in at least eight of nine cases. For the design-bid-build subgroup the Supportive Environment, Work Hazard Identification, Work Pressure, and Competence are all ranked consistently lower than the other constructs. Conversely, the design-build construct displays more homogeneity as only the Supportive Environment and Work Hazard Identification are ranked lower than at least four of the remaining nine constructs.

Table 4-33: Wilcoxon Signed Ranked Test for design-bid-build subgroup

Design-Bid-Build (N=284)		Mgt Commit	Comm	Safety Rules & Proc	Support Env	Super Env	Worker Inv	App of Risk	Work Haz ID	Work Pressure	Comp	Count of p-value < 0.00222
	Overall Avg	4.30	4.21	4.32	4.10	4.22	3.69	4.52	4.02	4.02	4.11	
Management Commitment	4.30											1
Communication	4.21	0.0002										2
Safety Rules & Procedures	4.32	0.2553	0.994									1
Supportive Environment	4.10	< 0.0001	< 0.0001	< 0.0001								5
Supervisory Environment	4.22	0..018	0.5141	0.0004	0.9999							2
Worker Involvement	3.69	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001						9
Personal Appreciation of Risk	4.52	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999					0
Work Hazard Identification	4.02	< 0.0001	< 0.0001	< 0.0001	0.0093	< 0.0001	0.9999	< 0.0001				5
Work Pressure	4.02	< 0.0001	< 0.0001	< 0.0001	0.0786	< 0.0001	0.9999	< 0.0001	0.6955			5
Competence	4.11	< 0.0001	0.0031	< 0.0001	0.6868	0.0017	0.9999	< 0.0001	0.9958	0.9486		4

Table 4-34: Wilcoxon Signed Ranked Test for design-build subgroup

Design-Build (N=63)		Mgt Commit	Comm	Safety Rules & Proc	Support Env	Super Env	Worker Inv	App of Risk	Work Haz ID	Work Pressure	Comp	Count of p-value < 0.00222
	Overall Avg	4.48	4.28	4.38	4.08	4.28	3.80	4.58	4.01	4.22	4.26	
Management Commitment	4.48											0
Communication	4.28	0.0034										1
Safety Rules & Procedures	4.38	0.0328	0.9525									0
Supportive Environment	4.08	< 0.0001	0.002	< 0.0001								4
Supervisory Environment	4.28	0.0131	0.5268	0.1591	0.9938							1
Worker Involvement	3.80	< 0.0001	< 0.0001	< 0.0001	0.0017	< 0.0001						8
Personal Appreciation of Risk	4.58	0.8899	0.9985	0.9956	0.9999	0.9986	0.9999					0
Work Hazard Identification	4.01	< 0.0001	0.0004	< 0.0001	0.223	0.0027	0.9952	< 0.0001				4
Work Pressure	4.22	0.0258	0.3346	0.0596	0.8798	0.304	0.9996	0.0001	0.962			1
Competence	4.26	0.0027	0.2465	0.0311	0.985	0.3326	0.9999	< 0.0001	0.9951	0.5707		1

4.7.9 Differences between OSHA Certification Levels

Respondents were asked to report the level of OSHA certified training they had completed. The responses were broken down with Level 1 = no level of OSHA certification (122 respondents), Level 2 = 10-hour certification (129 responses), and Level 3 = 30-hour certification (186 responses). The same series of nonparametric tests (Brown-Forsythe Unequal Variances Test, Welch or Kruskal-Wallis Test depending on unequal variances results, and a Steel-Dwass Multiple Comparisons test) were completed to identify any significant differences between OSHA training levels.

The results of the Steel-Dwass tests are below in Table 4-35, and seem to confirm that higher levels of OSHA training result in higher safety attitudes. One exception however that was also present in prior analysis is that the attitudes reported for the Work Pressure construct do not show evidence of varying between levels. Additionally, the Management Commitment construct did not produce a significant p-value for the Kruskal-Wallis test. Finally, as one might expect the most significant p-values occur when comparing 30-hour certification versus no OSHA training and then 10-hour certification to no certification. Interestingly, the level of training (30-hour versus 10-hour) does seem to have a positive effect on safety attitudes, as the attitudes of the 30-hour group are significantly ranked higher than the 10-hour group on five of the eight constructs had a significant difference between the two levels in addition to overall safety climate.

Table 4-35: P-values of tests determining differences between OSHA certification levels

Construct	Welch or Kruskal-Wallis	30-hr > None	10-hr > None	30-hr > 10-hr
Management Commitment	0.1509			
Communication	< 0.0001	< 0.0001	0.0073	0.0279
Safety Rules & Procedures	< 0.0001	< 0.0001	0.0192	0.0753
Supportive Environment	0.0005	0.0008	0.0199	
Supervisory Environment	0.0041	0.0030	0.1046	
Worker Involvement	0.0138	0.0145	0.0662	
Personal Appreciation of Risk	< 0.0001	< 0.0001	0.0009	0.0069
Work Hazard Identification	0.0003	0.0003	0.0057	
Work Pressure	0.1279			
Competence	< 0.0001	< 0.0001	0.0002	< 0.0001
Overall Safety Climate	< 0.0001	< 0.0001	0.0206	0.0276

Note – gray cells have p-value greater than 0.10

Differences between Training Levels (other than OSHA)

Another question on the survey instrument asked respondents the amount of safety-focused training they had received in the last year not including OSHA certification training. The levels were Level 1 = none (60 responses), Level 2 = 1-5 hours (133 responses), Level 3 = 6-10 hours (75 responses), and Level 4 = more than 10 hours (169 responses). The results for the nonparametric tests to determine significant differences are below in Table 4-36, and there were no signs of unequal variances between within any of the constructs (all p-values > 0.05).

Just as in OSHA training, there is evidence that other safety-focused training does increase safety attitudes. The two levels that had the least significant differences were on the extremes between the more than 10 hour and 6-10 hour groups and the 1-5 hour and no additional training groups. This is interesting because it appears minimal training does not have a positive effect on safety attitudes until at least 6-10 hours of training are involved. Additionally, once 6-10 hours of training is reached there does not seem to be a large positive effect on safety attitudes by performing more training.

Table 4-36: P-values of tests determining differences between other safety training levels

Construct	Kruskal-Wallis	4>3	4>2	4>1	3>2	3>1	2>1
Management Commitment	< 0.0001		< 0.0001	0.0061	0.0039	0.0932	
Communication	< 0.0001		0.0001	< 0.0001	0.0025	< 0.0001	0.0428
Safety Rules & Procedures	< 0.0001		< 0.0001	< 0.0001	0.0028	0.0011	
Supportive Environment	0.0007		0.0082	0.0061		0.0511	
Supervisory Environment	< .0001		< 0.0001	0.0015	0.0444	0.0495	
Worker Involvement	0.0036		0.0128	0.0238			
Personal Appreciation of Risk	< 0.0001	0.0377	< 0.0001	< 0.0001	0.0079	0.0463	
Work Hazard Identification	< 0.0001		0.0003	0.0037	0.0139	0.0312	
Work Pressure	0.0005		0.0047	0.0017			
Competence	< 0.0001	0.0917	< 0.0001	< 0.0001	0.0005	< 0.0001	
Overall Safety Climate	< 0.0001	0.0457	< 0.0001	< 0.0001	0.0454	0.0009	

Note – gray cells have p-value greater than 0.10

4.7.10 Differences Between Education Levels

Respondents were asked the level of education they had completed on five levels. The levels were Level 1 = No High School (no responses), Level 2 = Less than High School (two responses), Level 3 = High School/GED (90 responses), Level 4 = College Undergraduate Degree (246 responses), and Level 5 = College Graduate Degree (98 responses). There was no evidence of unequal variances within any of the constructs based on the Brown-Forsythe test, and the only construct that had a p-value less than 0.05 on the Kruskal-Wallis test was Safety Rules and Procedures with a p-value of 0.0267. The post-hoc Steel-Dwass test revealed that the only significant difference between levels within this construct was between levels 4 and 5 with a p-value of 0.0157. These results in general seem to suggest that education level has little effect on safety attitudes.

4.7.11 Differences Between Project Sizes

Respondents were asked to give the typical size of projects they were involved in on three levels. These levels were Level 1 = $0-$10 million (194 responses), Level 2 = $10 - $20 million (90 responses), and Level 3 = Greater than $20 million (152 responses). The reason this question was asked was to determine if safety attitudes differed for personnel on larger projects in which work is generally managed and performed by larger firms and that can last longer periods of time. As Table 4-37 shows, the significant differences appear to be mainly between Level 3 and Level 1 in the post-hoc tests.

Table 4-37: Difference between project size p-values

Construct	Welch or Kruskal-Wallis	Level 3 > Level 1	Level 3 > Level 2	Level 2 > Level 1
Management Commitment	0.0330	0.0232		
Communication	0.0012	0.0008	0.0674	
Safety Rules & Procedures	0.0030	0.0032	0.0461	
Supportive Environment	0.0929			
Supervisory Environment	0.5373			
Worker Involvement	0.1933			
Personal Appreciation of Risk	0.0030	0.0026	0.0764	
Work Hazard Identification	0.1933			
Work Pressure	0.0295	0.0293		
Competence	0.0111	0.0076		
Overall Safety Climate	0.0176	0.0015		

Note – gray cells have p-value greater than 0.10

Another hypothesis that was analyzed was whether larger firms perform more safety-focused training than smaller firms. As Figure 4-6 illustrates there does not seem to be a difference between the groups. The percent of respondents falling within each training level does not seem to differ between each of the project size categories. In fact, the chi-square ratio of 8.496 from the Likelihood Test for the logistic model only had a p-value of 0.2040. This does not suggest that there is much evidence that firms that participate on larger projects perform more safety-focused training than smaller ones.

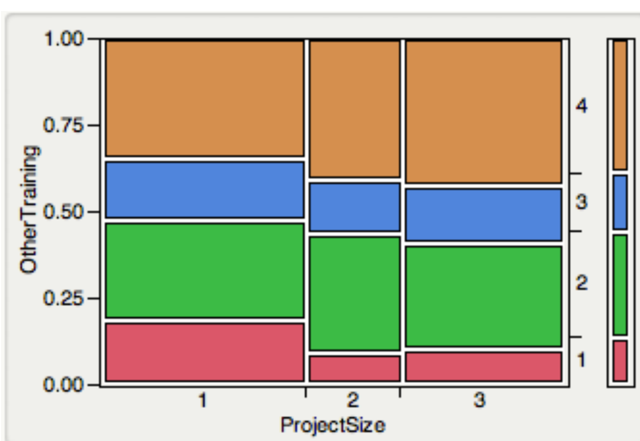


Figure 4-5: Mosaic plot between training (other than OSHA) and project size

4.7.12 Relationship between Experience and Safety Climate

Respondents were asked their years of experience in the construction industry and in their current role. The purpose of this data was to determine if there is a relationship between safety attitudes and experience. The results show little evidence of a relationship. As seen in Table 4-38, the Spearman's ρ coefficient displays a minimal correlation between the safety climate constructs and either type of experience. The three exceptions are the relationships between construction industry experience and work pressure and overall safety climate and current role experience and personal appreciation of risk.

Table 4-38: Spearman's ρ coefficient for Construction Industry Experience and Current Role Experience for each safety climate construct

Construct	Construction Experience Correlation (p-value)	Current Role Experience Correlation (p-value)
Management Commitment	-0.0157 (0.7439)	-0.0052 (0.9145)
Communication	-0.0280 (0.5600)	0.0199 (0.6793)
Safety Rules & Procedures	-0.0120 (0.8026)	0.0354 (0.4616)
Supportive Environment	-0.0194 (0.6869)	-0.0476 (0.3224)
Supervisory Environment	0.0229 (0.6337)	0.0099 (0.8378)
Worker Involvement	0.0272 (0.5711)	-0.0216 (0.6545)
Personal Appreciation of Risk	0.0375 (0.4358)	-0.0810 (0.0925)
Work Hazard Identification	-0.0081 (0.9709)	-0.0533 (0.2681)
Work Pressure	0.0920 (0.0547)	-0.0027 (0.9545)
Competence	0.0081 (0.8660)	0.0133 (0.7817)
Overall Safety Climate	0.0843 (0.0788)	0.0093 (0.8464)

Additional analysis supports the results of Spearman's ρ coefficient of weak relationships between experience and safety climate. As illustrated in 4-7, the scatter plot of Management Commitment and Construction Experience seems to be very random. A similar random pattern was evident in each of the safety climate constructs for both construction industry experience and current role experience. As expected, the residuals of the ANOVA were not normally distributed for any of the constructs tested regardless of the type of transform or fit performed.

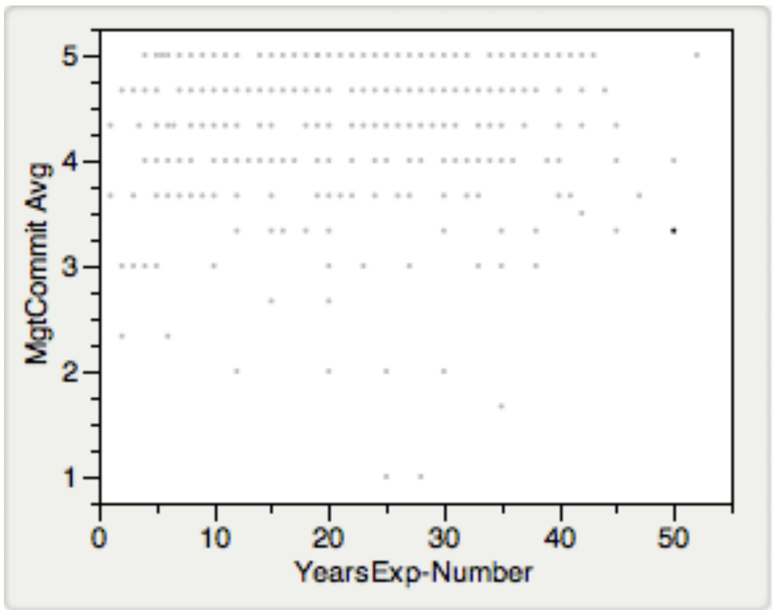


Figure 4-6: Scatterplot of Management Commitment versus Construction Industry Experience

4.7.13 Safety Attitude Origin

The final question in the survey asked respondents to tell the source of their attitudes toward construction worker safety. This question was free-form response, and its intent was to gain a deeper understanding of why personnel form the types of attitudes toward OSH they do. Understanding these sources could be a valuable piece of information when designing training for groups of employees or for motivating further research about why these differences exist. Figure 4-8 shows a Pareto chart for the entire data set. This chart is interesting in that it shows that 47% of safety attitudes can be traced back to personal issues formed outside of the person's place of employment such as the 'Work Experience' and Personal Feelings on Issue' categories (after breaking down 'Other' category).

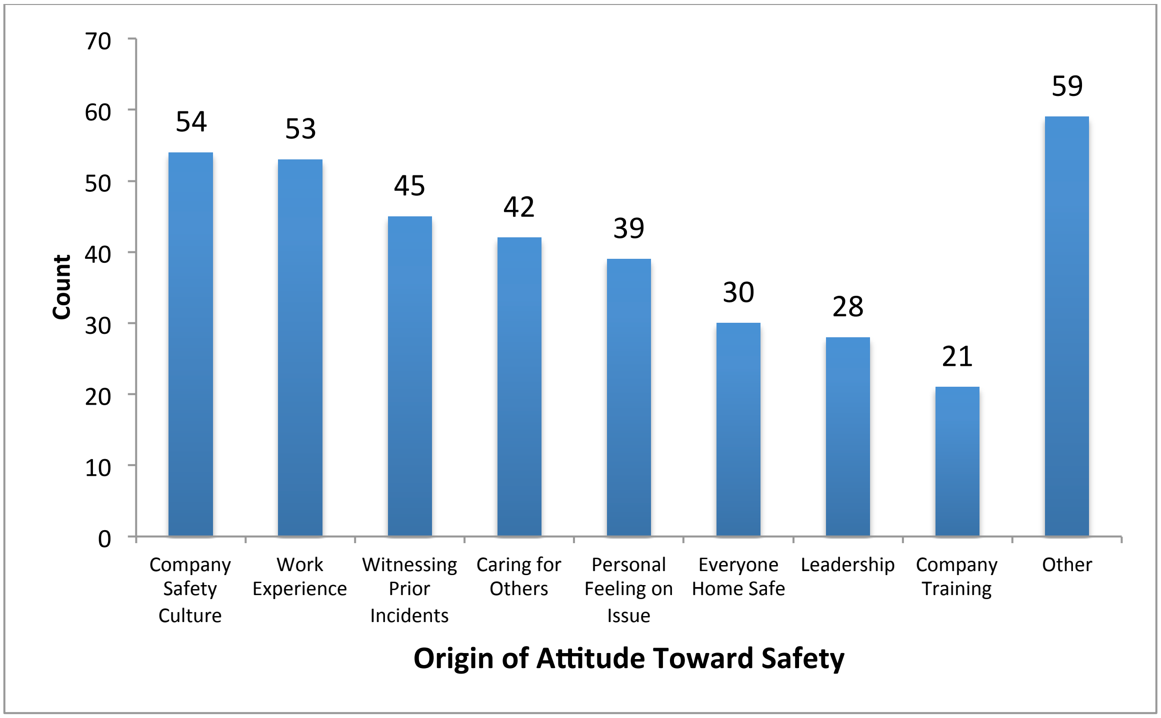


Figure 4-7: Origin of attitude toward safety (entire data set)

The data can be broken down by role to gain further insight into how personnel develop their attitudes toward safety. Table 4-39 contains this data, and reveals some very interesting results. The 'Caring for Others' and 'Work Experience' categories alone comprise 45% of the designer role. Both of these categories have little dependency on the safety culture of the designer's company, which suggests that the designer role's safety attitudes are not being formed at their place of employment. In fact, a full breakdown of the designer results are shown in Table 4-40, and show that only 21% of the categories reported by designers can be traced back to the company versus 53% for the rest of the data set.

Table 4-39: Origin of safety attitudes by role

Attitude Origin Category	Designer	Foreman	Project Engineer	Project Manager	Safety Manager	Supt.	Upper Mgmt.
Caring for Others	15%	5%	6%	9%	16%	15%	11%
Company Safety Culture	6%	20%	27%	19%	11%	9%	11%
Education	0%	0%	3%	1%	4%	4%	0%
Everyone Home Safe	3%	5%	6%	7%	7%	11%	11%
Insurance Issues	0%	0%	3%	2%	2%	4%	4%
Laws and Regulations	3%	5%	3%	1%	2%	5%	1%
Leadership	3%	10%	3%	10%	7%	7%	9%
Personal Feelings	6%	20%	9%	10%	16%	7%	10%
Self Preservation	6%	0%	6%	2%	0%	0%	0%
Training	6%	5%	6%	6%	5%	7%	4%
Witnessing Prior Incidents	3%	15%	6%	13%	14%	13%	16%
Work Experience	30%	5%	15%	16%	13%	9%	13%
Other	18%	10%	6%	4%	4%	9%	9%

Table 4-40: Safety attitude origin breakdown for designer role

Origin Type	Attitude Origin Category	Percentage of Total
Personal	Work Experience	30%
	Caring For Others	15%
	Liability	6%
	Personal Feelings	6%
	Self Preservation	6%
	Industry	3%
	Laws And Regulations	3%
	Leadership	3%
	Military or Public Service Experience	3%
	Witnessing Prior Incidents	3%
Company	Company Safety Culture	6%
	Supportive Environment Among Employees	6%
	Training	6%
	Everyone Home Safe	3%

4.8 Phase 2 Results

The results of Phase I showed differences in safety climate constructs between groups of personnel on a construction project, as well internal differences between the constructs within each type of personnel. This data can be used to determine what areas of safety should be focused on when designing training for a group of personnel. The results also show that designers have significantly lower attitudes within several of the constructs tested in Phase I. This group was thus the focus of an initial research to practice (r2p) exercise of transforming the information from Phase I of the research into an instrument that can be used within the construction industry to improve OSH performance.

4.8.1 Training Tool Development

As mentioned in Chapter 3, web-based training was chosen to develop a training tool to expose participants to the results from Phase I. These results show that designers have statistically significantly lower attitudes than other construction industry personnel in the communication, safety rules and procedures, supportive environment, appraisal of work hazards, competence, and overall safety climate constructs. These areas were thus chosen to be the focus areas for safety training targeted toward designers. This training also aligned with the Prevention through Design (PtD) initiative that was already a focus of NIOSH.

Student exploration, case-based learning, and problem-based learning were instructional approaches that have been found to be as effective in online learning environments as a traditional classroom environment (Bonk 2002). Additionally, web-based training research has found that strong opening are crucial to this type of training in order to grab the attention of the student and entice them to keep reading. Relevant content should be introduced as early as possible, and real-world information such as cases or stories that relates to the participant have been found to be an effective engagement strategy (Driscoll and Carliner 2005).

An initial version of the training website was sent to two professors at Virginia Tech affiliated with the Occupational Safety and Health Research Center for feedback. This resulted in changes to the website that were completed before sending the training to industry participants. These changes included larger font and graphics, and being more explicit that higher-level controls such as elimination and substitution are not possible in every situation. Following up on this suggestion, care was taken to clearly state that PtD is about considering safety in the decision-making process along with other factors such as cost and schedule during the design stage and not eliminating or substituting every hazard on a project. This is reinforced from feedback from the Phase I data with comments from designers such as "I design structures... I do not design methods of implementation".

The sections of the training listed below were developed based on the needs assessment and feedback from the experts. The initial training site sent to the experts included the same sections, but additional information was added and the order of the sections changed based on feedback. These pages are shown in Appendix C.

1. The first page introduced how the construction industry performs in OSH using fatality data. It was discussed in Chapter One that percentage of fatalities in the construction industry to all fatalities in the U.S. is four times greater than the percentage of construction workers to overall workers in the U.S. This information was used to relate the seriousness of the information in the training and hopefully engage trainees by surprising them with the discrepancy. This page was also a source to introduce the associated NIOSH initiative and display to participants that this information is important enough to be a focus of the federal government.
2. Training needs identified such as competency and hazard identification suggest that

designers lack an understanding of how they can affect construction worker safety. It is important to relate to them how their work can affect OSH with concrete examples. As mentioned above, case studies are an effective mechanism for introducing the training need (Driscoll and Carliner 2005), and the second page of the website therefore used three examples from an actual project to discuss how three different projects could have been affected during the design stage. A common theme identified in the related NIOSH-sponsored research project mentioned in Chapter 1 was that designers did not interact in OSH decisions because of fear of potential liability from dictating construction means and methods (Saunders, McCoy et al. 2011). This issue was thus addressed on this page in order to try and argue against the paradigm that designers cannot participate in safety activities without dictating means and methods. The focus of the case studies focused on how decisions made in the design stage affected construction worker safety, and then giving designers the opportunity to learn more information on the subject using NIOSH prevention through design resources.

3. The data collected in Phase I of the research was used to relate to designers opportunities for improving OSH among their peer group. Therefore, a graphic of the results of Phase I displaying the difference between designers and other personnel on a construction project along with a short explanation for each category was developed to support the need for improvement for designers specifically.
4. The hierarchy of controls has been discussed extensively in Chapter 1 and 2, and is a literature-based concept that can be used as a tool to educate designers on how to identify potential hazards and control them in the design stage. It also lends itself to an interactive exercise to assess the competency of designers in OSH material. Interaction is

an important advantage of web-based training can be used to engage participants and improve training performance (Barron 1998; Michau, Gentil et al. 2001; Driscoll and Carliner 2005). Therefore, before communicating the information of which types of controls are more effective, participants were asked to rate the controls in the hierarchy based on their own experience and knowledge.

5. Once, participants have completed this exercise, the actual hierarchy from literature (Behm 2005) was introduced so that the trainees can compare how well they understood the advantages of the different type of controls. This page also included data from literature linking accidents to the design stage to strengthen the argument that designers play an important role in OSH.
6. A follow-up survey to collect information on training performance. The page with the follow-up survey also included additional links to OSHA and NIOSH resources for those participants interested in obtaining more information on OSH in the construction industry.

An initial version of the training website was sent to two professors at Virginia Tech affiliated with the Occupational Safety and Health Research Center for feedback. This resulted in changes to the website that were completed before sending the training to industry participants. These changes included larger font and graphics, and being more explicit that higher-level controls such as elimination and substitution are not possible in every situation. Following up on this suggestion, care was taken to clearly state that PtD is about considering safety in the decision-making process along with other factors such as cost and schedule during the design stage and not eliminating or substituting every hazard on a project. These experts also suggested adding links to NIOSH and OSHA information for those that wanted to obtain more information on the subject.

The final website is shown in Appendix C, and can be found at the following web address:

- https://sites.google.com/site/constructionsafetytraining/.

The follow-up survey completed by participants is shown in Appendix D. The data that was needed from the survey was discussed in Chapter 3, and was used to develop the survey. Data was collected on the performance of the training mechanism, the degree the designers agreed with the results of the Phase I of the research, and which training formats and types were best suited to communicate the type of information in the website.

4.8.2 Participants

A link to the website was sent to potential participants as part of an email explaining the trainings purpose and benefits. The email was sent to approximately 250 designers and engineers throughout the United States. These potential participants were identified by searching the internet for architects and engineers with contact information on their website. Twenty-seven follow-up surveys were completed for a response rate of approximately 10.8%. Additionally, the exercise in which trainees ranked the hierarchy of controls was completed thirty-eight times, which means at least 15.2% of those contacted completed the training.

4.8.3 Follow-up Survey Results

4.8.3.1 Training Performance

Several questions were asked to determine the overall performance of the training. Particpants were asked to report their attitudes toward OSH before accessing the training website, and again after participating in the training. The question about pre-training attitudes could have been asked at the front-end before exposing the participants to any of the information, and therefore avoiding the possible confounding influence of answering the question after being exposed. The decision was made however to ask both questions after the training in order to showing a survey-type question on the front-end and possibly lowering the response rate to the inquiry email, as online training best practices suggest avoiding adminstrative information on the front-end (Driscoll and Carliner 2005).

The results for these two question are shown in Table 4-41 . The reported OSH importance prior to the training is significantly less than the post-training importance, as the 95% confidence intervals do not overlap. This supports the hypothesis that training based on the results of Phase I may have a positive effect on safety attitudes. As discussed in the delimitations for this Phase, this could have been improved by giving participants a pre and post safety climate test to more directly determine if the training did improve attitudes. This was not done because of time considerations for particpants, but another question directly asking if their attitudes toward safety have been changed as a result of being exposed to this information could have also improved the validity of the study.

Table 4-41: Training performance of designer training website

Question	Average	95% Lower Confidence Interval	95% Upper Confidence Interval
Thought OSH was important before accessing website	3.15	2.70	3.60
Exposing designers to OSH is important	4.00	3.74	4.26

Additionally, two other questions were asked to evaluate the performance of the training website and not just whether the training participant’s attitudes on the importance of OSH improved. Participants were asked on a 5-point Likert scale to rate how much the website added to their understanding of how designers affect OSH and the relevance of the material in the training to their job as a designer. The average score for these two items are shown in Table 4-42 along with their associated 95% confidence intervals. The results support that the message was on target and was valuable to trainees, as the lower confidence interval for both items is greater than the neutral value of 3. The counter argument is that neither upper confidence interval is greater than the first "positive" response of 4, and therefore there is room for improvement in the training mechanism. Overall, it appears the designers in the sample did feel the information was relevant to them, but that the relevance could be improved moving forward based on using more real-world examples to illustrate how design stage work can impact construction worker safety (see Section 4.8.3.6)

Table 4-42: Results for understanding and relevance items

Question	Average	95% Lower Confidence Interval	95% Upper Confidence Interval
Website material added to understanding	3.48	3.22	3.75
Material in website was relevant	3.48	3.14	3.82

4.8.3.2 External Validity

One of the questions in the follow-up survey asked respondents to rate the importance on a 5-point Likert scale (1=lowest, 5=highest) of several constructs and their importance to implementing prevention through design concepts in industry. The question was framed to ask the importance of the construct in implementing PtD concepts in order to distinguish that the question was asking about the industry as a whole and not their own personal opinion on the importance of the construct (to avoid personal opinions on OSH). The constructs in question were those in which designers were found to have statistically significantly lower attitudes than other personnel. This data was intended to be a mechanism to test the results of Phase I in terms of external validity by asking industry personnel their level of agreement with the results. The results are shown in Table 4-43 below.

Table 4-43: Results of external validity question

Construct	Level of Importance Average (n=27)	90% Lower Confidence Limit	Number of Respondents Rating 4 or 5
Communication	3.74	3.32	17 (63%)
Safety Rules & Procedures	3.22	2.83	13 (48%)
Supportive Environment	3.74	3.42	18 (67%)
Appraisal of Work Hazards	3.81	3.42	18 (67%)
Competence	3.44	3.00	16 (59%)

The results show moderate support that the designers in the sample agree with the results of Phase I. All of the constructs in question except safety rules and procedures have a lower confidence limit of at least the neutral value of 3 and a majority of respondants rating the construct a positive value of 4 or 5 in importance.

This data can also be used as a tool to determine the effectiveness of the training within each construct. Future versions of the training should reasses if there are more effective ways to communicate safety rules and procedures for designers, and could also be an indication that this area might be one for future research focus if the current state for designers is lacking. This could be more specific examples, or some other approach that improves how particpant designers perceive the importance of a safety rules and procedures in their work. There has been some work in this area (Hecker and Gambatese 2003; Gambatese, Behm et al. 2005), but these results could be an indication that more work is needed in the area.

4.8.3.3 Training Format

One of the main goals of this phase of the research was to identify the training format and type that participant designers felt was the most appropriate for this type of information. Respondents to the survey were asked to report the effectiveness of five different training formats for educating designers about construction safety issues on a 5-point Likert scale (1=least effective, 5=most effective). The results are shown in Table 4-44, and the live on-site training led by instructor has a 90% confidence interval that does not overlap with any of the other training formats with the exception of live online training led by instructor. The results indicate a preference for instructor led training by respondents being exposed to this type of material.

Table 4-44: Training format results

Training Format	Average Effectiveness	90% Lower Confidence Limit	90% Upper Confidence Limit
Onsite classroom led by instructor	3.93	3.52	4.33
Live online led by instructor	3.33	2.99	3.67
Self-guided website	3.11	2.82	3.41
Reference materials	3.04	2.69	3.38
Pre-recorded video courses	3.04	2.68	3.39

4.8.3.4 Training Type

Participants were also asked to rate the effectiveness of five types of training for educating designers about construction safety issues (on the same scale as training format). The results are shown in Table 4-45 below, and provide little clarity as to what types might be the most effective. All of the confidence intervals except internal workplace training and college/university courses overlap, which provides little statistical evidence of differences between the types.

Table 4-45: Training type results

Training Format	Average Effectiveness	90% Lower Confidence Limit	90% Upper Confidence Limit
American Institute of Architects (AIA) or Engineering Society Promotional Materials	3.37	3.03	3.71
College/University Courses	3.04	2.66	3.41
Professional Development/Continuing Education Courses	3.74	3.38	4.10
Sessions at Professional Conferences	3.48	3.16	3.80
Internal Training at Workplace	3.85	3.48	4.22

4.8.3.5 Hierarchy of Control Rankings

Some interesting results were also obtained from the exercise asking trainees to rank in order which control types they felt were most effective (from 1 to 6 with 1 being best and 6 being worst). The results are shown in Table 4-46, and include the average ranking are along with the difference from the actual ranking from literature and the associated 90% confidence interval.

Table 4-46: Hierarchy of Control rankings from training exercise

Control Type	Average Ranking	Difference from Actual Ranking	90% Lower Confidence Limit	90% Upper Confidence Limit
1. Elimination	1.87	-0.87	1.42	2.31
2. Substitution	4.29	-2.29	3.91	4.76
3. Isolation	2.84	0.16	2.54	3.14
4. Engineering Controls	4.45	-0.45	4.14	4.76
5. Administrative Controls	3.21	1.79	2.72	3.70
6. Personal Protective Equipment (PPE)	4.34	1.66	4.00	4.69

The results are interesting because they show a large difference in how designers rank different types of hazard controls versus the design for safety literature (Behm 2005). Substitution of a lesser hazard is only ranked as the fourth most effective control type with an overlapping confidence interval with both the fifth and sixth ranked hazards. In fact, it is only 0.16 from being the lowest ranked control type by designers in terms of average ranking. Additionally, behavioral controls (administrative controls and PPE) are both ranked much higher by the participant designers than the PtD literature. This data illustrates the opportunity in terms of competence and identification of hazards with the designer role in the construction supply chain.

4.8.3.6 Free Response Results

Three questions were left open to the respondent to give feedback on barriers they saw to implementing PtD concepts in the construction industry, how the training could be improved, and overall impression of the training. The results were very wide-ranging, and two key themes could be extracted from the questions.

1. The designers liked the use of the examples, and this needs to be a major focus of future training. One key concept that needs to be of focus is how the examples affected OSH on a construction project without the designers having to be involved with construction means and methods. This was mentioned multiple times in the responses as something that would improve future training.
2. Seven of the sixteen responses on the barriers question mentioned fear of liability from getting involved in worker safety issues. Future training should have a section on this area by discussing liability concerns directly.

5 Chapter 5 – Conclusions and Discussion

5.1 Introduction

Chapter 1 discussed the need for the research, and detailed five hypotheses to test across three key steps. These steps were to

1. Develop a tool to identify gaps in safety attitudes among the key safety roles in the construction supply chain,
2. Analyze these differences to develop a better understanding of the sources of fragmentation in the construction supply chain in regard to OSH, and
3. Develop a mechanism to educate roles in the construction work system based on the results.

This chapter gives an overview of the results for the hypotheses studied in this research, along with discussion on the practical implications for the construction industry.

5.2 Hypothesis 1 – Attitude Differences Between Roles

Hypothesis 1 focused on determining if there is a statistically significant difference in safety attitudes between key safety roles in the construction supply chain in one or more of the safety climate constructs in the Mohammed (2002) model. They key result for this hypothesis is shown in Figure 5.1, and is that designers have statistically lower attitudes in 5 constructs as well as overall safety climate than the other roles. Recent safety research has shown that there are opportunities for personnel throughout the construction work system to affect construction worker safety, and of the fragmentation of attitudes between designers and construction personnel (Huang 2003; Behm 2005; Gambatese, Behm et al. 2008). The exact location of these differences had not been quantitatively assessed however, and the fragmentation could have ranged from management commitment to competence as a root cause for these differences.

One specific opportunity that was identified from the research appears to be for designer organizations to communicate OSH issues and provide an overall supportive environment toward construction worker safety. The other three constructs with a significant difference support the need for more education and training in the design industry, as designers do not feel that they are as competent as other roles in OSH issues. This manifests itself in the fact that they feel safety rules and procedures lacking as well as the ability to identify hazards that could impact OSH. Safety rules and procedures and appraisal of work hazards are usually a component of a safety training program and should be primary focuses on training that results from this research. Also, the difference in overall safety climate lends validity to the measurement model that overall safety climate is a latent variable based on the constructs in survey instrument.

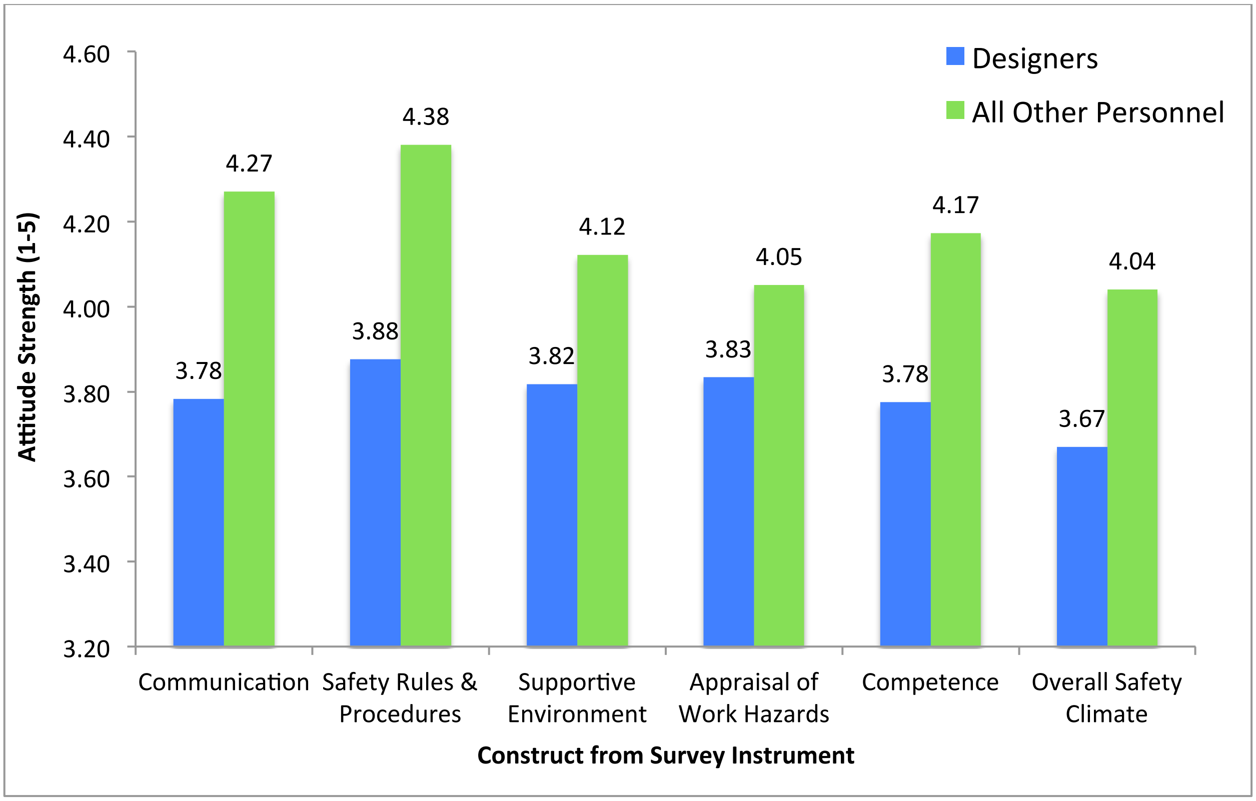


Figure 5-1: Constructs with a statistically significant difference between designers and other roles

The differences identified above were mapped to the Macroergonomic Model (Kleiner 2006) in Table 5-1 to illustrate opportunities within each subsystem of the overall work system. It appears that the fragmentation is not limited to one subsystem, and interventions must be designed with the four subsystems in mind. The variances identified in Table 5-1 should guide the changes to the work system through organizational or job design that are discussed as future research opportunities below.

Table 5-1: Macroergonomic Breakdown of Designer Differences

Subsystem	Interventions
Technical	Safety Rules and Procedures Appraisal of Work Hazards
Personnel	Competence
Internal Environment	Supportive Environment Overall Safety Climate
Organizational	Communication

Future research based on these results should focus on the specific areas that the gap between designers and other types of personnel exists. Previous literature mentioned discusses this gap, but this data quantitatively identifies specific areas that could be targeted to reduce the fragmentation. A start would be increased communication, and research into how and when this communication should occur. This gap in communication is discussed further below in Section 5.4, and consistently was the largest gap in the sample between designers and other personnel. However, the fear of liability from dictating construction means and methods is often cited as a major obstacle of considering constructor worker safety in the design (Behm 2005). While this is a practical issue in the U.S. construction industry, constructor worker safety does not have to be a purely behavioral issue in which construction means and methods are dictated. The purview of designers is often "high level" (i.e. determining loads, code implications, layout of designs), but safety can still be impacted in the planning and design stages of a project when these types of decisions are often considered.

The design for safety concept is founded on a hierarchy of controls in which higher level "technological" controls such as eliminating a hazard, substitution of a hazard for a lesser hazard, or the implementation of engineering controls are more effective than "behavioral" controls defined as administrative processes (safety rules and procedures, jobsite hazard analysis, etc.) and personal protective equipment (PPE) (Manuele 2003). Technological type controls can be analogized to constructability issues on a project, which are commonly a consideration in the design stage because it is accepted that these issues can have an important impact on cost and schedule. Designers are comfortable working with the constructor to consider how constructible the design is even though means and methods have to be considered at a high-level in order to determine if the design lends itself to an efficient construction process. Safety can be considered in a similar manner in which consideration is given to how the design will impact worker safety in the construction phase. This middle ground in which safety is a higher-level decision factor in design along with others such as cost, schedule, quality, etc. can be accomplished without directing lower-level means and methods. Training and communication based on this concept should be considered as a means to reduce the gap that was measured in the sample. This improvement would hopefully be a mechanism toward increasing communication and the supportive environment surrounding safety, and expose those outside the construction stage to the safety skills that the survey results indicated designers lacked as compared to others.

The other significant difference that was found was between safety managers and multiple other roles in the personal appreciation of risk, competence, and overall safety climate constructs. This is sensible because the focus of this role is OSH on the construction site. One issue that could create fragmentation in the work system and affect OSH performance is if OSH professionals over-estimate the risk appreciation and competence level of others in their organization. The focus needs to be on translating these levels to others in the organization, and not assuming that the organization is at the level of the safety professional.

This data also allowed analysis within each role to determine if certain constructs were higher than others regardless of how they compared to other roles. Several results were discussed in Chapter 4, but the key result was that every role ranked worker involvement as significantly lower than at least seven of the other nine constructs. This is important, because it illustrates that every role group in the research did not think OSH is an issue that everyone within the organization is involved. This is a large opportunity within the construction industry, as research has shown that (Johnson 2003; Fang, Chen et al. 2006) that safety attitudes and motivation can be influenced by peer group norms. This motivation can be strengthened by involvement in safety programs, and thus making personnel feel like they are a part of the safety process is important. Organizations must ensure that construction worker safety is not a top-down issue, and that workers at all levels are involved in shaping these processes.

5.3 Hypothesis 2 – Attitude Differences Between Project Delivery Types

Hypothesis 2 The difference in safety attitudes between roles in the construction supply chain statistically differ depending on whether a key safety role operates in a Design-Build or Design-Bid-Build project delivery supply chain. The intent of this hypothesis was to determine if a more collaborative project delivery such as design-build led to higher levels of safety attitudes. The only two delivery mechanisms that were analyzed were design-build-bid and design-build due to their high prevalence in the U.S. construction industry and ability to collect data. Although design-build projects do generally provide more involvement from constructors earlier in the lifecycle, they are not true collaborative projects in which the key organizations share a common contractual arrangement. A significant difference was not identified between these two delivery mechanisms. This is not necessarily a strong indication that no differences exist between project delivery mechanisms in the construction industry however, as data from true collaborative projects was not collected. The data collection requirements for collaborative projects was too cumbersome because these types of projects are not a common type in the U.S. compared to others, and delivery mechanisms were not the main focus of the research. Further research into this arena could be valuable however in determining the extent safety attitudes are affected on true collaborative projects in which designers and constructors form a true alliance contractually.

5.4 Hypothesis 3 – Organizational Home Differences

The third hypothesis focused on differences in safety attitudes between the organizational home of a key safety role (owner, designer, constructor, and sub-contractor). Figure 5.2 shows the differences between firms typically involved in the construction stage of a project (construction managers and subcontractors) versus ones that are usually more involved in decision-making earlier in the lifecycle (owners and designers). The results indicate that construction managers have significantly higher attitudes than both owners and designers in every construction except work pressure. This illustrates the gap in safety attitudes between the construction managers that are typically responsible for safety, and owners and designers that the design for safety literature mentioned in Section 1.3 discussed. Construction managers and subcontractors both have significantly higher attitudes than both owners and subcontractors in the communication, supportive environment, and competence constructs. The p-values were given in Section 4.7.4, and support where the main gaps between constructors and owners and designers are located.

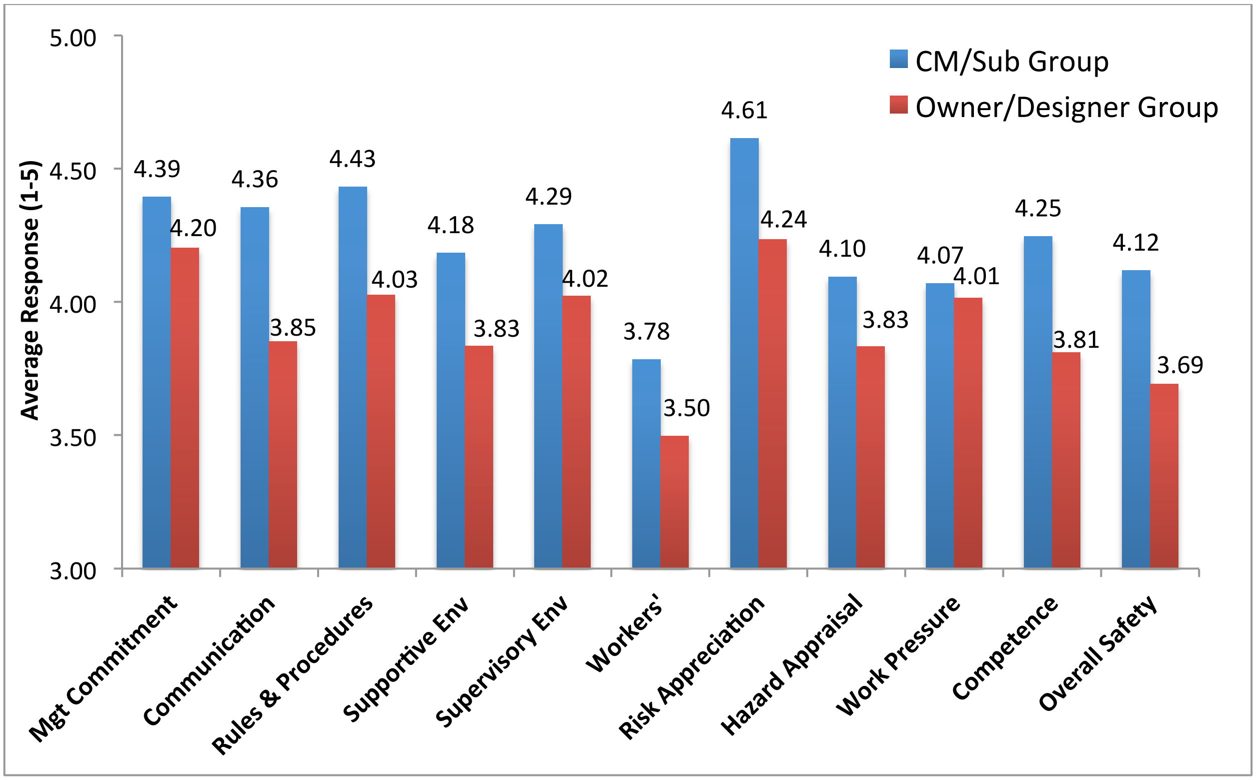


Figure 5-2: OSH attitude differences between firm types

The issue of OSH communication could be a future research opportunity to see if it is a starting point for decreasing fragmentation in the construction work system. In this sample, the CM/Designer group was 13% higher in the communication construct that the "Owner/Designer" group, and the Construction Manager group was 15% higher than just the Designer group. This gives an indication of the gap in the communication area, as both of these differences were the largest of any construct. It would be interesting to study what types of communication and when the communication occurs in the lifecycle of a project have an effect on the difference in attitudes. For example, researching the impact that design for safety plan reviews during the design phase versus discussing safety as an agenda item as part of team meetings during the construction stage would be an opportunity to determine the best types of communication for bridging this gap.

Additionally, the construction manager participants had significantly higher attitudes than the subcontractor group in the overall safety climate, personal appreciation of risk, and competence constructs. This is interesting in that construction managers need to ensure they manage their subcontractors knowing that the subcontractors potentially are less trained in terms of OSH issues and have lower risk perception attitudes.

This data was also used to analyze differences between the constructs within each of the four firm types. The results parallel the key within role differences that personnel throughout the construction supply chain have lower attitudes in the worker involvement construct. Some of the other key results from this analysis are as follows:

- Construction Managers rank Work Hazard Identification and Work Pressure as lower than six of the other nine constructs
- The subcontractor subgroup rates Work Hazard Identification as lower than five of the other nine constructs

This indicates that personnel that are typically involved in the construction stage feel that there is a gap in their attitudes in terms of their attitudes on their ability to properly identify work hazards versus other constructs. This could be an opportunity of emphasis in these types of organizations in terms of their safety processes and training.

5.5 Hypothesis 4 – Demographic Differences

Hypothesis four surrounds analyzing if the demographic data such as the respondent's age, experience level, education level, safety training, typical project size, and typical project sector have an effect on safety attitudes overall and for each key safety role. Some of the key results are as follows:

1. The industrial project sector has significantly higher attitudes than commercial in seven of the ten constructs and overall safety climate.
2. Respondents that have completed ten and thirty hour OSHA training have significantly higher attitudes than those that did not in all of the constructs except management commitment and work pressure. Additionally, the thirty-hour training subgroup had significantly higher attitudes than the ten-hour group in the communication, safety rules and procedures, personal appreciation of risk, competence, and overall safety climate constructs.
3. For other types of safety training, the two levels that had the least significant differences were on the extremes levels between the more than 10 hour and 6-10 hour groups and the 1-5 hour and no additional training subgroups. There are only 2 significant differences in constructs between the 10-hour group and 6-10 hour group, while both of these groups were significantly higher in at least seven constructs between the no additional training and 1-5 hour subgroups.
4. The size of the firm, education level, or experience of the respondent did have a significant effect on safety attitudes in the sample. One change to the levels of the firm size in hindsight should have been breaking the smallest group ($0-$10 million) down into two groups (less than $1 million and $1-10 million). Initially the target was large projects greater than $10 million, but there proved to be a wide range of responses even from large construction corporations. A better cut-off would have been $1 million so that the very smallest projects could be identified.
5. The origin of safety attitude question that was asked shows that 47% of safety attitudes can be traced back to personal issues formed outside of the person's place of

employment. For the designer role however 79% of the origins reported can be traced back to outside the place of employment.

The training results in particular are interesting, because it appears that cursory safety training does not seem to have a significant impact on safety attitudes. More intense training such as that required for OSHA training or a meaningful amount above six hours is needed to positively impact employee safety attitudes. A hypothesis for future research would be to determine the amount of training that is required to show employees the commitment that is required to impact safety attitudes. The type of training could also be studied in this research to analyze whether common types of training that are required by employers is having an impact, or whether new training focusing on more in-depth issues would have a more positive effect.

The origin data was also very interesting, as it highlights the lack of focus on by design firms on OSH issues. Only 21% of design firm respondents traced their safety attitudes back to their organization, versus 53% for the rest of the sample. This reinforces some of the other results that quantify the size of the difference in safety attitudes between designers and other project personnel.

5.6 Hypothesis 5 – Education of Differences

The fifth hypothesis's goal was to use the knowledge gained from the research to develop a tool to improve OSH performance in practice. The research's goal for this hypothesis was to determine if being exposed to this type of information would improve safety attitudes, and what types of formats and types of training that respondents felt would be the most effective way to convey this type of information. The designer role was chosen based on their low attitudes versus the other roles, and the opportunity that exists in impact this group.

An educational website was developed using the results of Phase I of the research as well as relevant academic and government literature on design for safety concepts. The results indicate that overall the designers that participated felt the information added to their understanding and was relevant to their work, as both of the 95% confidence intervals for these items were above the neutral value of three. Optimally these values would have been above the fourth point on the five point Likert-scale, and a future research opportunity exists to directly study the impact this type of training can have on safety attitudes using the survey instrument developed in Phase I. The participants were also used to test the external validity of the Phase I results, and all of the constructs in question except safety rules and procedures have a lower confidence limit of at least the neutral value of 3 and a majority of respondants rating the construct a positive value of 4 or 5 in importance.

The results on the best training format was very informative, as it was clear that the participants felt that this type of information would be most effective in an on-site training class led by an instructor. The confidence intervals for the training types overlap with the except of University/College Course and Internal Company Training, which leaves some room for additional research as to what type of training would be the most effective in conveying this information to designers. It is useful however that they do not feel their university training or companies are the appropriate place for this training, which makes sense since this training would usually be led by other designers.

The most interesting result from Phase II surrounds the exercise in which the participants were asked to rank which types of controls that they felt were the most effective when given a list of the hierarchy of safety control types. Behavioral controls such as safety rules and procedures and PPE are ranked higher by the group than the literature says they should be. This is an obvious opportunity to educate designers are the differences in control types and their benefits. The free response questions asking for how the training coukd be improved however suggest that specific examples should be used to educate on this information instead of taking a more theoretical approach.

References

Abudayyeh, O., T. K. Fredericks, et al. (2006). "An investigation of management's commitment to construction safety." International Journal of Project Management 24(2): 167-174.

Adams, R., C. Hede, et al. (1999). "Moving Safety Forward at Toowoomba Foundry: Attitudes & Commitment." Journal of Management 1(1): 1-12.

Agrilla, J. (1999). Construction safety management formula for success, Taylor & Francis.

Aguinis, H. and E. F. Stone-Romero (1997). "Methodological artifacts in moderated multiple regression and their effects on statistical power." Journal of Applied Psychology 82(1): 192.

Akintoye, A., G. McIntosh, et al. (2000). "A survey of supply chain collaboration and management in the UK construction industry." European Journal of Purchasing & Supply Management 6(3-4): 159-168.

Arditi, D. and H. M. Gunaydin (1997). "Total quality management in the construction process." International Journal of Project Management 15(4): 235-243.

Austin, J., M. Kessler, et al. (1996). "Using feedback and reinforcement to improve the performance and safety of a roofing crew." Journal of Organizational Behavior Management 16(2): 49-75.

Australian Workplace Relations Minister's Council (1999). Comparison of occupational health and safety arrangements in Australian jurisdictions W. R. a. S. B. Department of Employment. Canberra. 1.

Baiden, B., A. Price, et al. (2006). "The extent of team integration within construction projects." International Journal of Project Management 24(1): 13-23.

Baldwin, A., A. Thorpe, et al. (1999). "The use of electronic information exchange on construction alliance projects." Automation in Construction 8(6): 651-662.

Barnett, D. J., R. D. Balicer, et al. (2005). "The application of the Haddon matrix to public health readiness and response planning." Environmental health perspectives 113(5): 561.

Barron, A. (1998). "Designing Web‚Äêbased Training." British Journal of Educational Technology 29(4): 355-370.

Bartko, J. J. (1966). "The intraclass correlation coefficient as a measure of reliability." Psychological reports 19(1): 3.

Bartko, J. J. (1976). "On various intraclass correlation reliability coefficients." Psychological Bulletin 83(5): 762-765.

Battleson, B., A. Booth, et al. (2001). "Usability testing of an academic library web site: a case study." The Journal of Academic Librarianship 27(3): 188-198.

Behm, M. (2005). "Linking construction fatalities to the design for construction safety concept." Safety Science 43(8): 589-611.

Bertelsen, S. (2004). "Lean Construction: Where are we and how to proceed?" Lean Construction Journal 1(1): 46-69.

Bertelsen, S., G. Henrich, et al. (2007). Construction Physics.

Blayse, A. and K. Manley (2004). "Key influences on construction innovation." Construction Innovation 4(3): 143-154.

Bliese, P. D. and R. R. Halverson (1996). "Individual and Nomothetic Models of Job Stress: An Examination of Work Hours, Cohesion, and Well-Being1." Journal of Applied Social Psychology 26(13): 1171-1189.

Bonk, C. J. (2002). "Online training in an online world." Bloomington, IN: CourseShare. com.

Boomsma, A. and J. J. Hoogland (2001). "The robustness of LISREL modeling revisited." Structural equation modeling: Present and future: 139-168.

Boyce, T. (2009) "Pinpointing Behaviors and Designing an Observation Card: A First Step in Cultivating the Human Side of Safety."

Brown, T. A. (2006). Confirmatory factor analysis for applied research. New York, Guilford Press.

Brunette, M. (2004). "Construction safety research in the United States: targeting the Hispanic workforce." Injury Prevention 10(4): 244.

Budworth, N. (1997). "The development and evaluation of a safety climate measure as a diagnostic tool in safety management." Journal of the Institution of Occupational Safety and Health 1: 19-29.

Bureau of Labor Statistics (2010). Employment by major industry sector.

Bureau of Labor Statistics (2010). The Employment Situation - November 2010.

Bureau of Labor Statistics (2010). Fatal occupational injuries by industry and event or exposure, All United States, 2009.

Bureau of Labor Statistics (2010). Incidence rates of nonfatal occupational injuries and illnesses by industry and case types, 2009.

Bureau of Labor Statistics (2010). Industries at a Glance: Construction NAICS 23.

Bureau of Labor Statistics (2010). Output by major industry sector.

Cabrera-Nguyen, E. P. (2010). "Author guidelines for reporting scale development and validation results in the Journal of the Society for Social Work and Research." Journal of the Society for Social Work and Research 1(2): 99-103.

Cameron, I. and R. Duff (2007). "Use of performance measurement and goal setting to improve construction managers' focus on health and safety." Construction Management and Economics 25(8): 869-881.

Carmines, E. and R. Zeller (1986). Reliability and validity assessment, Sage Publications.

Carter, G. and S. Smith (2006). "Safety hazard identification on construction projects." Journal of construction engineering and management 132: 197.

Center for Construction Research and Training (2007). The Construction Chart Book: The US Construction Industry and Its Workers, CPWR-The Center for Construction Research and Training Silver Spring, MD. 4.

Chan, Y. and R. P. Walmsley (1997). "Learning and understanding the Kruskal-Wallis one-way analysis-of-variance-by-ranks test for differences among three or more independent groups." Physical therapy 77(12): 1755-1761.

Chen, F. F., K. H. Sousa, et al. (2005). "Teacher's corner: testing measurement invariance of second-order factor models." Structural Equation Modeling 12(3): 471-492.

Choudhry, R., D. Fang, et al. (2007). "The nature of safety culture: A survey of the state-of-the-art." Safety Science 45(10): 993-1012.

Choudhry, R. M. and D. Fang (2008). "Why operatives engage in unsafe work behavior: Investigating factors on construction sites." Safety Science 46(4): 566-584.

Christopher, M. (1999). "Logistics and supply chain management: strategies for reducing cost and improving service." International Journal of Logistics Research and Applications 2(1): 103-104.

Churchill Jr, G. A. (1979). "A paradigm for developing better measures of marketing constructs." Journal of marketing research: 64-73.

Chyene, A., S. Cox, et al. (1998). "Modelling safety climate in the prediction of levels of safety activity." Work & Stress 12(3): 255-271.

Citrix Education. (2012). "Training Formats."   Retrieved December 17, 2012, from http://training.citrix.com/cms/education/training-links/training-format/.

Clarke, S. (1999). "Perceptions of organizational safety: implications for the development of safety culture." Journal of Organizational Behavior 20(2): 185-198.

Clarke, S. (2006). "Safety climate in an automobile manufacturing plant: The effects of work environment, job communication and safety attitudes on accidents and unsafe behaviour." Personnel Review 35(4): 413-430.

Cohen, J. (1988). Statistical power analysis for the behavioral sciences, Lawrence Erlbaum.

Cook, J. D. and S. J. Heptworth (1981). The experience of work: A compendium and review of 249 measures and their use, Academic Press London.

Cooper, M. and R. Phillips (2004). "Exploratory analysis of the safety climate and safety behavior relationship." Journal of Safety Research 35(5): 497-512.

Cooper, M., R. Phillips, et al. (1994). "Reducing accidents using goal setting and feedback: A field study." Journal of occupational and organizational psychology 67(3): 219-240.

Corporation, M. (2007). "Test Your Document's Readability." Retrieved 2/1/2011, from http://office.microsoft.com/en-us/word-help/test-your-document-s-readability-HP010148506.aspx.

Costantino, N., R. Pietroforte, et al. (2001). "Subcontracting in commercial and residential construction: an empirical investigation." Construction Management & Economics 19(4): 439-447.

Costello, A. B. and J. W. Osborne (2005). "Best practices in exploratory factor analysis: four recommendations for getting the most from your analysis." Practical Assessment, Research & Evaluation 10(7): 1-9.

Cox, S. and A. Cheyne (2000). "Assessing safety culture in offshore environments." Safety Science 34(1-3): 111-129.

Cox, S. and T. Cox (1991). "The structure of employee attitudes to safety: A European example." Work & Stress 5(2): 93-106.

CPWR, C. f. C. R. a. T.-. (2002). The Construction Chart Book: The US Construction Industry and Its Workers, CPWR-The Center for Construction Research and Training Silver Spring, MD.

Cronbach, L. J. (1951). "Coefficient alpha and the internal structure of tests." Psychometrika 16(3): 297-334.

Dainty, A., G. Briscoe, et al. (2001). "New perspectives on construction supply chain integration." Supply Chain Management: An International Journal 6(4): 163-173.

Dedobbeleer, N. and F. Béland (1998). "Is risk perception one of the dimensions of safety climate." Occupational injury: Risk prevention and intervention: 73-81.

Delgado-Hernandez, D. and E. Aspinwall (2008). "A framework for building quality into construction projects–Part I." Total Quality Management & Business Excellence 19(10): 1013-1028.

Delgado-Hernandez, D. and E. Aspinwall (2008). "Quality management case studies in the UK construction industry." Total Quality Management & Business Excellence 19(9): 919-938.

Dimeff, L. A., K. Koerner, et al. (2009). "Which training method works best? A randomized controlled trial comparing three methods of training clinicians in dialectical behavior therapy skills." Behaviour Research and Therapy 47(11): 921-930.

Dingsdag, D., H. Biggs, et al. (2008). "Understanding and defining OH&S competency for construction site positions: Worker perceptions." Safety Science 46(4): 619-633.

Dingsdag, D., H. Biggs, et al. (2010). "A Construction Safety Competency Framework: Improving OH&S performance by creating and maintaining a safety culture."

Donald, I. (1996). "Managing safety: an attitudinal-based approach to improving safety in organizations." Leadership & Organization Development Journal 17(4): 13-20.

Dov, Z. (2008). "Safety climate and beyond: A multi-level multi-climate framework." Safety Science 46(3): 376-387.

Driscoll, M. and S. Carliner (2005). Advanced web-based training strategies: Unlocking instructionally sound online learning, Pfeiffer.

Dubois, A. and L. Gadde (2002). "The construction industry as a loosely coupled system: implications for productivity and innovation." Construction Management and Economics 20(7): 621-631.

Duff, A., I. Robertson, et al. (1994). "Improving safety by the modification of behaviour." Construction Management and Economics 12(1): 67-78.

DuPont Corporation. (2010). "STOP For Each Other." 2010, from http://www.coastal.com/site/dupont-stop/dupont-stop/stop-for-each-other.html.

Enders, C. K. and D. L. Bandalos (2001). "The relative performance of full information maximum likelihood estimation for missing data in structural equation models." Structural Equation Modeling 8(3): 430-457.

Environmental Protection Agency (2007) "Guidance for Preparing Standard Operating Procedures (SOPs)."

Fagerland, M. W. and L. Sandvik (2009). "Performance of five two-sample location tests for skewed distributions with unequal variances." Contemporary clinical trials 30(5): 490-496.

Fan, W. and Z. Yan (2010). "Factors affecting response rates of the web survey: A systematic review." Computers in Human Behavior 26(2): 132-139.

Fang, D., Y. Chen, et al. (2006). "Safety climate in construction industry: a case study in Hong Kong." Journal of construction engineering and management 132: 573.

Fang, D., R. M. Choudhry, et al. (2006). Proceedings of CIB W99 International Conference on Global Unity for Safety & Health in Construction: 28-30 June 2006, Beijing, China, Tsinghua University Press.

Fazio, P., O. Moselhi, et al. (1988). "Design impact of construction fast-track." Construction Management and Economics 6(3): 195-208.

Fernie, S. and A. Thorpe (2007). "Exploring change in construction: supply chain management." Engineering Construction and Architectural Management 14(4): 319-333.

Fisk, E. and W. Reynolds (2003). Construction project administration, prentice hall.

Flin, R. (2003). "“Danger-men at work”: Management influence on safety." Human Factors and Ergonomics in Manufacturing & Service Industries 13(4): 261-268.

Flin, R., K. Mearns, et al. (2000). "Measuring safety climate: identifying the common features." Safety Science 34(1-3): 177-192.

Flora, D. B. and P. J. Curran (2004). "An empirical evaluation of alternative methods of estimation for confirmatory factor analysis with ordinal data." Psychological methods 9(4): 466.

Flynn, B. B., R. G. Schroeder, et al. (1994). "A framework for quality management research and an associated measurement instrument." Journal of Operations Management 11(4): 339-366.

Fornell, C. and D. Larcker (1981). "Evaluating structural equation models with unobservable variables and measurement error." Journal of marketing research 18(1): 39-50.

Gagne, R. M., L. J. Briggs, et al. (1992). "Principles of Instructional Design. Holt, Rinehart and Winston." Inc., New York.

Gambatese, J., M. Behm, et al. (2005). "Viability of designing for construction worker safety." Journal of construction engineering and management 131: 1029.

Gambatese, J. and J. Hinze (1999). "Addressing construction worker safety in the design phase:: Designing for construction worker safety." Automation in Construction 8(6): 643-649.

Gambatese, J., J. Hinze, et al. (1997). "Tool to design for construction worker safety." Journal of Architectural Engineering 3(1): 32-41.

Gambatese, J. A., M. Behm, et al. (2008). "Designer's role in construction accident causality and prevention: Perspectives from an expert panel." Safety Science 46(4): 675-691.

Geller, E. S., D. S. Roberts, et al. (1996). "Predicting propensity to actively care for occupational safety." Journal of Safety Research 27(1): 1-8.

Gilkey, D. P., T. J. Keefe, et al. (2003). "Management commitment to safety and health in residential construction: HomeSafe spending trends 1991–1999." Work 20(1): 35.

Gillen, M. (2004). "Construction managers' perceptions of construction safety practices in small and large firms: A qualitative investigation." Work (Reading, Mass.) 23(3): 233.

Gillen, M., D. Baltz, et al. (2002). "Perceived safety climate, job demands, and coworker support among union and nonunion injured construction workers* 1." Journal of Safety Research 33(1): 33-51.

Gittleman, J., P. Gardner, et al. (2010). "[Case Study] CityCenter and Cosmopolitan Construction Projects, Las Vegas, Nevada: Lessons learned from the use of multiple sources and mixed methods in a safety needs assessment." Journal of Safety Research 41(3): 263-281.

Glazner, J., J. Borgerding, et al. (1999). "Contractor safety practices and injury rates in construction of the Denver International Airport." American journal of industrial medicine 35(2): 175-185.

Glendon, A. and D. Litherland (2001). "Safety climate factors, group differences and safety behaviour in road construction." Safety Science 39(3): 157-188.

Glendon, A., N. Stanton, et al. (1994). "Factor analysing a performance shaping concepts questionnaire." Ergonomics for all: University of Warwick, 19-22 April 1994: 340.

Glick, W. H. (1985). "Conceptualizing and measuring organizational and psychological climate: Pitfalls in multilevel research." Academy of management review 10(3): 601-616.

Gliem, J. A. and R. R. Gliem (2003). "Calculating, interpreting, and reporting Cronbach's alpha reliability coefficient for Likert-type scales."

Godfrey, P. and H. Lindgard (2007). "Safer construction: the development of a voluntary code of practice to improve safety performance in the Australian construction industry."

Goldberg, A., E. Dar-El, et al. (1991). "Threat perception and the readiness to participate in safety programs." Journal of Organizational Behavior 12(2): 109-122.

Goldenhar, L. M., S. K. Moran, et al. (2001). "Health and safety training in a sample of open-shop construction companies." Journal of Safety Research 32(2): 237-252.

Goldstein, I. L. (2002). Training in organizations: Needs assessment, development, and evaluation, Thomson Brooks/Cole Publishing Co.

González-Romá, V., J. Peiro, et al. (1999). "The validity of collective climates." Journal of occupational and organizational psychology 72(1): 25-40.

Gould, F. (2005). Managing the construction process: estimating, scheduling, and project control, Prentice Hall.

Grewal, R., J. A. Cote, et al. (2004). "Multicollinearity and measurement error in structural equation models: Implications for theory testing." Marketing Science: 519-529.

Grissom, R. J. (2000). "Heterogeneity of variance in clinical data." Journal of Consulting and Clinical Psychology 68(1): 155.

Guldenmund, F. (2000). "The nature of safety culture: a review of theory and research." Safety Science 34(1): 215-257.

Gyekye, S. (2005). "Workers' perceptions of workplace safety and job satisfaction." International Journal of Occupational Safety and Ergonomics (JOSE) 11(3): 291-302.

Hair, J. F., R. E. Anderson, et al. (1998). Black (1998), Multivariate data analysis, Upper Saddle River, NJ: Prentice Hall.

Haro, E. and B. Kleiner (2008). "Macroergonomics as an organizing process for systems safety." Applied Ergonomics 39(4): 450-458.

Hatcher, L. (1994). A step-by-step approach to using the SAS system for factor analysis and structural equation modeling, SAS Publishing.

Haynes, S., D. Richard, et al. (1995). "Content validity in psychological assessment: A functional approach to concepts and methods." Psychological Assessment 7(3): 238-247.

Hayter, A. J. (1984). "A proof of the conjecture that the Tukey-Kramer multiple comparisons procedure is conservative." The Annals of Statistics: 61-75.

Hecker, S. and J. Gambatese (2003). "Safety in design: a proactive approach to construction worker safety and health." Applied Occupational and Environmental Hygiene 18(5): 339-342.

Hendrick, H. and B. Kleiner, Eds. (2002). Macroergonomics: Theory, Methods, and Applications. Mahwah, New Jersey, Lawerence Erlbaum Associates.

Hendrick, H. W. and B. Kleiner (2001). Macroergonomics: An introduction to work system design. Santa Monica, CA, Human Factors and Ergonomics Society.

Hinkin, T. R. (1998). "A brief tutorial on the development of measures for use in survey questionnaires." Organizational research methods 1(1): 104-121.

Hinze, J. (1981). "Human aspects of construction safety." Journal of the Construction Division 107(1): 61-72.

Hinze, J. (1996). Construction safety, Prentice Hall.

Hinze, J. (2005). "Use of trench boxes for worker protection." Journal of construction engineering and management 131: 494.

Hinze, J. and J. Gambatese (2003). "Factors that influence safety performance of specialty contractors." Journal of construction engineering and management 129: 159.

Hinze, J. and R. Godfrey (2003). "An evaluation of safety performance measures for construction projects." Journal of Construction Research 4(1): 5-15.

Hinze, J. and F. Wiegand (1992). "Role of designers in construction worker safety." Journal of construction engineering and management 118(4): 677-684.

Hofmann, D. and F. Morgeson (1999). "Safety-related behavior as a social exchange: The role of perceived organizational support and leader-member exchange." Journal of Applied Psychology 84(2): 286-296.

Hofmann, D. and A. Stetzer (1996). "A Cross Level Investigation Of Factors Influencing Unsafe Behaviors and Accidents." Personnel Psychology 49(2): 307-339.

Horwitz, I. and B. McCall (2004). "Disabling and fatal occupational claim rates, risks, and costs in the Oregon construction industry 1990-1997." Journal of occupational and environmental hygiene 1(10): 688-698.

Hoyle, R. H. (1995). Structural equation modeling: Concepts, issues, and applications, SAGE publications, Inc.

Hu, L. and P. M. Bentler (1999). "Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives." Structural Equation Modeling: A Multidisciplinary Journal 6(1): 1-55.

Huang, X. (2003). Owner's role in construction safety. 132.

James, L. R. (1982). "Aggregation bias in estimates of perceptual agreement." Journal of Applied Psychology 67(2): 219-229.

James, P. and D. Walters (1994). "Non-union rights of involvement: The case of health and safety at work." Employee Relations 16(7): 33-42.

Jeselskis, E., S. Anderson, et al. (1996). "Strategies for achieving excellence in construction safety performance." ASCE Journal of Construction Engineering and Management 122: 61.

Johnson, S. E. (2003). "Behavioral safety theory." Professional Safety 48(10): 39-44.

Jolliffe, I. (2005). "Principal component analysis."

Jun, D. H. and K. El Rayes (2010). Optimizing Labor Utilization in Multiple Shifts for Construction Projects, ASCE.

Kitchenham, B. and S. L. Pfleeger (2003). "Principles of survey research part 6: data analysis." ACM SIGSOFT Software Engineering Notes 28(2): 24-27.

Kleiner, B. (1999). "Macroergonomic analysis and design for improved safety and quality performance." International journal of occupational safety and ergonomics: JOSE 5(2): 217.

Kleiner, B. M. (2006). "Macroergonomics: Analysis and design of work systems." Applied Ergonomics 37(1): 81-89.

Laitinen, H. and I. Ruohomäki (1996). "The effects of feedback and goal setting on safety performance at two construction sites." Safety Science 24(1): 61-73.

Langford, D., S. Rowlinson, et al. (1993). "Safety behaviour and safety management: its influence on the attitudes of workers in the UK construction industry." Engineering, Construction and Architectural Management 7(2): 133-140.

Lau, A. and S. Tang (2009). "A survey on the advancement of QA(quality assurance) to TQM(total quality management) for construction contractors in Hong Kong." International Journal of Quality & Reliability Management 26(5): 410-425.

Laurence, D. (2005). "Safety rules and regulations on mine sites-the problem and a solution." Journal of Safety Research 36(1): 39-50.

Lawrence, P. R. and J. W. Lorsch (1967). "Managing differentiation and integration." Organization and Environment.

Leather, P. (1987). "Safety and accidents in the construction industry: a work design perspective." Work & Stress 1(2): 167-174.

Lee, T. and K. Harrison (2000). "Assessing safety culture in nuclear power stations." Safety Science 34(1-3): 61-97.

Levitt, R. and N. Samelson (1993). Construction safety management, Wiley.

Lewis, J. R. (1995). "IBM computer usability satisfaction questionnaires: psychometric evaluation and instructions for use." International Journal of Human-Computer Interaction 7(1): 57-78.

Lin, J. (2001). "Measuring the occupational health and safety performance of construction companies in Australia." Facilities (Bradford, West Yorkshire, England) 19(3/4): 131-139.

Ling, F. Y. Y., S. L. Chan, et al. (2004). "Predicting performance of design-build and design-bid-build projects." Journal of construction engineering and management 130: 75.

Lingard, H. (2002). "The effect of first aid training on Australian construction workers occupational health and safety knowledge and motivation to avoid work-related injury or illness." Construction Management and Economics 20(3): 263-273.

Lingard, H., T. Cooke, et al. (2009). "Group-level safety climate in the Australian construction industry: within-group homogeneity and between-group differences in road construction and maintenance." Construction Management and Economics 27(4): 419-432.

Lingard, H. and S. Rowlinson (1998). "Behavior-based safety management in Hong Kong's construction industry." Journal of Safety Research 28(4): 243-256.

Litwin, M. (1995). How to measure survey reliability and validity, Sage Publications, Inc.

Lynn, M. (1986). "Determination and quantification of content validity." Nursing Research 35(6): 382.

Lytle, W. O. (1998). Designing a High-Performance Organization. Clark, New Jersey, Block, Petrella, Weisbord, Inc.

Manuele, F. (2003). On the practice of safety, Wiley-Interscience.

March, J. and Z. Shapira (1992). "Variable risk preferences and the focus of attention." Psychological Review 99(1): 172-183.

Marsh, H. W., J. R. Balla, et al. (1988). "Goodness-of-fit indexes in confirmatory factor analysis." Psychological Bulletin 103(3): 391-410.

Marsh, T., R. Davies, et al. (1998). "The role of management commitment in determining the success of a behavioural safety intervention." JOURNAL-INSTITUTION OF OCCUPATIONAL SAFETY AND HEALTH 2: 45-56.

Mason, S. and G. Simpson (1995). Measuring safety attitudes to target management actions. The Safety and Health Practitioner: 17-20.

Matthews, J., L. Pellew, et al. (2000). "Quality relationships: partnering in the construction supply chain." International Journal of Quality and Reliability Management 17(4-5): 493-510.

McDonald, N., S. Corrigan, et al. (2000). "Safety management systems and safety culture in aircraft maintenance organisations." Safety Science 34(1-3): 151-176.

McGraw, K. O. and S. Wong (1996). "Forming inferences about some intraclass correlation coefficients." Psychological methods 1(1): 30-46.

Mearns, K., S. Whitaker, et al. (2003). "Safety climate, safety management practice and safety performance in offshore environments." Safety Science 41(8): 641-680.

Meglino, B., E. Ravlin, et al. (1989). "A work values approach to corporate culture: A field test of the value congruence process and its relationship to individual outcomes." Journal of Applied Psychology 74(3): 424.

Michau, F., S. Gentil, et al. (2001). "Expected benefits of web-based learning for engineering education: examples in control engineering." European Journal of Engineering Education 26(2): 151-168.

Milgate, N. (2002). "Examining the effectiveness of health and safety committees and representatives: a review." Work (Reading, Mass.) 19(3): 281.

Mitropoulos, P. (2005). "Systems Model of Construction Accident Causation." Journal of construction engineering and management 131(7): 816.

Mohamed, S. (2002). "Safety climate in construction site environments." Journal of construction engineering and management 128: 375.

Mohamed, S. (2003). "Scorecard approach to benchmarking organizational safety culture in construction." Journal of construction engineering and management 129: 80.

Mohamed, S., T. H. Ali, et al. (2009). "National culture and safe work behaviour of construction workers in Pakistan." Safety Science 47(1): 29-35.

Muench, S. T. and J. P. Mahoney (2004). "Computer-Based Multimedia Pavement Training Tool for Self-Directed Learning." Transportation Research Record: Journal of the Transportation Research Board 1896(-1): 3-12.

Munoz-Leiva, F., J. Sanchez-Fernandez, et al. (2010). "Improving the response rate and quality in Web-based surveys through the personalization and frequency of reminder mailings." Quality & Quantity 44(5): 1037-1052.

Muthen, B. and D. Kaplan (1985). "A comparison of some methodologies for the factor analysis of non‚Äênormal Likert variables." British Journal of Mathematical and Statistical Psychology 38(2): 171-189.

National Institute of Occupational Safety and Health. (2010, 6/25/2010). "Engineering Controls." Retrieved September 8, 2010, from http://www.cdc.gov/niosh/topics/engcontrols/.

National Research Council (2003). Safety is Seguridad. Washington D.C., National Academy of Sciences.

Neal, A. and M. Griffin (2002). "Safety climate and safety behaviour." Australian journal of Management 27(2).

Neal, A., M. Griffin, et al. (2000). "The impact of organizational climate on safety climate and individual behavior." Safety Science 34(1-3): 99-109.

Neter, J., W. Wasserman, et al. (1996). "Applied linear statistical models."

NIOSH (2006). NIOSH Fatal Occupational Injury Cost Fact Sheet: Construction.

Noria Corporation (2010) "DuPont enhances STOP For Each Other safety program." Reliable Plant.

Nunnally, J. C., I. H. Bernstein, et al. (1967). Psychometric theory, McGraw-Hill New York.

Occupational Safety & Health Administration (1993). The 100 Most Frequently Cited OSHA Construction Standards in 1991: A Guide for the Abatement of the Top 25 Associated Physical Hazards. Washington D.C., Government Printing Office.

Occupational Safety & Health Administration (2002) "Job Hazard Analysis (OSHA 3071)."

Occupational Safety and Health Administration. (1996). "Training Requirements in OSHA Construction Industry Standards and Training Guidelines." from http://www.osha.gov/doc/outreachtraining/htmlfiles/osha2254.html.

Oracle University. (2012). "Oracle Training Formats." Retrieved December 17, 2012, from http://education.oracle.com/pls/web_prod-plq-dad/db_pages.getpage?page_id=69.

Peckitt, S., I. Glendon, et al. (2004). "Societal Influences on Safety Culture in the Construction Industry." Construction safety management systems: 14.

Polit, D., C. Beck, et al. (2007). "Is the CVI an acceptable indicator of content validity? Appraisal and recommendations." Research in nursing & health 30(4): 459-467.

Pousette, A., S. Larsson, et al. (2008). "Safety climate cross-validation, strength and prediction of safety behaviour." Safety Science 46(3): 398-404.

Prussia, G., K. Brown, et al. (2003). "Mental models of safety: do managers and employees see eye to eye." Journal of Safety Research 34(2): 143-156.

Raykov, T. (2005). "Analysis of longitudinal studies with missing data using covariance structure modeling with full-information maximum likelihood." Structural Equation Modeling 12(3): 493-505.

Reader, T. W., R. Flin, et al. (2007). "Interdisciplinary communication in the intensive care unit." British journal of anaesthesia 98(3): 347.

Reese, C. and J. Eidson (2006). Handbook of OSHA construction safety and health, CRC.

Richter, A. and C. Koch (2004). "Integration, differentiation and ambiguity in safety cultures." Safety Science 42(8): 703-722.

Ringen, K. (1995). "Safety and health in the construction industry." Annual review of public health 16(1): 165.

Ringen, K. (1996). "Intervention research in occupational safety and health: Examples from construction." American journal of industrial medicine 29(4): 314-320.

Rombel, A. (2009) "Construction industry hit hard in August U.S. employment report." All Business.

Ropohl, G. (1999). "Philosophy of Socio-Technical Systems." Society for Philosophy and Technology 4(3).

Rowlinson, S. (2004). Construction safety management systems, Taylor & Francis.

Rowlinson, S. (2004). "Overview of Construction Site Safety Issues." Construction safety management systems: 1.

Rundmo, T. (1997). "Associations between risk perception and safety." Safety Science 24(3): 197.

Rundmo, T. (2000). "Safety climate, attitudes and risk perception in Norsk Hydro." Safety Science 34(1-3): 47.

Runyan, C. W. (1998). "Using the Haddon matrix: introducing the third dimension." Injury Prevention 4(4): 302.

Runyan, C. W. (2003). "Introduction: back to the future—revisiting Haddon's conceptualization of injury epidemiology and prevention." Epidemiologic Reviews 25(1): 60.

SafeWork South Australia. (2007, 7/11/2007). "Hierarchy of Control Measures." Retrieved September 8, 2010, from http://www.safework.sa.gov.au/contentPages/EducationAndTraining/HazardManagement/Machinery/TheAnswers/machAnswerHierarchy.htm.

Salem, O., J. Solomon, et al. (2006). "Lean construction: From theory to implementation." Journal of management in engineering 22: 168.

Santos, J. R. A. (1999). "Cronbach's alpha: A tool for assessing the reliability of scales." Journal of Extension 37(2): 1-5.

Saunders, L., A. McCoy, et al. (2011). How Do Project Manager's View Construction Safety in Australia Versus the United States? CIB W099: International Council for Research and Innovation in Building and Construction. Washington DC.

Sawacha, E., S. Naoum, et al. (1999). "Factors affecting safety performance on construction sites." International Journal of Project Management 17(5): 309-315.

Schneider, P. J. and D. A. Penfield (1997). "Alexander and Govern's approximation: Providing an alternative to ANOVA under variance heterogeneity." The Journal of experimental education 65(3): 271-286.

Schreiber, J. B., A. Nora, et al. (2006). "Reporting structural equation modeling and confirmatory factor analysis results: A review." The Journal of Educational Research 99(6): 323-338.

Shrout, P. E. and J. L. Fleiss (1979). "Intraclass correlations: uses in assessing rater reliability." Psychol Bull 86(2): 420-428.

Simard, M. and A. Marchand (1997). "Workgroups propensity to comply with safety rules: the influence of micro-macro organisational factors." Ergonomics 40(2): 172-188.

Siu, O., D. R. Phillips, et al. (2004). "Safety climate and safety performance among construction workers in Hong Kong: The role of psychological strains as mediators." Accident Analysis & Prevention 36(3): 359-366.

SQCOnline (2010). Military Standard 105E (ANSI/ASQC Z1.4, ISO 2859) Tables.

Straub, D., M. C. Boudreau, et al. (2004). "Validation guidelines for IS positivist research." Communications of the Association for Information Systems 13(24): 380-427.

Stup, R. (2001) "Standard Operating Procedures: A Writing Guide."

Suhr, D. D. (2006). "Exploratory or Confirmatory Factor Analysis?" Statistics and Data Analysis, SUGI 31: 26-29.

Suraji, A., A. Duff, et al. (2001). "Development of causal model of construction accident causation." Journal of construction engineering and management 127: 337.

Szymberski, R. T. (1997). "Construction project safety planning." TAPPI Journal.

Teo, A. (2006). Measurement of Safety Climate in Construction Industry; Studies in Singapore and Hong Kong, Tsinghua University Press.

Teret, S. (1997). "Chapter 6: Identifying and Choosing Prevention Strategies." Violence and Injury Control through Education, Networking and Training Retrieved 9/8/2010, from http://www.ibiblio.org/vincentweb/chapter6.html.

Tomarken, A. J. and R. C. Serlin (1986). "Comparison of ANOVA alternatives under variance heterogeneity and specific noncentrality structures." Psychological Bulletin 99(1): 90.

Tomás, J. and A. Oliver (1995). The perceived effect of safety climate on occupational accidents.

Toole, T. M. (2002). "Comparison of Site Safety Policies of Construction Industry Trade Groups." Practice Periodical on Structural Design and Construction 7: 90.

Trist, E. (1981). "The Evolution of Socio-technical Systems." The Journal of the Royal College of General Practitioners. Occasional paper 2: 67.

Vandenberg, R. J. and C. E. Lance (2000). "A review and synthesis of the measurement invariance literature: Suggestions, practices, and recommendations for organizational research." Organizational research methods 3(1): 4-70.

Vargha, A. s. and H. D. Delaney (1998). "The Kruskal-Wallis Test and Stochastic Homogeneity." Journal of Educational and Behavioral Statistics 23(2): 170-192.

Vrijhoef, R. and L. Koskela (2000). "The four roles of supply chain management in construction." European Journal of Purchasing & Supply Management 6(3-4): 169-178.

Vrijhoef, R. and L. Koskela (2008). "Roles of Supply Chain Management in Construction ROLES OF SUPPLY CHAIN MANAGEMENT IN CONSTRUCTION."

Waehrer, G., X. Dong, et al. (2007). "Costs of occupational injuries in construction in the United States." Accident Analysis & Prevention 39(6): 1258-1266.

Waltz, E. and M. Montgomery (2003). "Fast-Track Construction." Corrections Today Magazine Dated: April 2003: 4.

Ward, R., A. Brazier, et al. (2003). Different types of supervision and the impact on safety in the chemical and allied industries, Literature review-Prepared by Entec UK Ltd. for the Health and Safety Executive.

Weinstein, M., J. Gambatese, et al. (2005). "Can design improve construction safety?: Assessing the impact of a collaborative safety-in-design process." Journal of construction engineering and management 131: 1125.

Whittington, C., A. Livingston, et al. (1992). "Research into management, organisational and human factors in the construction industry." HSE Contract Research Report.

Williamson, A., A. Feyer, et al. (1997). "The development of a measure of safety climate: The role of safety perceptions and attitudes* 1." Safety Science 25(1-3): 15-27.

Wong, A. (1999). "Total quality management in the construction industry in Hong Kong: a supply chain management perspective." Total Quality Management & Business Excellence 10(2): 199-208.

Worker's Compensation Board of Prince Edward Island (2009). Guide to Workplace Health & Safety Committees. Charlottetown. 1.

Wynd, C., B. Schmidt, et al. (2003). "Two quantitative approaches for estimating content validity." Western Journal of Nursing Research 25(5): 508.

Zohar, D. (1980). "Safety climate in industrial organizations: Theoretical and applied implications." Journal of Applied Psychology 65(1): 96-102.

Zohar, D. and G. Luria (2005). "A multilevel model of safety climate: Cross-level relationships between organization and group-level climates." Journal of Applied Psychology 90(4): 616-628.

Appendix A: Final Survey Instrument

Virginia Tech Safety Survey

This survey is intended to measure your attitudes toward construction worker safety and the control of potential risks and hazards on a construction project. You will read some statements regarding construction worker safety and the management and control of risks and hazards, and be asked to rate how much you agree with each statement. Please assume the following as you take the survey:

- The control of potential risks and hazards that can impact construction worker safety on a construction project can occur throughout the entire life of a project from initial planning and design activities through construction.
- The phrase "risk control" means the process by which potential hazards on a construction project are identified and controlled.
- Answer each question from the perspective of your role on a construction project.
- Answer each question about your company/organization, and not the construction project(s) you are a member of.

Definitions for the roles the survey is intended for are given below. Please use them to select the one that matches your role at your company.

- **Designer** - employees such as an architect, engineer, or other design professional that assist in converting a concept into construction documents that can be used through the construction process
- **Foreman** - generally manage a team of construction workers and make decisions related to production on a daily basis
- **Project Engineer** - do not perform design work, but are a bridge between technical areas and project management by helping construction personnel and subcontractors interpret design drawings, ensuring construction is done according to the design, and helping to develop solutions when construction varies from the design
- **Project Manager** - the lead person responsible for planning, coordinating, directing, and budgeting on a project, and oversight of issues such as cost, schedule, and quality. On very large construction projects, this person may be responsible for just part of a project such as the excavation or structure.
- **Safety Manager** - responsible for implementing and managing a company's safety program and working with construction personnel to increase the visibility of safety on projects
- **Superintendent** - manage the activities of the workforce, material and equipment deliveries, and keep records of daily progress at the construction site
- **Upper Management** - defined as the executive level management within a company such as the CEO, CFO, and COO and other high-level level personnel such as vice presidents that are responsible for at least regional level management and project executives that oversee multiple projects

This data will be used for research intended at identifying differences in safety attitudes between your role and others on a construction project. Your responses will be kept anonymous, and be used for research intended to improve knowledge within the construction safety field. By completing the survey you are consenting to your data being used for this research.

Please circle or mark the answer that best describes your level of agreement to each question

My company's management clearly thinks safety is as important as other factors on a project (time, cost, quality, etc.).	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

My company's management shows concern if employees do not think about safety and potential risks in their work.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

My company's management disciplines employees when they do not consider safety and potential risks in their work.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

My company's management clearly communicates safety and risk control issues.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

My company's management regularly brings safety and risk control info to the attention of employees.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

My company's management has campaigns to promote considering safety and potential risks in their work.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Current safety rules and procedures are made available to prevent and protect us from accidents.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

Current safety rules and procedures meet my needs as a source of information on safety and risk control.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

Current safety rules and procedures are not enforced by my company.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
My company always offers help when needed to create a safe work environment.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
My company tries to ensure that construction workers do not work alone in hazardous situations.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
My company tries to make sure that the workload is reasonably balanced among all members.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
My supervisor (person I report to) does not think safety and risk control are important parts of the construction process.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
My supervisor (person I report to) is a good resource for solving safety and risk control problems.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
My supervisor (person I report to) values my ideas on how to improve safety and prevent hazards even if major changes to the design or work methods are proposed.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Everyone at my company reports potential hazards, incidents, and accidents no matter how severe they are.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Everyone at my company is part of safety planning for a project.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

Everyone at my company contributes to a job safety/hazard analysis if they are asked.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

I understand how I can affect safety on a construction project.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

I understand what my responsibilities are for safety and risk control on a construction project.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

I am aware that safety/risk control should be the number one priority in my mind while working.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

On my company's projects identifying potential hazards is not a major aim of the design process.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

On my company's projects working with defective equipment is not allowed at any time.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

On my company's projects potential risks and outcomes are identified prior to the start of construction work.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

Under pressure I at times need to depart from normal safety and risk control procedures in order to get the job done.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

Under pressure it is normal for me to take shortcuts at the expense of safety.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

Under pressure I tolerate minor potentially unsafe conditions on the project site.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

I received adequate training on how to consider safety in my job.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I am aware of relevant safety and risk control procedures.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I fully understand current and relevant laws on occupational safety and health (OSH)	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
The focus in my company on construction worker safety and the prevention and control of potential risks plays an effective role in preventing accidents.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
The focus in my company on construction worker safety and the prevention and control of potential risks reduces risk for construction workers	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
The focus in my company on construction worker safety and the prevention and control of potential risks is not restrictive or superficial.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
The focus in my company on construction worker safety and the prevention and control of potential risks helps increase output on the construction site.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

The focus in my company on construction worker safety and the prevention and control of potential risks contributes to my work satisfaction.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

The focus in my company on construction worker safety and the prevention and control of potential risks has a positive influence on morale.	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

What is your current position/role at your company?	1. Designer 2. Foreman 3. Project Engineer 4. Project Manager 5. Safety Manager 6. Superintendent 7. Upper Management

What is your company's typical function on a construction project?	1. Owner 2. Design Firm 3. Constructor (Construction Manager) 4. Subcontractor

In what industry sector are most of the projects you work on?	1. Commercial (Retail, Schools, Hospitals, etc.) 2. Industrial (Manufacturing Plants, Refineries, Power Plants, etc.) 3. Heavy Engineering (Roads, Bridges, Sewer Pipe, etc.) 4. Residential

What is the typical size of projects that you are involved in?	1. $0-$10 million 2. $10-$20 million

	3. Greater than $20 million

How many years experience do you have in the construction industry?	

How many years have you worked in your current position/role?	

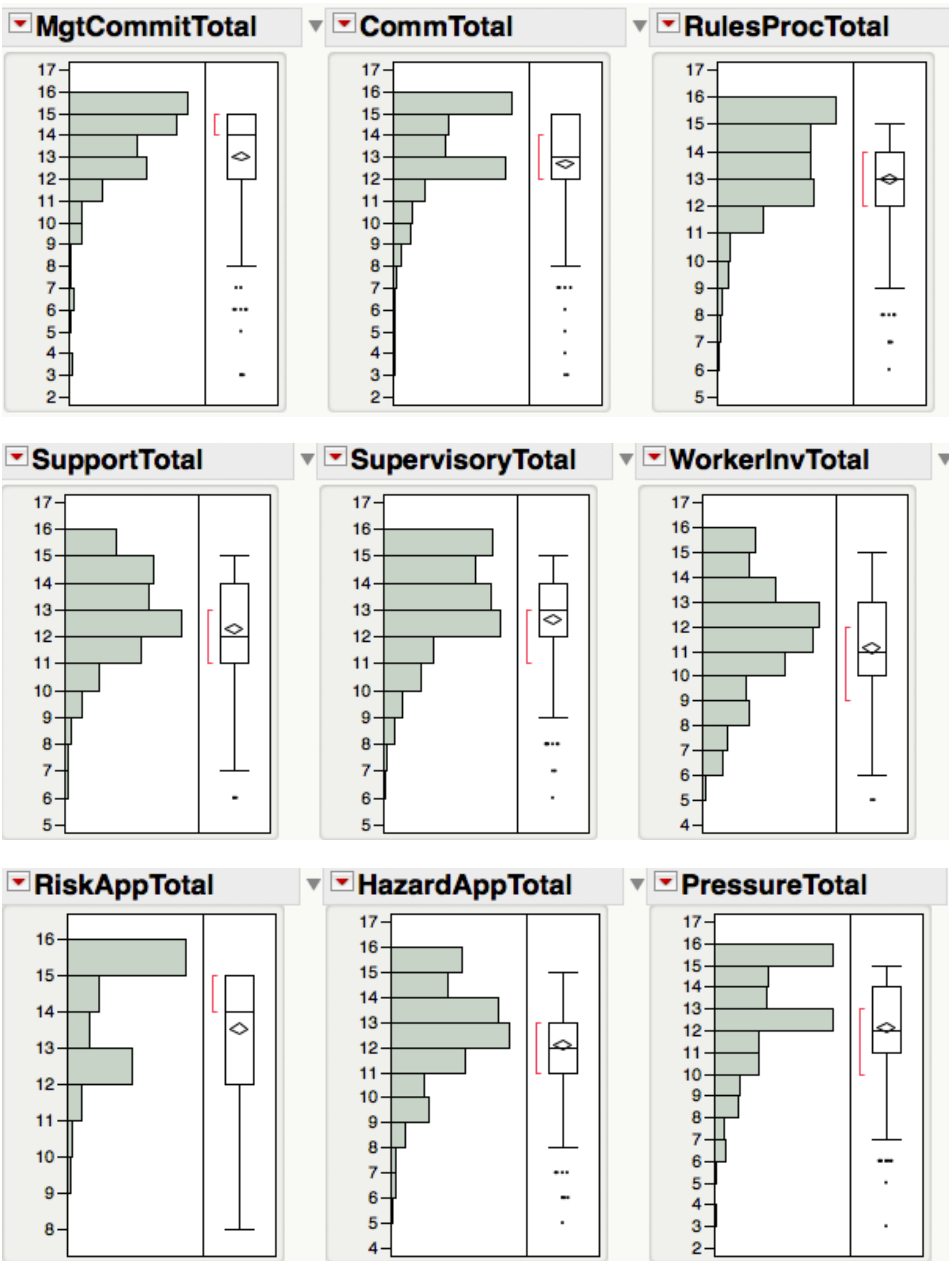
What type of projects do you usually work on?	1. Design-Bid Build(Traditional) 2. Design-Build 3. Other ____________________

What is the highest education level you have completed?	1. No High School 2. Some High School 3. High School / GED 4. College - Undergraduate Degree 5. College - Graduate Degree
What level of OSHA training have you completed?	1. None 2. OSHA 10 hour training program 3. OSHA 30 hour training program

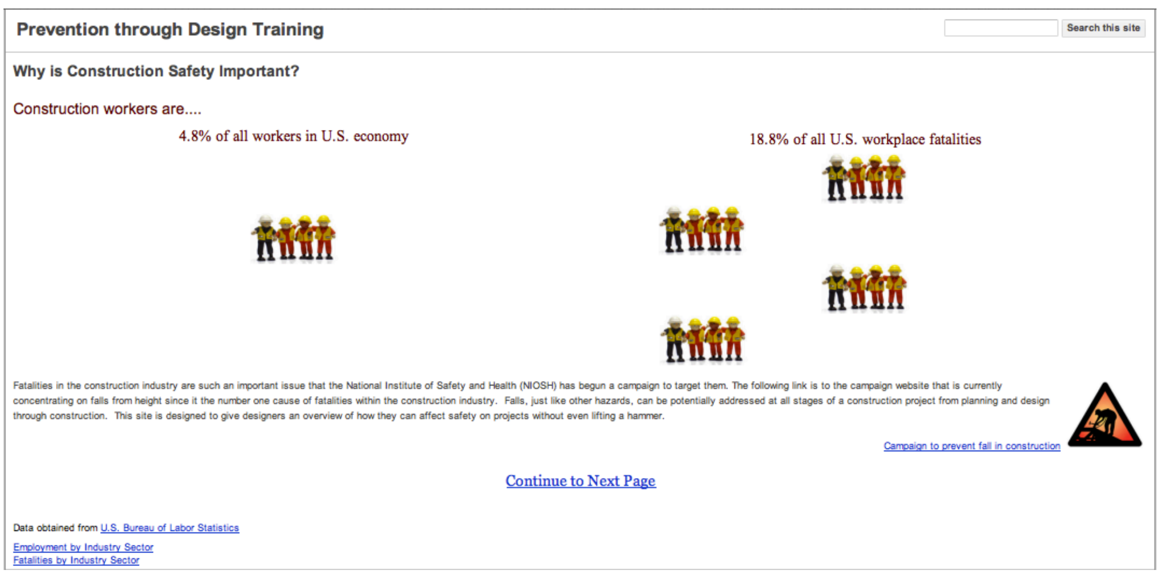
Not including OSHA training, approximately how much training have you completed specifically related to safety and risk control in the last year?	1. None (1) 2. 1 to 5 hours (2) 3. 6 to 10 hours (3) 4. More than 10 hours (4)

What do you think is the source or origin of your attitudes about safety?	

Appendix B: Distributions by Construct



Appendix C: Prevention through Design training website for Designers



Prevention through Design Examples

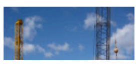
Construction projects go though multiple stages, and in the United States construction worker safety is typically left to the construction manager and subcontractors during the construction stage. A typical reply from owners and designers when asked how they approach construction worker safety is that they leave it up to the constructor in order to not dictate "means and methods" and expose themselves to potential liability.

The following is a series of examples about how safety could have potentially been incorporated into the pre-construction phases of a project for a new building on a college campus. These examples all involve design decisions that positively affected construction worker safety, but did not involve the designer dictating "means and methods" during the construction stage.

Excavation and Foundation

The site required a retaining wall at one edge because of the slope of the site. The wall was integral to the surrounding traffic and flow of the public around the site, and the small size of the site made the area adjacent to the wall needed for material laydown. Therefore, it was deemed by the project team that the wall be backfilled quickly and the design of the wall was made to accept this intervention by widening the footing underneath to require minimal bracing.

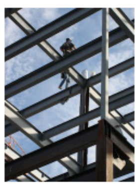
Once accelerated as a change, the backfilling of the wall provided multiple benefits to the safety environment of the site. Workers were able to work without the danger of heights, a major cause of hazard in the United States. Pedestrian and vehicle traffic around the site was also deemed safer as well. If controlling this hazard was left until the construction stage, workers would not have been able to work from the outside of the building without fall protection procedures and personal protective equipment (PPE).



Steel Erection

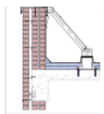
The erection of steel beams necessitates the consideration of multiple hazards during the construction lifecycle. These include the delivery and storage of the steel in potentially cramped construction sites, the lifting and placing of steel beams using cranes with limited lines of site, and working at heights while installing the steel. This building had all of these plus the additional hazard of a large volume of pedestrians traveling to and from classes around the site. The construction team tried to alleviate these hazards by breaking up the steel erection into small "kits" that were delivered as needed before 8am and after 4pm to avoid times of heavy class changes. This small change during the procurement stage, drastically reduced the number of potential interactions between students and steel delivery equipment.

Another safety decision option was to choose a steel erector that installed "rat lines" for fall protection on the ground before lifting instead of once the beams were placed. This eliminated workers being unsecured for a small time after placement while the fall protection was hooked to the beam.



Roof Fall Protection

Falls from roofs are an important safety hazard on commercial and residential construction. Temporary leading edge fall restraint systems should be used when working at heights over OSHA mandated limits, and most roofs obviously fit these requirements. One way to eliminate the need for these type of temporary controls is to design a parapet of at least 42 inches. While this might not be economically or aestheitcally feasible on some buildings, consideration of this design feature is one way to eliminate a potential hazard and install a permanent barrier for not only construction but also maintenance workers.



These are examples of the Prevention through Design (PtD) concept. This concept does not involve dictating construction means and methods, but rather just thinking about and being aware of potential hazards during the early stages of the project lifecycle. It also includes considering safety along with other important project issues such as cost, schedule, and quality. Interventions like the above are not feasible for every situation, but just thinking about how design decisions might affect construction and maintenance worker safety can lead to improved occupational safety and health performance.

Here is a link to NIOSH's website with more information on the PtD initiative in the United States.

PtD
Prevention through Design

Continue to Next Page

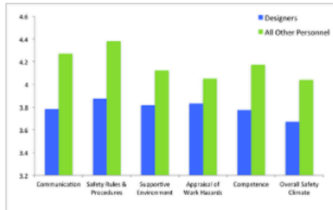
Prevention through Design Training

Search this site

How designer attitudes toward safety compare to other construction project personnel

In a recent survey conducted at Virginia Tech, 435 construction industry personnel such as designers, project managers, upper management, and superintendents were asked their attitudes toward construction safety in 11 categories. Each question was answered using 5-point scale from "strongly disagree = 1" to "strongly agree = 5".

One of the key results from the study was that designers had scores significantly lower than other respondents in numerous categories. The categories are shown below, and improving designer attitudes in these areas would be a step in removing the barriers that currently exist in fully integrating designers into the safety planning process of a construction project.



The results have the following take-aways that can be used by design firms to improve the safety attitudes of their workers

As compared to other construction personnel, designers:

1. report **less communication** from their organization about risk management and construction worker safety.
2. receive the safety rules and procedures in their organization as **less effective or available** to them.
3. see their work environment as **less supportive** toward construction worker safety and controlling potential safety risks.
4. rank their organization's processes of identifying potential safety hazards as **less prevalent and widespread**.
5. rate themselves as having a **lower competence** of risk management and construction worker safety issues.
6. display **less positive attitudes** toward their organizations' overall risk management and construction safety processes

Continue to Next Page

Prevention through Design Training

Search this site

A short exercise - What are the most effective safety control methods?

Hazard Control Rankings

Please rank the following hazard control types according to how effective you think they are in managing safety for construction workers. Please only choose each option once.
* Required

Choose the control type that you feel is the most effective way to manage safety on a construction project *
Administrative Controls (pre-task job safety analysis, safety audits, etc.)

Choose the control type that you feel is the 2nd most effective way to manage safety on a construction project *
Administrative Controls (pre-task job safety analysis, safety audits, etc.)

Choose the control type that you feel is the 3rd most effective way to manage safety on a construction project *
Administrative Controls (pre-task job safety analysis, safety audits, etc.)

Choose the control type that you feel is the 4th most effective way to manage safety on a construction project *
Administrative Controls (pre-task job safety analysis, safety audits, etc.)

Choose the control type that you feel is the 5th most effective way to manage safety on a construction project *
Administrative Controls (pre-task job safety analysis, safety audits, etc.)

Choose the control type that you feel is the 6th most effective way to manage safety on a construction project *
Administrative Controls (pre-task job safety analysis, safety audits, etc.)

Submit

Continue to Next Page

Prevention through Design Training

Search this site

How well does this picture match your answers from the previous exercise?

The figure below is called the Hierarchy of Safety controls, and ranks the hazard control methods in the preceding survey from most to least effective (from top to bottom of the pyramid). The top two levels of the pyramid can generally be affected in the planning and design phases by designers before construction methods are even addressed. Just identifying and discussing potential hazards in the planning and design stages as part of a design for safety review or even during constructability reviews with other decision influences such as function, cost, and schedule is an effective way to improve safety performance on construction projects.

Figure Adapted from SafeWork Australia

There has been an increase recently on research focusing on Prevention through Design and its impact on construction worker safety. Some examples of this research and relevant results are summarized below.

- A study of 100 construction accidents in the United Kingdom was conducted to identify the originating factors of each. 50% of the accidents were found to have the design as an originating factor, and could have had the risk of the accident reduced by a change in the design (Haslam 2003).
- A group of 224 construction fatalities in the United States was analyzed to determine a link to the design phase. The research found that 42% of the fatalities could be linked to design, and that risk for the construction worker could have been reduced by a change to the design (Behm 2005)
- A survey of design professionals in Western Australia, where legislation has been in place since 1984 regulating the requirements of upstream construction activities in construction safety, found that two-thirds of design professionals had positive attitudes on the impact of the design for construction safety concept (over 90% were either positive or neutral). Also, multiple examples were given from the professionals of design decisions made for safety reasons that led to positive benefits in cost or schedule (Behm and Culvenor 2011).

Continue to Next Page

Appendix D: Prevention through Design Follow-up Survey

I thought construction worker safety was already an important issue for designers before being exposed to this website

Strongly Disagree
Disagree
Neither Agree or Disagree
Agree
Strongly Agree

This material in this website added to my understanding about how designers can influence safety on a construction project

Strongly Disagree
Disagree
Neither Agree or Disagree
Agree
Strongly Agree

The information including in the website was relevant to my job as a designer

Strongly Disagree
Disagree
Neither Agree or Disagree
Agree
Strongly Agree

I think exposing designers to information about how they affect safety on a construction project is important.

Strongly Disagree
Disagree
Neither Agree or Disagree
Agree
Strongly Agree

Please rate the following areas on their importance (1=lowest, 5=highest) in implementing prevention through design concepts *

Communication of safety issues and information to designers
Safety Rules and Procedures for

designers

A Supportive Environment at design firms toward construction worker safety
Improving the ability of designers to identify potential safety hazards
Training to improve designer competence regarding construction worker safety issues

Please rate the following training types as to how effective (1=very ineffective, 2=somewhat ineffective, 3=neither ineffective or effective, 4=somewhat effective, 5=very effective) you think they would be in educating designers about safety issues

Training Types

AIA or Engineering Society Promotional Materials
College/University Courses
Professional Development (Continuing Education) Courses and Seminars
Sessions at Professional Conferences
Internal Training at my Company

Please rate the following training formats as to how effective (1=very ineffective, 2=somewhat ineffective, 3=neither ineffective or effective, 4=somewhat effective, 5=very effective) you think they would be in educating designers about safety issues

Training Formats

Onsite classroom led by instructor
Live online led by instructor
Self-guided website

Reference materials (articles, case studies, handouts, etc.)
Pre-recorded video courses

What are the barriers in the industry that this type of training needs to address to make implementing prevention through design concepts practical in the U.S.?

Is there information not included on this website that would make the training more effective for educating designers about construction safety issues?

Please include any other comments about the material in this website such as the parts you liked best or areas that could be improved

Appendix E: Annotated List of Figures

List of Figures

Appendix F: Institutional Review Board (IRB) Approval Letter

VirginiaTech

Office of Research Compliance
Institutional Review Board
2000 Kraft Drive, Suite 2000 (0497)
Blacksburg, Virginia 24060
540/231-4606 Fax 540/231-0959
e-mail irb@vt.edu
Website: www.irb.vt.edu

MEMORANDUM

DATE: June 28, 2011

TO: Brian M. Kleiner, Lance Saunders

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires May 31, 2014)

PROTOCOL TITLE: Measuring Safety Attitudes in Construction Supply Chain

IRB NUMBER: 11-596

Effective June 28, 2011, the Virginia Tech IRB PAM, Andrea Nash, approved the new protocol for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report promptly to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at http://www.irb.vt.edu/pages/responsibilities.htm (please review before the commencement of your research).

PROTOCOL INFORMATION:
Approved as: **Exempt, under 45 CFR 46.101(b) category(ies) 2**
Protocol Approval Date: **6/28/2011**
Protocol Expiration Date: **NA**
Continuing Review Due Date*: **NA**
*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:
Per federally regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals / work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

Invent the Future

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

An equal opportunity, affirmative action institution

Date*	OSP Number	Sponsor	Grant Comparison Conducted?

*Date this proposal number was compared, assessed as not requiring comparison, or comparison information was revised.

If this IRB protocol is to cover any other grant proposals, please contact the IRB office (irbadmin@vt.edu) immediately.