MEASURING, MODELING, AND ASSESSING SAFETY COMMUNICATION IN CONSTRUCTION CREWS IN THE US USING SOCIAL NETWORK ANALYSIS

By

RAYYAN MOHAMMEDNOUR ALSAMADANI

B.S., King Abdul Aziz University, 2003

M.S., University of Wisconsin, 2009

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This dissertation entitled:

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Written by Rayyan Mohammednour Alsamadani

has been approved for the Department of Civil, Environmental, and Architectural Engineering

Director of research / adviser

Professor **Matthew. R. Hallowell ____**

Committee approvals

Professor **Amy Javernick-Will ____**

Emeritus Professor **James E. Diekmann __________________________________**

Professor **Keith R. Molenaar ____**

Professor **Rodolfo Valdes-Vasquez ______________________________________**

The final copy of this thesis has been examined by the signatories, and we

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ABSTRACT

Alsamadani, Rayyan Mohammednour (Ph.D., Civil, Environmental, and Architectural Engineering)

Measuring, Modeling, and Assessing Safety Communication in Construction Crews in the US using Social Network Analysis

Dissertation directed by Assistant Professor Matthew R. Hallowell

Effective safety communication has been found as a major practice to enhance safety performance. Open discussion from supervisors to employees, immediate feedback and corrections, and implementing a lesson-learned program are examples of practices that help managers to improve on-site safety communication. Yet, safety communication has become more challenging, especially for bi or multi-lingual construction work crews in which Hispanic workers account the majority of the construction workforce in some States. Beside the language barrier, cultural differences have also influenced safety practices for Hispanic workers. This dissertation employs social network analysis approach to quantify and model the weaknesses and potential points of safety communication for small work crews. Additionally, it uses exploratory interview and Photovoice techniques to study safety challenges for Hispanic workers. This dissertation follows a three-journal paper formation. The first paper is an exploratory study that models and quantifies the five safety communication modes of local small construction crews; in addition, it generates visualized networks of communication patterns. The second paper investigates the relationships between personal attributes, communication patterns, and safety performance of 161 participants from 14 different work crews. The third paper proposes research to study and determine the cultural challenge of safety for Hispanic workers. Further, it aims to

determine theoretical and practical solutions about existing concerns and issues from Hispanic workers' perspectives.

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CHAPTER 1

INTRODUCTION

Observed Problems

A chief concern in the construction industry is safety. Although the construction industry in the United States (US) employs 6% of all workers, it accounts for more than 16% of all occupational fatalities (Bureau of Labor Statistics 2012). The characteristics of the construction industry make safety communication particularly difficult. These include size and complexity of the work, labor demographics, skills and training, and the transient nature of the workforce (Loosemore *et al.* 2003). To address this observed problem researchers have investigated safety communication and found that open communication and frequent interaction between employees and upper level management personnel, or among employees themselves are significant characteristics that differentiate organizations with low accident rates from organizations with high rates (Zohar 1980; Smith et al. 1978). For example, Smith et al. (1978) claimed that immediate feedback from supervisors to employees with good safety performance and correcting unsafe behaviors increase workplace safety performance. Other studies pointed out that the most effective supervisors who have the ability to discuss safety issues with construction workers from different trades, and provide criticism about safety behavior, issues and performance to those workers (Mattila et al. 1994; Niskanen, 1994; and Simard and Marchand, 1994). Moreover, clear communication has been listed as one of the top ten management practices that encourage safety behaviors and performance (Bentley and Haslam, 2001; Hofmann and Morgeson 1999; Sawacha et al. 1999).

These prior studies have made significant contributions to our understanding of the importance of effective safety communication at the construction workplace; however, there is a dearth of research in the area of empirical modeling of safety communication and identification of strengths and weaknesses.

A more specific issue related to safety communication is the safety communication barriers in multilingual work crews. Currently, Hispanic workers account for 23% of the construction workforce in the US (Pew Hispanic Center 2012) and the percentage of Hispanic US citizens is expected to increase to 128 million (43%) by 2060 (Bureau of the Census 2011). Unfortunately, Hispanic workers are injured at significantly higher rates than their Caucasian counterparts. In fact, the Center for Construction Research and Training (2013) reported that the fatality rate for Hispanic workers is 12.4 per 100,000 workers while non-Hispanic workers' fatality rate is 10.5. One of the cultural factors that may contribute to the disproportionate injury rate is a barrier in communication when more than one primary language is spoken in a crew.

Several scholars have investigated the phenomenon of Hispanic worker safety, all of whom have cited communication barriers as fundamental. For example, Jaselskis (2004) found that the inability of Caucasian and Hispanic workers to communicate on demand is one of the main causes of construction injuries. Additionally, Loden and Rosener (1991) found that improper safety communication often leads to misunderstanding of safety rules and best practices and, consequently, unintentional safety violations committed by Hispanic workers. Finally, Anderson et al. (2000) noted that, because most of the construction safety standards and programs are written and presented in English, Hispanic workers often are not capable to comprehend safety information during training, on signs, or during ad hoc presentations.

This study addresses this observed problem and fills a knowledge gap by being the first to measure, model, and explore safety communication within multilingual crews.

Structure and Contributions of this Dissertation

The aim of this dissertation is to present a two phase study that investigated safety communication in small, multilingual work crews in the US. This publication also proposes new methods for investigating the cultural barriers Hispanic workers face and impact their ability to work safely. Theoretically, the umbrella of this dissertation is to comprehend the dynamic of safety communication in small work crews in the US. Thus, the overall goal of the whole dissertation is to better understand the impact of the work crew's safety performance (e.g. recordable injury rate RIR) and individual's attributes on safety knowledge exchange.

The research questions and salient findings in this dissertation are presented in manuscript format. Chapters 2 and 3 are papers that have been published in *Construction Management and Economics* and *the Journal of Construction Engineering and Management*, respectively. These papers contain their own abstract, introduction, literature review, research methodology, findings, conclusion, and references. This introduction provides a brief summary of these manuscripts. Chapter 4 includes a research proposal to investigate the cultural barriers that Hispanic workers currently face using a pseudo-ethnographic approach known as Photovoice. Figure 1 illustrates an overall structure of this dissertation. Finally, included in this dissertation are a glossary and guide to social network analysis and a complete database as appendices.

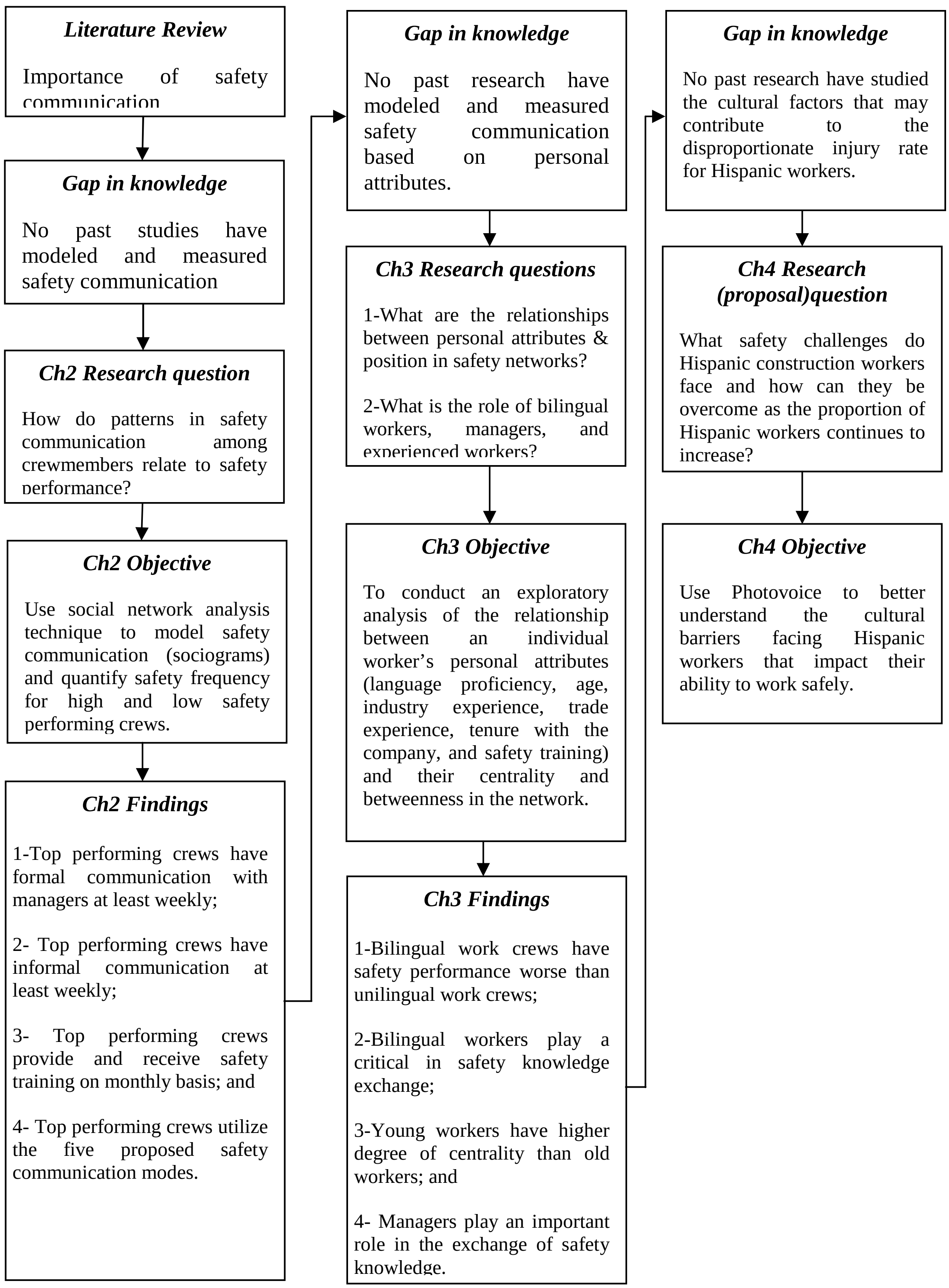


Figure 1 overall structure of this dissertation

Chapter 2 overview

Alsamadani, R., Hallowell, M.R., and Javernick-Will, A. (2013). "Measuring and modeling safety communication in small work crews in the US using social network analysis." ***Construction Management and Economics*****, 31(6): 568-579.**

Effective safety communication is essential for optimal safety performance. To enhance safety communication managers and supervisors must facilitate open, frequent, and clear discussion with all individuals within an organization. This paper aims to model the nature of safety communication within small project networks. For the first time, we measured the safety communication frequency, identified the safety communication mode (e.g., informal discussion, toolbox talks)employed by crewmembers, and modeled the communication patterns and trends for each crew.

To conduct this study, we designed a survey questionnaire in both English and Spanish. In the survey each participant was asked to: provide demographic information (e.g. name and position); specify to whom they provide and from whom they receive safety information; indicate the frequency of communication; and identify communication modes used. A total of nine small construction crews working on active construction projects in Denver Metropolitan region of the US were included in this study. The data were then analyzed using social network analysis (SNA) modeling software called UCINET. Measures of safety communication such as centrality, density, and betweenness were computed and sociograms that visually depicted communication patterns were generated for each crew.

A cross-case comparison was made using the organization's recordable injury rate and a composite safety metric known as relative safety performance (RSP). The results showed that top-performing crews differentiated themselves by having formal safety communication from management and informal safety communication on at least a weekly basis; formal safety training on at least a monthly basis; and programs that involve the use of multiple modes of safety communication from formal training to informal ad-hoc conversations. The study also revealed that safety communication is inhibited when multiple languages are spoken on site.

Chapter 3 overview

Alsamadani, R., Hallowell, M.R., Javernick-Will, A., and Cabello, J. (2013). "Relationships among language proficiency, communication patterns, and safety performance in small work crews in the US." ***Journal of Construction Engineering and Management,*** **ASCE, 139(9): 1125-1134.**

The Center for Construction Research and Training (2007) indicates that over 40% of all U.S. construction workers do not speak English at proficient level. To ensure optimal safety performance, it is important to ensure every individual in a construction crew is involved in safety-related communications regardless of language proficiency. The goals of this research study are first to determine the relationship between personal attributes (e.g. language proficiency, age, industry experience, trade experience, safety education) and position in a dynamic safety network. Similar to *Chapter* 2 social network analysis (SNA) was utilized to analyze the relationship between the personal attributes and their centrality and betweenness in the network. Secondly, this study aims to investigate the role and position of bilingual workers within multilingual work crews.

To achieve these objectives we performed interviews with 17 multilingual construction crews in the Denver Metropolitan region of the United States. A total of 161 participants (25 field-level managers and 136 field workers) were involved. Once the data were collected, they were coded and imported into UCINET software that computes SNA metrics and attribute-based sociograms. The data then were aggregated and statistically analyzed.

The results revealed suggestive evidence that multilingual work crews have lower safety performance than unilingual work crews (p=0.10) and workers under age of 35 have a higher degree of centrality than older workers (p=0.11). Furthermore, strong evidence was found that indicated that bilingual workers play a critical role in the exchange of safety knowledge in multilingual work crew ($p < 0.001$) and managers also play an important role in disseminating and exchanging safety knowledge, regardless of language proficiency ($p<0.001$). These results highlight the strong need for bilingual workers who can serve as cultural barrier spanners. In addition to the primary contributions, this study revealed the strong need for deep exploration of the plethora of cultural barriers that Hispanic workers face in US construction crews.

Chapter 4 overview

The issue of safety for Hispanic workers is becoming more important as the proportion of Hispanic workers continues to increase in the US. Currently, Hispanic workers account for 23% of the US construction workforce and 30% of Colorado construction workforce (Pew Hispanic

Center 2012). The percentage of Hispanic US citizens is expected to increase to 128 million by 2060 (Bureau of the Census 2011). Consequently, the number of Hispanic construction workers in construction is expected to increase proportionally, with Hispanic workers accounting for over 25% of all workers.

The goal of this proposed project is to use Photovoice to better understand the cultural barriers facing Hispanic workers face that impact their ability to work safely. Two research phases are proposed to achieve this goal.

Phase 1

The goal of the first phase is to identify the chief cultural issues faced by Hispanic workers through a set of exploratory interviews. An interview protocol has been established that starts with bridging relationships and trust between researchers and Hispanic participants. To establish trust and confidence within the Hispanic groups, a Hispanic student who has some construction work experience is suggested for the research. Open-ended interview questions were designed to comply with a pseudo-ethnographic approach. The objective of these interviews is to identify the dimensions of culture that impact Hispanic worker construction safety. To identify these dimensions the interview transcripts will be content analyzed with NVIVO. The dimensions will then serve as prompts for the subsequent phase, which uses Photovoice.

Phase 2

Once cultural barriers are identified and discussed, a deep and detailed investigation will be performed by engaging a new group of Hispanic participants using Photovoice. Photovoice is a research technique that involves asking participants to represent a particular community, take photos according to prompts related to a social issue facing that community, and discuss the photos as a group to obtain rich and deep information about the social issues and potential solutions. A 7-step process suggested by Wang (1999) will be used to create a valid and reliable process of collecting and analyzing the data. To ensure alignment and high quality data, a photography training session will also be provided. During the photography step, each participant will be asked to capture a maximum of 25 pictures and then select between 6 and 10 of the most significant. The photos will then be thematically analyzed through group interviews using the *"SHOWeD"* technique developed by Wang and Burris (1997). Once all significant pictures are analyzed a summary report will be then used as a tool for exhibition and sharing with policy makers.

References

Anderson, J. T., Hunting, K. L., and Welch, L. S. (2000). "Injury and employment patterns among Hispanic construction worker." *Journal of Occupational Environmental Medicine*, 42, 176-186.

Bentley, T. A., and Haslam, R. A. (2001). "A comparison of safety practices used by managers of high and low accident rate postal delivery offices." *Safety Science*, 37, 19-37.

Chinowsky, P. S., Diekmann, J., and Galotti, V. (2008). "Social network model of construction." *Journal of Construction Engineering and Management*, 134(10), 804-812.

CPWR - The Center for Construction Research and Training. (2007). Construction Chart Book the U.S. Construction Industry and its Workers. 4th ed. Silver Spring, MD: CPWR - The Center for Construction Research and Training.

Fang, D., Huang, J., and Fong, P. S. W. (2010). "Sharing construction safety knowledge through social networks." Proceedings of W099- Special Track 18th CIB World Building Congress, Salford, United Kingdom, May 10-13, 2010.

Hofmann, D. A., and Morgeson, F. P. (1999). "Safety related behavior as a social exchange: the role of perceived organizational support and leader member exchange." *Journal of Applied Psychology*, 59 (2), 286-296.

Jaselskis, E. (2004). Developing an effective construction training program for Hispanic supervisors and craft workers, Center for Transportation Research and Education (CTRE)— Project 03-132, Iowa State University Report.

Loden, M. & Rosener, J. B. (1991). Workforce America: Managing employee diversity as a vital resource. New York, NY: McGraw-Hill.

Loosemore, M., and Andonakis, N. (2007). "Barriers to implementing OHS reforms- the experience of small subcontractors in the Australian construction industry." *International Journal of Project Management*, 25, 579-588.

Mattila, M., Hyttinen, M., and Rantanen, E. (1994). "Effective supervisory behavior and safety on building site." *International Journal of Industrial Ergonomics*, 13, 85-93.

Niskanen, T. (1994). "Safety climate in the road administration." *Safety Science*, 17, 237-255.

Pew Hispanic Center. (2012). The Demographics of the Jobs Recovery. Washington, Dc. Retrieved June 24, 2012, from http://www.pewhispanic.org/files/2012/03/PHC-Labor-report-FINAL_3-21-12.pdf

Sawacha, E.., Naoum, S., and Fong, D. (1999). “Factors affecting safety performance on construction sites.” *International Journal of Project Management*, 17(5), 309-315.

Simard, M., and Marchand, A. (1994). “The behavior of first-line supervisors in accident prevention and effectiveness in occupational safety.” *Safety Science*,17, 169-185.

Smith, M. J., Cohen, H. H., Cohen, A. (1978). “Characteristics of a successful safety program.” *Journal of Safety Research*, 10, 5-15.

Taylor, J.E. and Bernstein, P.G. (2009) “Paradigm trajecto- ries of building information modeling practice in project networks.” *Journal of Management in Engineering*, 25(2), 69–76.

US Bureau of Labor Statistics. (2011). Hispanic Population of the United States. BLS Washington, DC, available at http://stats.bls.gov/news.release/pdf/osh.pdf.

Wang, C. (1999). “A participatory action research strategy applied to women’s health.” *Journal of Women’s Health*, 8(2), 185-192.

Wang, C., and Burris, M. A. (1997). “Photovoice: Concept, methodology, and use for participatory needs assessment.” *Health Education & Behavior*, 24 (3), 369-387.

Zohar, D. (1980). “Safety climate in industrial organizations: theoretical and applied implications.” *Journal of Applied Psychology*, 65, 96-102.

CHAPTER 2

Measuring and Modeling Safety Communication in Small Work Crews in the US using Social Network Analysis

ABSTRACT

Effective safety communication amongst all parties in a construction project is essential for optimal safety performance. Literature suggests that open safety communication across all levels of the organization enhances safety success. Previous studies have found that open communication and frequent interaction between employees and supervisors differentiates construction companies that have low accident rates from companies that have high rates. Through interviews with construction crewmembers on active construction projects in the Rocky Mountain region of the US, the patterns of safety communication were identified, modeled, and quantified. Social Network Analysis (SNA) was utilized to obtain measures of safety communication such as centrality, density, and betweenness within small crews and to generate sociograms that visually depicted communication patterns within effective and ineffective safety networks. A cross-case comparison revealed that the frequency and method of communication are important differentiators between project teams with low and high accident rates. Specifically, top performing crews have: (1) formal safety communication from management on at least weekly basis; (2) informal safety communication on a weekly basis; (3) formal safety training; and (4) use all proposed safety communication methods on a monthly basis. In addition, typical SNA metrics, including density, centrality, and betweenness, are not significant parameters to distinguish high from low performing crews.

INTRODUCTION

Although workers in the construction industry account for 8% of the US workforce, statistics show that the industry consistently accounts for 17% of work-related fatalities (Bureau of Labor Statistics, 2011). Additionally, the National Safety Council (2001; 2002; 2003) reported over 700 fatal work-related injuries and over a million injuries in the construction industry per year. In 2005, 55% of construction work related deaths occurred in construction establishments that employ 20 or fewer employees (CPWR, 2007).

As a project-based industry, construction combines multiple organizations and individuals to construct a unique project. In these project-based forms of organizations, interdependence is emphasized over independence (Daft and Lewin, 1993), thus making communication among these teams and individuals critical. Although true of construction projects in general, communication is critically important when implementing an effective safety program. According to Vecchio-Sadus (2007), effective safety communication should include:

- Clear communication and open discussion regarding safety issues to all individuals from different levels within one or more organizations;
- Encouraging safe behavior by providing feedback; and
- Implementing a lessons-learned program for safety.

To address the issue of safety communication in small work crews, social network analysis (SNA) was used to: (1) quantify the level of safety communication within small and medium-sized construction crews, (2) model the communication patterns and trends within these crews; and (3) analyze the characteristics of high and low safety performance crews with regard to safety communication on construction worksites. SNA is employed for the first time as a potential method to measure and analyze the communication of safety information. SNA is a relatively new research technique to the construction engineering and management (CEM) domain that has recently enjoyed prolific success in CEM research to study project teams (e.g.

Chinowsky et al. 2010, DiMarco and Taylor, 2010, Javernick-Will, 2011, etc.). Additionally, the relationships between contract type, project complexity, and litigation concerns have been analyzed using SNA (Pryke, 2004). SNA was employed to find the unique characteristics (Wegner, 1987) and understand collaborative working processes (Son and Rojas, 2011) of temporary project teams in large-scale construction projects, focusing on safety communication.

LITERATURE REVIEW

This research focuses on the communication of safety information, including the frequency and mode of information exchange. Thus, literature is reviewed regarding safety communication, safety communication modes, and SNA below.

Safety communication

It has been recognized that open communication and frequent interaction between employees and supervisors and among employees distinguishes organizations with low incident rates from those with high incident rates (Zohar, 1980; Smith et al. 1978). For example, Smith et al. (1978) claimed that immediate verbal feedback to employees with strong safety performance and correction of unsafe behaviors enhances safety performance. Others showed that the most successful supervisors tend to have open discussion with workers from different trades about safety issues and provide necessary advices (Mattila et al. 1994; Niskanen, 1994; and Simard and Marchand, 1994). Additionally, communication has been listed as one of the top ten management practices that have a direct positive impact on safety (Bentley and Haslam, 2001; Hofmann and Morgeson, 1999; Sawacha et al. 1999).

Studies have also discussed safety communication within the context of the overall safety program. For example, Loosemore and Andonakis (2007) found that organizations with in-person safety orientations are more likely to promote behavior that prevents accidents. They also found that high quantity and quality of safety communication during the project helps to overcome language and educational barriers. Similarly, Van Dyck et al. (2005), Parker et al. (2001), and Cigularov et al. (2010) all found that strong communication about safety issues was a critical component of total quality and error management.

Consistent and effective safety communication is expected to become even more important in the US in coming years as project teams become more diverse in culture and language. According to the Occupational Safety and Health Administration (OSHA, 2008), these communication barriers have begun to increase the proportion of citations that are linked to ineffective safety communication. These expected trends make measuring and monitoring safety communication increasingly important (Emmitt and Gorse 2003). One emerging method of measuring communication among project participants is Social Network Analysis (SNA). This method may be an effective strategy to rapidly and accurately measure and model safety communication within the various demographics of work crews.

Modes of Safety Communication

Safety communication was modeled as either formal or informal. Formal safety communication included any sharing of safety knowledge that occurs through channels that are pre-established specifically for safety. Typical examples include formal presentations from upper management, written communication, training, and toolbox talks. In contrast, informal communication includes ad hoc communication amongst individual crewmembers. For example, informal safety communication could occur when one worker passes by another crewmember and informs her of a hazard that has been created by work in transition.

Formal communication from upper management

Upper management support for and commitment to safety is a vital component of a basic injury prevention program (Jaselskis et al. 1996; Rajendran et al. 2009). Such support and commitment typically requires management to actively participate actively in safety activities such as toolbox talks and site audits and to provide adequate resources for safety staffing and prevention activities. For example, upper-level managers may visit individual project sites and participate as a team member in pre-task planning events. Management must also send a clear verbal message that safety is a priority, communicate expectations, and reward safe behavior (Huang and Hinze, 2006). Although previous studies have implied that management must provide safety information to and receive safety information from the network of workers, the volume and frequency of such formal communications has yet to be modeled with empirical and objective data.

Formal written communication

Written safety programs are an approach for initial evaluation, analysis, and control of workplace safety. These programs include policies and procedures that are known to maintain safe working environment. The ultimate benefit of this program is that it serves as a constant reference for workers and managers (New Hampshire Department of Labor, 2010). Other forms of written safety communication may include memos, emails, posters, and signs (Hallowell, 2011).

Formal safety training

Safety training refers to scheduled instruction that facilitates the development of safe work practices, technical skills, and knowledge of safety protocol. Safety training can also refer to knowledge and skills that construction workers need to effectively respond to hazards (Hale, 1984). Training can be delivered through classroom instruction, video, online modules, and hands-on simulations (U.S Department of Labor, 2011). A study by Sawacha et al. 1999 confirms the safety training is vital because it increases safety awareness and reaction. Training may be provided to the crew by an internal member of the organization or outsourced to an external consultant (Hallowell, 2011) and is considered by Rajendran et al. (2007) to be the foundation of an effective safety culture.

Formal toolbox talks

Toolbox talks are regular safety meetings that are typically performed on site immediately before the work takes place (Huang and Hinze, 2006). The content, frequency, and structure of these meetings vary greatly among organizations. Some researchers suggest that these meetings should take place before each new work task and should be facilitated by formal and documented job safety analyses (Boud et al. 2009). Based on the results of previous research (e.g., Jaselskis et al. 1996 and Hurst et al. 1996), these discussions are expected to be an important element that contributes to the successful development of an effective safety network.

Informal communication among workers

Approximately 70% of organizational communication is informal (De Mare, 1989). Informal communication typically takes the form of ad hoc conversations and announcements based on the current exposures on worksites that may be urgent and alarming. Surprisingly, informal safety communication within crews has yet to be studied.

Social Network Analysis

Social Network Analysis (SNA) was first developed by Jacob Moreno to study the social interactions of groups. Moreno (1960 pg 17) defined SNA as, “A quantitative analytic tool used to study the exchange of resources among different groups.” Alternatively, it is defined by Haythornthwaite (1996 pg 323) as “An approach and set of techniques used to study the exchange of resources among actors.” Regardless of definition, the main benefit of SNA is that it is an analytical tool that allows a researcher to identify patterns of social relations among many actors with visual models and objective metrics that are grounded in scientific theory (Wasserman and Faust 1994). SNA also facilitates the analysis of the structure of communication patterns that typically are latent in other observational research techniques. In the past decade, SNA has been used as research method within the social and behavioral sciences to model the relationships among different actors within one or more organizations (Hawe and Ghali, 2008).

At a minimum, social network data consists of actors and relationships (or links) among actors. Additional data can be collected on attributes, or characteristics of each actor, as well as additional insight into their relationship, for example, the frequency of communication or mode of knowledge exchange. In order to analyze a social network it’s essential to plot a diagram that depicts the proximal relationships among actors (Wasserman and Faust, 1994). These ‘sociograms’ model nodes as actors (e.g., crew members) and the links between actors as the relationship of interest (e.g., communication about injury prevention). Accurate and meaningful network visualization depends on the underlying mathematical analysis and methods implemented to gather input data. Once valid and reliable input data are obtained and appropriate and accurate mathematical models are designed, SNA can produce several metrics that may serve as leading indicators of network performance.

SNA is an accepted analytical technique that has seen widespread use. For example, SNA was used in supply chain management (Silva et al. 2008), terrorist networks (Ressler 2006), and tracking the spread of AIDS (Morris 1993). In construction, SNA models have been used to identify strengths and weaknesses within and among projects teams (e.g., Taylor and Bernstein 2009; Comu et al 2010) and organizations to improve project performance (e.g., Chinowsky et al. 2008). SNA metrics will be reviewed briefly below. For a detailed overview of SNA metrics, the reader is encouraged to review Freeman (1997).

Network density

Density is a measurement that indicates the ratio of the actual links or relationships available between the network actors to the maximum possible number links that the network could have (Borgatti and Everett, 2006). The higher is the density value, the more likely that actors are connected to each other (see Equation 1). Connections are defined by information or knowledge exchange that occur through formal correspondence or ad hoc communication that is established to solve problems.

$$\Delta = \frac{L}{g(g-1)}$$ **Equation 1**

Where Δ is the network density, (L) is the number of existing connections (relationships) in the network, and g is the total number of actors.

Actor Centrality

Centrality can be measured for each individual actor or for the network as a whole. Given the context of safety communication, where it is important that each crewmember have communication channels to receive or provide information pertaining to safety, our research focused on the centrality of individual actors. The level of centrality of an actor measures the total number of direct relationships that any actor in the network has with other actors in the network (Freeman, 1977). Equation 2 is used to compute the standardized degree of centrality for a particular individual.

$$C_D\text{ (actor x)} = \frac{(c_D\text{ (actor x))}}{(g-1)}$$ **Equation 2**

Where C_D (actor x) is the total number of relationship that the actor x has (in or out), and (g-1) is the maximum possible number of relationship that actor x can have, where g is the total number of network actors.

Betweenness

Betweenness measures the total number of occurrences when a specific actor is required to connect two disparate actors in a network (Freeman, 1977). An actor with a high degree of betweenness is sometimes referred to as a ‘gatekeeper’ of information. These individuals may impede information flow or greatly disrupt the network if they are removed.

These metrics represent the heart of the hypothetical constructs when modeling communication patterns. We use SNA as a tool to study the safety communication patterns among actors in small building construction crews with the goal of determining if the SNA metrics and patterns observed may be used as leading indicators of safety performance.

RESEARCH METHODS

To determine safety communication patterns amongst crewmembers, the research team administered questionnaires to nine crews on active building construction projects in the Denver Metropolitan area of the US. Before surveys were administered, the team discussed the objectives of the study and the research protocol with the safety manager or project superintendent. Once this introduction was complete, the survey was administered to a small crew on the project. To avoid bias, the research team insisted on administering the surveys directly to the worker rather than allowing the surveys to be distributed and described by the project leadership. Additionally, to ensure that the crew members understood the survey, both Spanish and English versions of the questionnaire were designed and the survey orientation was provided in both English and Spanish by bilingual researchers. This direct communication from the research team to the workers also allowed the research team to provide detailed directions and answer questions. In addition, because the research aimed to determine safety communication patterns of a crew, it was of utmost importance that ***everyone*** on the crew participated in the study. As a result, surveys were administered and analyzed for a complete network, or a stable crew. If even one individual in the crew declined to participate or was not present, the results were not analyzed.

For the purpose of our study, a crew included all field-level employees and field-level managers who (1) work for the same employer in the same physical location; (2) have worked together for at least half of the project duration; (3) are dedicated to the same project; and (4) participate in a collaborative work environment. Thus, upper-level managers who may visit the site occasionally or short-service employees are not included. The limitations associated with these boundary conditions are discussed in the conclusions.

Several constraints were placed on the selection of case crews to ensure internal and external validity of the results. Only stable crews that had been working together as one unit on a project that was at least 50 percent complete were included. This constraint prevented the analysis of ad hoc or transient crews that the team did not intend to study. Additionally, the crew size was limited to 5 to 12 members, including field-level managers. This constraint was imposed to prevent variations that exist when networks of dissimilar sizes are analyzed and compared. By constraining the size of the networks, a cross-case comparison of network patterns and calculations was more meaningful.. Table 1 shows the salient demographics of the participating crews. Because this effort was largely exploratory (i.e., the first known application of SNA to the safety domain), the research team conducted the interviews in an iterative process as new information was received and challenges were recognized. Fortunately, the project participants agreed to provide data during follow-up interviews. This iterative process was important for preserving internal validity; for example, the research team returned to determine the frequency of use of each mode identified to communicate safety knowledge.

The English version of the questionnaire administered to crewmembers is shown in Figure 1. The respondents were asked to provide demographic information such as their name and position. These attributes were linked to nodes (or individuals) in the network. Each individual's name was redacted and replaced with pseudonyms to protect the worker's identities. . In the second component of the survey respondents were asked to record with whom they *provided* safety information and the average frequency of communication using each of the five communication modes, namely formal communication with management, written communication, training, informal discussions and toolbox talks. The third component of the survey was identical to the second except the respondents were asked to indicate whom they *received* safety information from and the average frequency of this communication for each of the five communication modes.

Although the questionnaire was administered to a complete network, we used an egocentric data collection approach where each individual was asked to identify with whom they communicated safety information versus responding to a survey pre-populated with crewmembers names. Because the crew size was small and every member of each crew participated, the resulting data included all members. This is important because having data from a complete crew enhances the internal validity of the analyses.

Your Name: ______________________________________

Your Position: __________________ Company: _____________________

To whom on your crew do you **PROVIDE** safety information to, how often do you communicate, and through which means?												
Name of individuals who you **PROVIDE** safety information to		Frequency of communication (check boxes)					Most common mode(s) of communication (check all boxes that apply)					
First Name	Last Name	Once a month	Bi-weekly	Weekly	Once a day	More than once a day	Formal communication (mgt role)	Written communication	Training	Informal discussions	Toolbox talk	Other (please specify)
Participant 1				×				×	×			
Participant 2				×		×	×	×				
Participant 3				×							×	
Participant 4				×	×					×	×	

Figure 1. English version of the SNA questionnaire

The data were coded and sorted using MS Excel so that it was compatible with the most standard SNA modeling software: UCINET. This software system computes the aforementioned SNA metrics, which are nearly impossible to calculate by hand or through MS Excel functions once project networks exceed 4 members. When coding the frequency of safety communication, the following scheme was used: 1= once a month; 2= bi-weekly; 3= weekly; 4= once a day; and 5= more than once a day.

Once all data were coded and entered into UCINET, the software system produced the aforementioned metrics and sociograms. We plotted the sociograms using NetDraw within

UCINET for each crew based upon metrics collected. These data can be filtered to report, visualize and analyze singular or combined metrics. For example, direction, frequency and mode of exchange can be analyzed individually or in combination (e.g. the receipt of safety information on a weekly basis or written safety communication that occurs on a weekly basis).

Composite measure of safety performance

One of the goals was to correlate SNA metrics and sociogram characteristics with lagging indicators of safety performance. Typically, safety performance is measured using a company's OSHA recordable injury rate (RIR) or experience modification rate (EMR) (Jaselskis et al. 1997). According to the Occupational Safety and Health Administration (2004), RIR is the number of recordable injuries and illnesses occurred over certain period of time (usually one year). This metric is usually used to compare any construction company's safety performance against the national or state averages. Unfortunately, an RIR is rarely recorded for a specific work crew. Additionally, the actual safety performance may be related not only to the organization's RIR but also to the relative performance of the specific crew within the company as a whole. Consequently, a composite safety metric was used to compare the safety performance of the case crews. Although different trades were included in the case studies, and the variability in work performed may inherently lead to differences in RIR, the Center for Construction Research and Training (2008) has reported very consistent injury rates for the selected trades over the past decade.

Following the survey administration the research team requested that an upper-level manager who is in a position to directly oversee a large proportion of the organization's work crews (e.g., safety manager or program manager) provide the organization's RIR for the past calendar year and a rating of the target crew's relative safety performance within the organization (i.e., percentile rating). The composite safety score was then calculated by multiplying the inverse of the RIR by the percentile rating. The data were then normalized by computing a relative performance metric by dividing each composite safety metric by the maximum metric achieved ('percent of maximum' rating). The score of 1.0 corresponds to the highest performing crew in the study and all other metrics are measured against the performance of this crew. These computations can be achieved using Equations 3 and 4.

$$\textit{Crew safety performance} = \frac{safety\ performance\ percentile}{recordable\ injury\ rate\ (RIR)} \qquad \textbf{Equation 3}$$

$$\textit{Percent of maximum} = \frac{crew\ safety\ performance}{the\ highest\ safety\ performance\ among\ the\ 8\ crews} \qquad \textbf{Equation 4}$$

Once the necessary safety performance data were collected and analyzed, the crews were sorted by relative performance to identify the relative tiers of performance as shown in Table 1. Three clear tiers emerged based on their percent of maximum safety performance: top three performers and three bottom performers are the two selected groups in analyzing the data; the third (or the middle) performers were analyzed but not compared.

Table 1. Relative safety performance summary (high to low)

Crew	Trade	Crew size	RIR	Percentile rating	Safety performance	Percent of Maximum Performance
5	Drywall	10	2.8	85%	0.304	1.000
9	Carpentry	5	3.9	90%	0.231	0.760
6	General	12	4.1	90%	0.220	0.723
7	Drywall	5	4.4	95%	0.216	0.711
2	Glazing	7	5.4	90%	0.167	0.549
3	HVAC	5	6.8	95%	0.140	0.460
4	HVAC	7	6.8	95%	0.140	0.460
8	Carpentry	6	5.4	75%	0.139	0.458
1	Electrical	5	12.1	100%	0.083	0.272

DATA ANALYSIS AND DISCUSSION

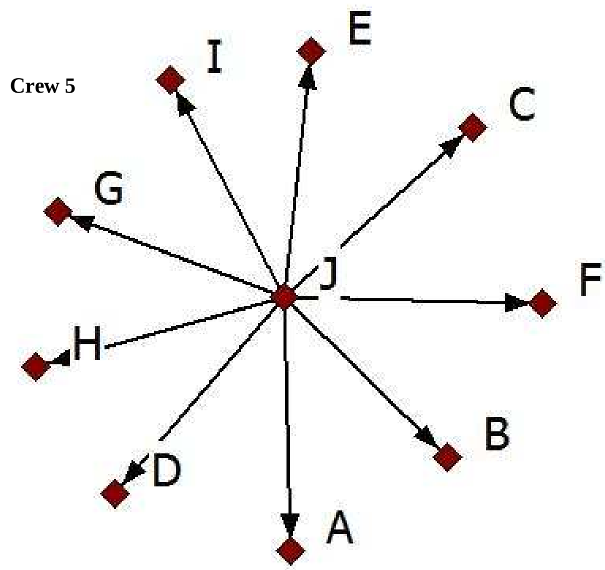
The results revealed interesting trends. On a macro level, toolbox talks were found to be the most commonly used and most frequently used communication mode. In fact, all nine crews used this communication mode on at least a weekly basis. Alternatively, only three of the nine crews had any form of written safety communication. After a detailed analysis of the data was conducted, several important trends were observed. These findings are described below along with their supporting data. One may note that, because this is an exploratory study, the findings below can be used as propositions for future studies.

Finding 1: Top performing crews receive formal safety communication from management on at least a weekly basis. Based on the network density values, the three crews with the highest relative safety performance have formal safety communication from management at least weekly while the bottom three performers have very little to no formal management safety communication between workers and managers. Table 2 highlights these data.

Table 2. Formal communication network density (weekly)

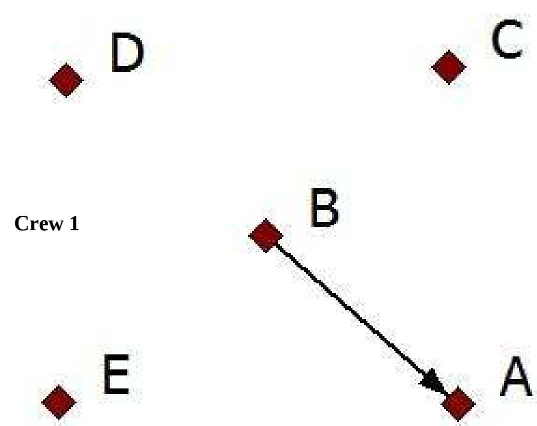
	Crew	Network Density
Top Crews	5	11%
	6	14%
	9	10%
Bottom Crews	8	5%
	3	0
	1	5%

Figure 2A shows the sociogram for the crew with the top relative safety performance (Crew 5) and Figure 2B provides the sociogram for the crew with the lowest safety performance (Crew 1). These sociograms depict the number and patterns of connections that exist for management providing safety information to workers in the network at least weekly. As one can see, the top performing network contained many connections with the actor J, the upper-level manager and the lowest performing network included only one communication link between management, actor B, and the workforce on a weekly basis.



The letters (A, B… etc) refer to the actor name in the network. A "node" represented each actor . The line with arrow refers to the communication link "relationship".

(A)



(B)

Figure 2. Selected weekly formal safety communication sociograms

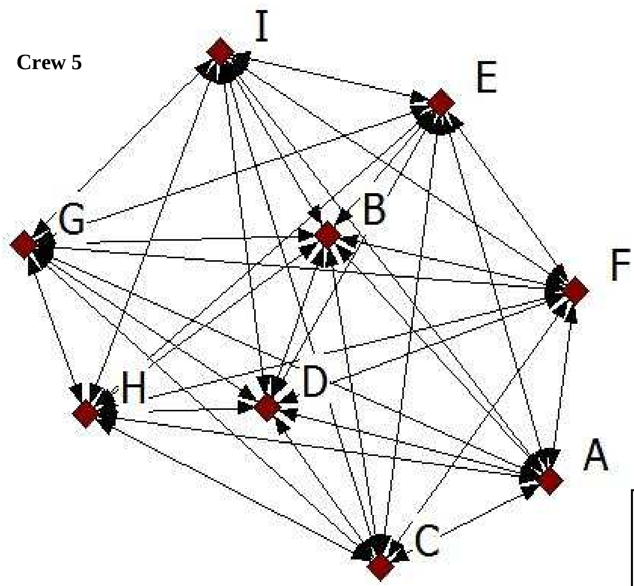
These data show that the interactions between workers and managers may be important influencing factors for safety performance. This finding supports previous research findings that open and frequent communication between supervisor and employees differentiates the high from the low safety performance crews (Zohar, 1980; Smith et al., 1978; Cigularov et al., 2010).

Finding 2: Top performing crews have informal weekly safety communication on at least a weekly basis. Workers within high performing crews tend to share safety information in an ad hoc basis on a weekly basis. As shown in Table 3 and Figure 3, the greater number of crew members that are connected through informal safety communication on a weekly basis, the better the relative safety performance.

Table 3. Informal weekly safety communication network density

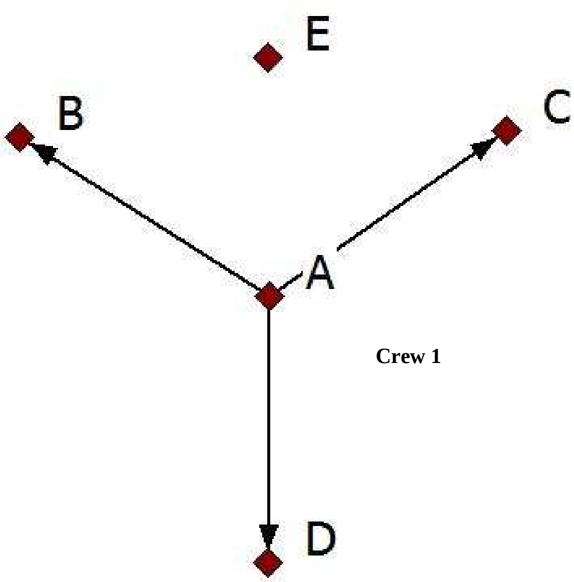
	Crew	Network Density
Top crews	5	80%
	6	23%
	9	30%
Bottom crews	8	0
	3	0
	1	15%

In crew 1, the foreman, actor A, is the only individual who shares safety information informally on a weekly basis; conversely, the links in crew 5 are numerous and seemingly independent from the crew members' positions. This finding is also theoretically supported from previous research that found that cohesive networks tend to have shared attitudes and behaviors, which enhance performance (Seashore, 1954; Wyer, 1966). Additionally, through strong and frequent informal connections crews have increased capacity to manage potential errors before they lead to an incident (Van Dyck et al. 2005).



(A)

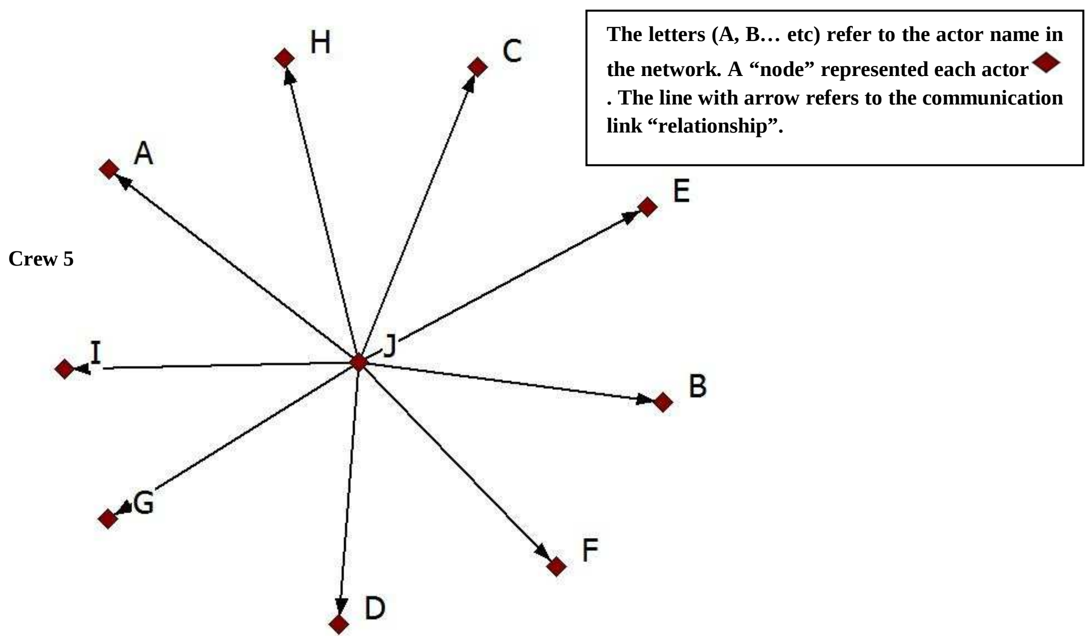
The letters (A, B… etc) refer to the actor name in the network. A "node" represented each actor . The line with arrow refers to the communication link "relationship".



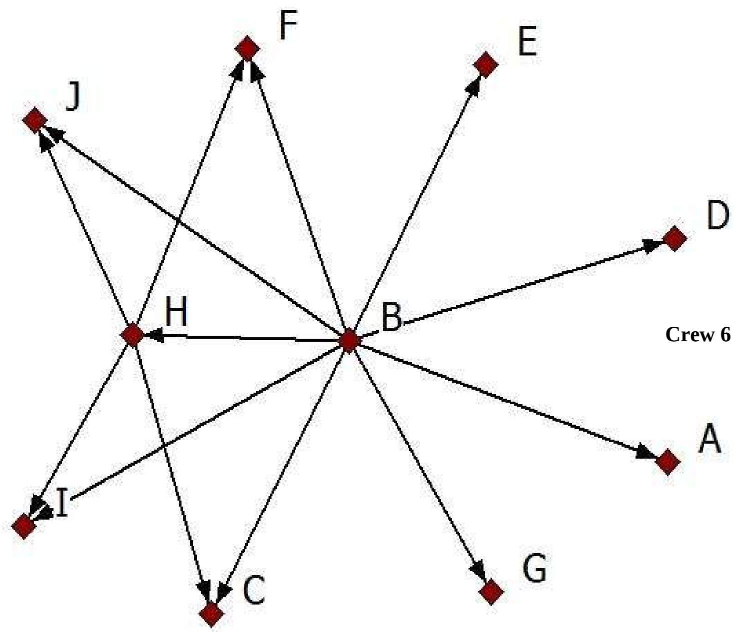
(B)

Figure 3. Informal weekly safety communication sociograms selected crews

Finding 3: High performing crews provide and receive formal safety training on at least a monthly basis. The results indicate that training is an essential communication mode for high performing crews and tend to occur on at least a monthly basis. In high performing safety networks, supervisors were responsible for providing monthly or weekly safety training for their workers. Figure 4 depicts the two top performing crews. These crews have management-led safety training that enhances the density of the safety communication network drastically. In comparison, low performing crews had no connections among members when the data were dichotomized for monthly communication. As a result, the sociograms for low performing crews are not shown (see table 4 for crew metrics). As indicated in past research, regular training is an essential component to strong safety performance and safety awareness (Rajendran et al. 2009; Shimmin et al. 1980; Sawacha et al. 1999).



(A)



(B)

Figure 4. Safety training communication sociograms in high performing crews on a monthly basis

Table 4. Network density degrees for safety training on a monthly basis for high and low performing crews

	Crew	Network Density
Top Crews	5	20%
	6	16%
	9	20%
Bottom Crews	8	0%
	3	0%
	1	0%

Finding 4: High performing crews use the all proposed safety communication modes studied. Interestingly, one of the factors that distinguished high performing from low performing crews was the variety of communication modes used, regardless of their frequency. As shown in Table 5, the three top performing firms used all communication modes while the low performing crews used only a portion of the modes. This finding is supported by March and Simon (1958)

who showed that the general communication structure of a successful organization must includes both formal and informal modes.

Table 5. Safety communication modes used by high and low performing crew

	Crew	Formal communication	Written communication	Training	Informal discussion	Toolbox talk
Top Crews	5	X	X	X	X	X
	6	X	X	X	X	X
	9	X	X	X	X	X
Bottom Crews	8	0	0	0	X	X
	3	0	X	X	0	X
	1	X	0	X	X	X

Finding 5: The general SNA metrics other than density were not significant measures that distinguish the high from the low performing crews. Although one of the research teams' initial hypotheses was that the typical SNA metrics (e.g., betweeness) would correlate with the relative safety performance metrics on a macro basis when all communication modes were considered, these correlations were not supported by the data as shown in Table 6. Instead, the findings showed that only density was significant in the analyses. Effective networks were found to have a high degree of density for the training and management communication modes but diffuse networks were shown to be more effective for informal communication. These results extend existing findings that effective communication of knowledge is contingent on many factors, including type of knowledge exchanged and the mode or method of knowledge exchanged (Javernick-Will and Levitt 2010). Specifically, it adds to existing literature that has shown that the frequency of exchange, in combination with the mode, is vital for effective communication. The common finding for safety networks, however, is that a variety of communication modes must be used where all a large proportion of crew members participate in the safety information exchange to achieve excellent safety performance.

Table 6. SNA metrics for high and low performing crews

		Provide information	Receive information
	Crew	**Network Density**	**Network Density**
Top Crews	5	90.00%	90.00%
	6	20.00%	35.00%
	9	18.89%	22.22%
Bottom Crews	8	16.67%	6.67%
	3	5.00%	20.00%
	1	40.00%	60.00%

LIMITATIONS

Although the data support several new conclusions, the study is limited in its external and internal validity in several ways. First, the scope of inference is statistically limited to the State of Colorado in the US because all participating crews worked and resided in this region. Second, all crews were actively working on building construction projects. Therefore, the results only extend theoretically to infrastructure and other construction projects. Third, although nine crews is a sufficient size for case study research and network analyses, the results were only analyzed qualitatively. Statistical analyses would require a much larger sample. Fourth, the risks that each participating crew could be exposed to were not considered. A future research study is recommended to explore how variable risks affect safety communication behaviors. Fifth, the size of the crews was limited to 5 to 12 members. Thus, the results only theoretically extend to small crews within this size range. Sixth, all work crews were stable and short-service employees were not included so the results do not apply to transient work crews. Finally, only hierarchical position was collected as demographic information for each crewmember. Despite these limitations, the findings of this study confirm past research and provide compelling qualitative evidence that the patterns of safety communications for various modes are predictive indicators of safety performance.

CONCLUSIONS AND RECOMMENDATIONS

Past research has revealed that safety communication in various modes is important to achieve safety success in large construction companies. However, the frequency and structure of effective safety communication within each mode and within small project teams has yet to be investigated. To address this gap in knowledge, SNA was used to model and measure safety communication within small crews in nine construction firms in the Denver Metropolitan region of the US. The results indicate that the characteristics of requisite safety communication for small firms are consistent with previous studies of large firms but that the actual patterns of effective information exchange are dependent on the communication mode. Thus, safety communication appears to be a much more complex issue than discussed previously.

We recommend future research that explores this topic in greater detail and confirms the findings presented with a large dataset and statistical tests. Additionally, given the changing demographics of the US workforce, future work could attend to the importance of personal attributes on network communication structure and formation. Specifically, the influence of language is likely to influence frequency and mode of safety communication for effective performance. Employing Qualitative Comparative Analysis (QCA) to determine the combinatorial pathways, along with necessary and sufficient causal conditions, that lead to safety performance could be studied to determine if multiple combinations of frequency and mode lead to differing outcomes (for instance, monthly exchange of safety communication using formal mode AND weekly exchange of safety communication using informal modes). Finally, research into inter-organizational safety communication, particularly among crews representing different employers, is suggested to model the dynamic nature of construction projects.

It is expected that advanced knowledge of safety communication networks could have the potential to transform the structure of safety programs. Additionally, the use of SNA metrics may serve as a very efficient leading indicator of safety performance that can be quickly measured and modeled as a project commences. Such data could be used to evaluate actual network patterns and compare against ideal networks to identify connections that should be bolstered. Based on the observations in this study, SNA could be a very fruitful research technique in the safety domain because so many safety management issues are related to social interactions and teamwork.

REFERENCES

Bentley, T. A., and Haslam, R. A. (2001). "A comparison of safety practices used by managers of high and low accident rate postal delivery offices." *Safety Science*, 37, 19-37.

Borgatti, S. P., and Everett, M.G. (2006). "A graph-theoretic framework for classifying centrality measures." *Social Networks*, 28(4), 466-484.

Boud, D., Rooney, D., and Solomon, N. (2009). "Talking up learning at work: Cautionary tales in co-opting everyday learning." *International Journal of Lifelong Education*, 28(3), 323-334.

Chinowsky, P. S., Diekmann, J., and Galotti, V. (2008). "Social network model of construction." *Journal of Construction Engineering and Management*, 134(10), 804-812.

Chinowsky, P. S., Diekmann, J., and O'Brien, J. (2010). "Project organizations as social networks." *Journal of Construction Engineering and Management*, 136(4), 452-458.

Cigularov, K. P., Chen, P. Y., and Rosecrane, J. (2010). “The effects of error management climate and safety communication on safety: A multi-level study.” *Accident Analysis and Prevention,* 42, 1498-1506.

Center for Construction Research and Training. (2008). Construction Chart Book the U.S. Construction Industry and its Workers. 4th ed. Silver Spring, MD: CPWR - The Center for Construction Research and Training.

Comu, S., Unsal, H. I., and Taylor, J. E. (2011). “Dual impact of cultural and linguistic diversity on project network performance.” *Journal of Management in Engineering,* 27(3), 179-187.

Daft, R., and Lewin, A. (1993). “Where are the theories for the ‘new’ Organizational forms? an editorial essay.” *Organization Science,* 4(4), 1-6.

De Mare, G. (1989). “Communicating: the key to establishing good working relationships.” *Price Waterhouse Review,* 33, 30-37.

Di Marco, M. K., Taylor, J. E. (2011). “The impact of cultural boundary spanners on global project network performance.” *Engineering Project Organization Journal,* 1(1), 27-39.

Emmitt, S. and Gorse, C. (2003). “Construction communication.” Blackwell Publishing Ltd.

Freeman, L. C. (1977). “A set of measures of centrality based on betweenness. Sociometry,” 40, 35–41.

Hale, A. R. (1984). “Is safety training worthwhile?.” *Journal of Occupational Accidents*, 6, 17-33.

Hallowell, M. R. (2011). “Safety knowledge management in American constructin organizations.” *Journal of Management in Engineering,* in press.

Havold, J. I. (2005). “Measuring occupational safety: from safety culture to safety orientation.” *Policy and Practice in Health and Safety,* 1, 85-105.

Hawe, P., and Ghali, L. (2008). “Use of social network analysis to map the social relationships of staff and teachers at school.” *Health Education Research*, 23 (1): 62-69.

Haythornthwaite, C. (1996). “Social network analysis: an approach and technique for the study of information exchange.” *Social Science*, 18(4), 323-342.

Hofmann, D. A., and Morgeson, F. P. (1999). “Safety related behavior as a social exchange: the role of perceived organizational support and leader member exchange.” *Journal of Applied Psychology,* 59 (2), 286-296.

Hurst, N. W., Young, S., Donald, I., Gibson, H., and Muyselaar, A. (1996). “Measures of safety management performance and attitudes to safety at major hazard sites.” *Journal of Loss Prevention in the Process Industries,* 9(2), 161-172.

Huang, X., and Hinze, J. (2006). “Owner’s role in construction safety.” *Journal of Construction Engineering and Management,* 123(2), 164-173.

Jaselskis, E., Anderson, S., and Russel, J. (1996). “Strategies for achieving excellence in construction safety performance.” *Journal of Construction Engineering and Management,* 122(1), 61-70.

Javernick-Will, A. N., and Levitt, R. E. (2010). “Mobilizing institutional knowledge for international projects.” *Journal of Construction Engineering and Management,* 136(4), 430-441.

Javernick-Will, A. N. (2011). “Motivating knowledge sharing in engineering and construction organizations: the power of social motivations.” *Journal of Management in Engineering.,*in press.

Loosemore, M., and Andonakis, N. (2007). “Barriers to implementing OHS reforms- the experience of small subcontractors in the Australian construction industry.” *International Journal of Project Management,* 25, 579-588.

March, J. G., and Simon, H. A. (1958). Organizations, Wiley, New York, NY.

Mattila, M., Hyttinen, M., and Rantanen, E. (1994). “Effective supervisory behavior and safety on building site.” *International Journal of Industrial Ergonomics*, 13, 85-93.

Moreno, J. L. (1960). “The sociometry reader.” *The Free Press,* Glencoe.

Morris, M. (1993). “Epidemiology and social networks: modeling structures diffusion.” *Sociological Methods Research,* 2(1), 99-126.

National Safety Council. (2001). Injury facts. Itasca, III

National Safety Council. (2002). Injury facts. Itasca, III

National Safety Council. (2003). Injury facts. Itasca, III

Niskanen, T. (1994). “Safety climate in the road administration.” *Safety Science*, 17, 237-255.

Parker, S. K., Axtell, C. M., and Turner, N. (2001). "Designing a safer workplace: importance of job autonomy, communication quality, and supportive supervisors." *Journal of Occupational Health Psychology,* 6(3), 211-228.

Pryke, S.D. (2004). "Analysis construction project coalition: exploring the application of social network analysis." *Construction Management and Economy,* 22(8), 787-797.

Rajendran, S., Gambatese, J. A., and Behm, M. G. (2009). "Impact of green building design and construction on worker safety and health." *Journal of Construction Engineering and Management*, 135(10), 1058-1066.

Ressler, S. (2006). "Social network analysis as an approach to combat terrorism: past, present, and future research." *Homeland Security Affairs,* 2(2).

Sawacha, E., Naoum, S., and Fong, D. (1999). "Factors affecting safety performance on construction sites." *International Journal of Project Management*, 17(5), 309-315.

Seashore, S. E. (1977). Group cohesiveness in the industrial work group, Institute for Social Research, University of Michigan, Ann Arbor.

Scott, J. (1991). Social network analysis: A handbook, Saga, London.

Shimmin, S., Corbett, J., and McHugh, D. (1980). "Human behavior: some aspects of risk-taking in the construction industry." *Institute of Civil Engineering.* London, UK, 13-22.

Silve, C. A., Sousa, J. M. C., Runkler, T. A., and Sa da Costa, J. M. G. (2008). "Distributed supply chain management using ant colony optimization." *European Journal of Operational Research*, 10, 1016-1026.

Simard, M., and Marchand, A. (1994). "The behavior of first-line supervisors in accident prevention and effectiveness in occupational safety." *Safety Science*,17, 169-185.

Smith, M. J., Cohen, H. H., Cohen, A. (1978). "Characteristics of a successful safety program." *Journal of Safety Research*, 10, 5-15.

Son, J.W., and Rojas, E.M. (2011). "Evolution of collaboration in temporary project teams: an agent-based modeling and simulation approach." *Journal of Construction Engineering and Management,* 137(8), 1943-1944.

Taylor, J. E., and Bernstein, P. G. (2009). "Paradigm trajectories of building information modeling practice in project networks." *Journal of Management in Engineering*, 25(2), 69-76.

The National Institute and for Occupational Safety and Health (NIOSH) and Center for Disease Control and Prevention (CDC). (1998). Assessing occupational safety and health training. Retrieved October 31, 2011, from http://www.cdc.gov/niosh/pdfs/98-145.pdf

The New Hampshire Department of Labor. (2010). A guide for developing a written safety program and lab 600 rules. Concord, NH. Retrieved November 14, 2011, from http://www.labor.state.nh.us/ST-WrittenSafetyProgram.pdf

U.S. Bureau of Labor Statistics. (2002). Workplace injuries and illnesses in 2002. BLS Washington, DC. Retrieved April 11, 2010, from http://stats.bls.gov/news.release/pdf/osh.pdf

U.S. Bureau of Labor Statistics. (2008). Hispanic Population of the United States. BLS Washington, DC. Retrieved April 11, 2010, from http://stats.bls.gov/news.release/pdf/osh.pdf

U.S. Bureau of Labor Statistics. (2011). Hispanic Population of the United States. BLS Washington, DC. Retrieved November 1, 2011, from http://www.bls.gov/news.release/pdf/cfoi.pdf

U.S. Census Bureau. (2006). United States Census Bureau. Retrieved April 11, 2010, from http://www.census.gov/econ/census02/guide/INDRPT23.HTM

U.S Department of Labor. (2004). Occupational Safety and Health Administration. Retrieved October 31, 2011, from http://www.osha.gov/recordkeeping/new-osha300form1-1-04.pdf

U.S Department of Labor. (2008). Workplace injuries and illnesses in 2007. Retrieved October 31, 2011, from http://www.bls.gov/iif/oshwc/osh/os/osnr0030.pdf

U.S Department of Labor. (2011). Occupational Safety and Health Administration. Retrieved October 31, 2011, from http://www.osha.gov/dte/outreach/construction/index.html

Van Dyck, C., Frese, M., Baer, M., and Sonnentag, S. (2005). "Organizational error management culture and its impact on performance." *Journal of Applied Psychology*, 6, 1228-1240.

Vecchio-Sadus, A. M. (2007). "Enhancing safety culture through effective communication." *Safety Science Monitor*, (11) 3, 1-10.

Wagner, D. M. (1987). "Transactive memory: a contemporary analysis of the group mind." *Theories of Group Behavior*, 185-208.

Wasserman, S., and Faust, K. (1994). Social network analysis, Cambridge University Press, Cambridge, Mass.

Wyer, R.S. (1966). “Effects of incentive o perform well, goup aractioin, and group acceptance on conformity in judgmental task.” *Journal of Personality and Social Psychology*, 4(1), 21-26.

Zohar, D. (1980). “Safety climate in industrial organizations: theoretical and applied implications.” *Journal of Applied Psychology*, 65, 96-102.

CHAPTER 3

RELATIONSHIPS AMONG LANGUAGE PROFICIENCY, COMMUNICATION PATTERNS, AND SAFETY PERFORMANCE IN SMALL WORK CREWS IN THE US

ABSTRACT

The construction industry employs approximately 6% of all US workers but accounts for over 16% of all occupational fatalities. Recent statistics indicate that over 40% of all US construction laborers cannot speak English at a proficient level. To ensure strong safety performance it is vital to include *every* individual in a construction crew in safety-related communications, regardless of language proficiency. Considering that most safety communication is delivered in English, it is not surprising that Spanish-speaking construction workers are fatally injured at a disproportionate rate. To conduct the first exploration of the characteristics of strong, multi-lingual safety networks in the Denver Metropolitan region of the US, a multi-lingual research team conducted interviews with the members of fourteen construction crews. Demographic attribute data for each individual (e.g., language proficiency, years of experience, position in the company, etc.) and network data were collected to analyze the safety communication network for each crew. The units of analysis included the individual actors in the network and the networks as a whole. The exploratory results contribute to the body of knowledge by revealing that unilingual work crews have safety performance that is 51% better than multilingual work crews (p-value = 0.10); bilingual workers play a more central role than unilingual workers when more than one language is spoken (p-value < 0.001); workers less than 35 years of age have a higher degree of centrality than do workers who are older than 35 years old (p-value 0.11); and managers play an important role in the exchange and diffusion of safety knowledge regardless of language proficiency (p-value < 0.001). Most importantly, SNA metrics show that these language boundary spanners often form the core of a network that connects disparate groups of individuals. On the other hand, crews with relatively weak safety performance tend to have clear and disparate sub-networks distinguished by language and high rates of turnover. Such

characteristics are of concern because individual actors are not able to effectively warn one another of uncontrolled hazardous exposures or work in transition.

INTRODUCTION

Although the construction industry in the United States (US) accounts for 6% of all workers, it accounts for more than 16% of all occupational fatalities (Bureau of Labor Statistics, 2011). Within this disproportionately dangerous industry, Hispanic workers are injured at significantly higher rates. In fact, the Center for Construction Research and Training (2007) reported that in 2005 the fatality rate for Hispanic workers was 12.4 per 100,000 workers while non-Hispanic workers' fatality rate was 10.5. To add to these issues, the proportion of Hispanic workers continues to increase in the US. Hispanic workers account for 23% of construction workers in the US and 30% of construction workers in the state of Colorado (Pew Hispanic Center 2012). One of the factors that may contribute to the disproportionate injury rate for Hispanic workers is a barrier in communication when Hispanic workers are the minority on a worksite or within a crew. Of these workers, 42% reported that they do not speak English even at a proficient level (the Center for Construction Research and Training, 2007). As the proportion of Spanish-speaking workers continues to increase in the US construction industry, attention should be paid to the impacts of language barriers on safety-related knowledge exchange. Other factors that may contribute to this phenomenon include the type of work that Hispanic workers are required to perform, risk tolerance, and elements of culture.

The issue of multilingual worker crews is not confined to the US. For example, in Germany foreign construction workers were four times more likely to be killed by falling objects than their German counterparts (Arndt et al., 2004). Finally, in Portugal the fatality rate for foreigner construction workers was 4% higher for non-Portuguese workers (EWCO 2011). The authors of this paper believe that a potential explanation for these disproportionate injury rates is the lack of safety-related knowledge exchange among workers who speak different languages and the fact that safety training and signage is typically only delivered in the project host country's primary language.

Construction typically involves multiple organizations and cultures working together in the same workplace. Cultural and linguistic diversity can have a negative impact on the initial multicultural project networks performance, but it has a benefit on long-run performance (Comu et al., 2011) The ability to communicate effectively among individuals with cultural diversity is challenging, especially when attempting to effectively implement a safety program. According to Vecchio-Sadus (2007), to improve safety communication during the implementation of safety activities managers should:

- Ensure open and clear discussion with all individuals from different levels regarding safety in all languages represented;
- Communicate in the primary language that is spoken within the crew;
- Simply and clearly describe goals and rules of workplace safety;
- Provide immediate verbal feedback that reinforces safe behavior; and
- Implement an accessible lessons-learned program for safety.

Each of these suggested strategies is linked to ensuring adequate safety knowledge exchange during planning and execution. In order to facilitate optimum knowledge exchange across crews, it is important to understand the impacts that personal attributes such as language proficiency, age, and experience have on the position of an individual within a network.

To study the relationship between personal attributes and network position we used social network analyses of small work crews in Colorado. This research conducted exploratory analysis of the relationship between an individual worker's personal attributes (language proficiency, age, industry experience, trade experience, tenure with the company, and safety training) and their centrality and betweeness in the network. The research also investigated the role and position of bilingual workers within multilingual crews. As will be discussed, previous literature has focused on the communication patterns that differentiate the safety performance of comparable work crews (Alsamadani et al. in press). We depart from and contribute to the body of knowledge by investigating the role of personal attributes on network dynamics and the relationship between network dynamics and safety performance. Further, we contribute to the area of social network analysis for organizations by conducting an in-situ attribute-based analysis of small project-based networks and linking this to safety performance.

LITERATURE REVIEW

Social network analysis (SNA) is used as the primary data collection and analysis method for this study accompanied by statistical analyses of SNA metrics and attribute data. The theoretical underpinnings are the research in safety communication and project-based network research.

Safety communication

Researchers have found that open communication among employees and field-level supervisors is the cornerstone of an effective safety program and differentiates organizations with strong safety performance from those with weak performance (Zohar, 1980; Smith et al. 1978). In fact, safety communication between managers and employees has been found to be one of the top five favorable safety management practices in a large number of independent research studies (e.g., Bentley and Haslam, 2001; Hofmann and Morgeson, 1999; Sawacha et al. 1999). Specifically, Smith et al. (1978) showed that supervisors can enhance safety performance by providing consistent verbal feedback with particular attention on positive feedback for safe behavior. Further, Mattila et al. (1994), Niskanen (1994), and Simard and Marchand (1994) claimed that safety leaders must actively participate during safety planning meetings by communicating known hazards and organizational priorities in order to achieve worker buy-in. Finally, Van Dyck et al. (2005), Parker et al. (2001), and Cigularov et al. (2010) all found that immediate safety communication during accident investigations and error management enhanced safety performance.

Safety communication can be divided into two categories: formal and informal. Formal safety communication includes communication among workers and managers in scheduled safety meetings such as toolbox talks, safety committee meetings, and safety orientations and written safety communication such as safety signage, posters, emails, and memos (Jaselskis et al. 1996; Rajendran et al. 2009; Hallowell 2011). Alternatively, informal safety communication includes all ad hoc safety conversation that is held during planning or at the workface that is not facilitated by a regular scheduled meeting (Schein, 1965).

Network Analysis

SNA has recently been used to investigate knowledge exchange within and among project-based organizations in the Architecture, Engineering, and Construction (AEC) industry (Loosemore, 1998). Specifically, recent researchers have used SNA to assess construction team performance (Chinowsky, 2008); knowledge exchange among and within construction firms (Morton et al. 2006; Katsanis, 2006; Javernick-Will, 2011); and the relationships between individuals' roles, procurement strategies, and team performance (Pryke, 2004). Recently SNA was used for the first time at the crew level to assess the relationships between network dynamics and safety performance of crews on a jobsite (Alsamadani et al., in press).

When collecting data for SNA, there are two approaches:

1. Egocentric Networks: where the researcher asks each actor to indicate with whom they communicate. In this type of research each individual in the crew is an actor. This approach is useful when the boundary of the network is not identified or the network size is large (Haythornthwaite 1996). This strategy is typically employed when studying large or ill-defined networks.
2. Complete Networks: where the researcher provides each member of the network with a list of all others in the network and asks them to indicate with whom they communicate. This requirement places limits on the size of the population and the number of ties. The number of possible ties is equal to the size of the population "n" times "n-1". This data collection method is feasible when the network is small or when all members have been identified prior to data collection.

Within any network study, metrics can be obtained at the network level and individual levels. SNA metrics of interest for this study included network density, actor centrality, and actor betweenness. In this study, each individual in the crew was an actor and the crew represented a network. Network density is the ratio of the total number of connections existing in a network to the total number of possible connections (Borgatti and Everett, 2006) and actor centrality is the ratio of the total number of actual relationship that an individual has with the total number of possible relationships (Freeman, 1977). Individuals with high centrality typically control knowledge exchange in a network. Actor betweeness, however, is a measure of the degree to which an actor serves as a bridge between other otherwise disconnected actors (Freeman, 1977). An individual with high betweenness can also be referred to as a "goalkeeper." Because SNA is a relatively mature research method, the writers refer the reader to Freeman (1977), a resource that provides a strong background in basic SNA metrics, definitions, and equations.

Cultural boundary spanners

With a growing proportion of Spanish and other non-English speaker construction workers in the United States, cultural differences and language barriers may create boundary splitting conditions that result in fragmented work teams (Cramton and Hinds 2005). These boundaries may pose challenges that hinder project performance (Levina and Vaast, 2008; Ozorhon et al., 2008; Nayak and Taylor 2009; Chen et al., 2009). As discussed by Cross and Prusak (2002) and Levina and Vaast (2005), individuals who possess or understand the characteristics of multiple cultures may be able to integrate these otherwise disparate groups. Such individuals are known as cultural boundary spanners.

According to Cross and Parker (2004), to overcome the weaknesses in fragmented networks an organization should identify and designate cultural barrier spanners. Some suggest that middle managers should fill these roles because of their hierarchical position and social capital (Levina and Vaast, 2005) although subsequent research has not shown clear evidence middle managers are effective boundary spanners (Lu, 2006). The importance of cultural barrier spanners has been discussed theoretically but past research has provided limited empirical evidence that supports their position as critical members of a network. However, in a recent experiment, Di Marco et al. (2010) successfully used SNA to show how emerging cultural barrier spanners effectively resolve conflict in cross-cultural engineering projects. Because of this research, we hypothesize that bilingual workers may serve as cultural barrier spanners who link clusters of unilingual workers in small crews.

Structural Holes

There are many features within networks that contribute to their success or failure. A network feature commonly observed in fragmented networks is a structural hole, which is defined as a non-redundant relationship between two individuals (Burt, 1995). Such a feature is important because, once a tie between these two individuals is broken, a hole in the network forms and acts as an insulator that significantly decreases network density and can result in disconnected clusters. To reduce the potential impacts of structural holes it is important to have frequent communication among emotionally close non-redundant individuals (Marsden and Hurlbert, 1988) or redundant connections outside of the primary network (Geletkanycz and Hambrick, 1997). The reduction of structural holes in project networks has been tied to enhanced organizational performance (Baum et al., 2000). It should be noted that the term structural hole refers to a *potential* deficiency if an actor were to be removed; it is not in reference to an existing feature of the network.

Safety and social network analysis

Only two studies in the safety domain have used SNA for data collection and analysis. First, Fang et al. (2010) studied safety knowledge exchange in China and found that less educated and trained workers are more likely to re-direct all safety related questions to the their supervisors. Second, Alsamadani et al. (in press) studied safety knowledge exchange among workers in small work crews and identified that dense crews with frequent informal and formal communication have stronger safety performance. The use of SNA as an analytical technique represents an opportunity for the safety research community to measure and model safety communication.

CONTRIBUTION TO THE BODY OF KNOWLEDGE AND POINT OF DEPARTURE

This study departs from the current body of safety knowledge by objectively measuring and modeling safety communication patterns using SNA and evaluating the potential relationships between individual attributes and network position. Past research has focused on the safety roles of various functions within a construction company but no study has attempted to model the safety communication patterns at the crew level. Studying *active* crews that are mainly composed of field-level workers and managers also adds to the general knowledge base of network modeling and cultural barrier spanners.

RESEARCH METHODS

This research collected and analyzed SNA data from 14 crews, each with less than 40 workers, in the Denver Metro Region of the United States. This approach was used because the team was not able to obtain the names of all crewmembers prior to the SNA questionnaire development as data were collected during a one-day visit to each project site.

SNA data collection protocol

The research team collected data originally from 17 crews during one-day visits to each project site. Each crew was employed by a different organization. These organizations represent a convenience sample as the research team used their personal contacts to identify project managers and owner representatives on local building construction projects. These project leaders identified five project sites to collect data from these 17 crews. Data were collected from the crews that were present on the day of the site visit.

Every site visit followed the same protocol. Before questionnaires were administered to the crewmembers, the research team met with the superintendent or, on larger projects, the safety manager to introduce the objectives of the study and discuss the protection of human subjects' information. Once these introductions were completed, the survey was administered to the crew. To ensure internal validity, we administered the surveys directly to the workers. A bilingual research team was vital to the validity of the study. It enabled the creation of both Spanish and English versions of the questionnaire and enabled the research team to provide verbal orientations to the survey in both English and Spanish was given to ensure that all crew members understood the survey.

The research team was not able to obtain the names of all crew members prior to the site visits where the SNA questionnaires were administered. As a result, each crew member was asked to specify the names of other crew members with whom they exchange knowledge. This approach is useful when the boundary of the network is not identified or the network size is large (Haythornthwaite 1996). Data were collected using an egocentric approach because, at the time that the survey was administered, the boundaries of the network could not be identified. This self-identification is a typical characteristic of an ego-centric network approach. However, a complete network of crewmembers was identified from the complete list of responses, which was validated with the crew leader on the day of the interview. Thus, we were able to identify the complete crew, or network. To ensure validity, particularly with our small crew/network sizes, the authors analyzed complete networks where every crew member completed the survey.

On the day of the site visit, the research team obtained the crew size and validated the members of each crew. Because the research team wanted to bound the crew and determine the number of existing connections in comparison to the number of possible connections (where the number of possible connections is equal to the size of the crew, “n”, times “n-1”), analysis was only conducted for complete networks where *every* crew member completed the survey. A total of three crews were dismissed from the study because of incomplete networks. Because this is a relatively small proportion of the overall target sample, we favored enhancement of internal validity to a small compromise to external validity.

The crew is defined as all field-level employees and field-level managers who (1) work for the same employer in the same physical location; (2) have worked together for at least half of the project duration; (3) are assigned full time to one project; (4) participate in a collaborative work environment; and (5) working together to complete the same task. This definition does not include short-service employees, safety managers or other upper-level managers, or employees of other organizations. Additionally, we included only crews that had been working together as one unit on a project that was at least 50% complete to ensure crew stability and to prevent potential network disturbances from transient workers. We also only included crews with between 5 and 40 workers to prevent variations that exist when performing SNA on networks of dissimilar sizes. Even within the sample, the slight differences in size can limit the power of the comparisons that are observed.

The survey was structured to obtain demographic data for each participant and the necessary data to perform the SNA. Each participant was asked to provide the following demographic information: name, age, language proficiency, number of years with the employer, number of years in the trade, number of years in the construction industry, and any safety training that they have received in their career. To ensure confidentiality, all names were replaced with a pseudonym. Following these demographic questions, each participant was asked to indicate with whom they *provided* safety information on at least a daily basis, the average frequency of communication, and the mode of communication that was typically used (e.g., written communication, training, informal discussions, and toolbox talks). Please see Figure 1 for a sample questionnaire. The third component of the survey was identical to the second except the respondents were asked to indicate from whom they *received* safety information and the average frequency of this communication. We coded and imported the data into UCINET, a software system that computes SNA metrics and provides network visualization. The data were filtered and reported by actor attribute (e.g., the demographic data) and this data was used to perform statistical analysis. For this analysis, connections were considered when safety communication occurred at least once a month.

Your Name:______________________________ Age ____________ University of Colorado Boulder

Your Position: ________________________ Company ______________________

Years of experience in : Industry __________ With this company____________ in this trade ____________

Safety education: OSHA class ☐ Special training ☐

Compared with cost and schedule safety is : The most important ☐ Somewhat Important ☐ Not Very important ☐

Fluent in: English only ☐ Spanish only ☐ English and Spanish ☐

To whom on your crew do you PROVIDE safety information to, how often do you communicate, and through which means?												
Name of individuals who you **PROVIDE** safety information to		Frequency of communication (check boxes)					Most common mode(s) of communication (check all boxes that apply)					
First Name	Last Name	once a month	bi-weekly	weekly	once a day	more than once a day	Formal communicaiton (mgt role)	Written communication	Training	Informal discussions	Toolbox talk	Other (please specify)
Participant	**Number one**			×				×				
Participant	**Number two**		×				×					
Participant	**Number three**	×							×			
Participant	**Number four**					×				×		
Participant	**Number five**			×							×	
Participant	**Number six**				×					×		

***If you need additional pages, please let the researcher know

Figure 1 – English version of the questionnaire

Relative safety performance (RSP)

Since one of the aims of this study was to observe the differences in network characteristics among relatively high performing and low performing crews, a metric of safety performance for each crew was desired. Traditionally, safety is measured through lagging indicators of performance such as Occupational Safety and Health (OSHA) recordable injury rates (OSHA RIR), the rate at which workers are injured badly enough that they cannot return to work or are transferred to a less physically demanding tasks (DART rate), and Experience Modification Rates (EMR) (Jaselskis et al. 1996). Unfortunately, these metrics of safety performance are typically measured at the organization level. Since the research team focused at the crew level, a new safety metric was needed.

To be consistent with past comparative safety studies at the crew level, we used a composite safety score (Alsamadani et al., 2011; 2012a; b). To calculate this score we requested the organization's recordable injury rate (RIR) from the past calendar year and an approximation of the subject crew's relative safety performance within the organization (e.g., percentile). Researchers obtained these data during the opening conference from a manager in the organization who directly oversaw a large proportion of the organization's work crews (e.g., safety manager).

With these two data points researchers were able to calculate a composite crew safety performance score by multiplying the inverse of the RIR by the percentile rating (refer to Equation 1). After the crew safety performance was calculated for each of the 14 crews, a relative safety performance (RSP) was calculated by normalizing the crew safety performance scores. Thus, each crew composite safety metric was divided by the maximum metric achieved amongst the crews studied ('percent of maximum' rating) (refer to Equation 2). A relative safety performance (RSP) score of 1.0 corresponds to the best performing crew in the study and all other metrics are measured against the performance of this crew. Although different trades were included in the case studies, the RIRs obtained for the 14 crews showed no statistical difference among trades. However, this is in conflict with what is reported by the Center for Construction Research and Training (2007), which found inconsistent injury rates among construction trades. The demographics of the case crews are included in Table 1.

Crew safety performance = Safety performance (percentile) / organization RIR *Eq. 1*

Relative safety performance = crew safety performance / top crew safety performance *Eq. 2*

As one can see from Table 1, we sorted the data by languages spoken (English only, Spanish only, and bilingual). To be considered bilingual, a worker must be fluent in both English and Spanish languages and able to communicate all safety-related information that may be required in either language. It should be noted that some workers confirmed that they could speak a broken version of the other language; however, these workers were not considered to be bilingual in the analyses. A total of 161 construction workers were involved in this study. Among them twenty-five field-level managers, thirteen of whom are bilingual. All unilingual managers spoke English only. The research study also included a total of 136 field workers, 28 of whom were bilingual. Of the remaining workers, 45 spoke only English and 63 spoke only Spanish.

Table 1 – Crew demographics

Crew no	Trade	Size	Number of workers fluent in: English	Spanish	Bilingual	Relative safety performance
13	Sheet metal	9	8	0	1	1.00
14	Plumbing	10	9	0	1	0.66
6	Landscaping	5	0	4	1	0.57
4*	Drywall	21	11	5	5	0.54
5	Electrical	7	7	0	0	0.51
9	Cleaning	5	0	4	1	0.48
12	Electrical	6	5	0	1	0.47
3	HVAC	5	0	2	3	0.40
8	Electrical	10	8	0	2	0.36
2	Concrete	8	0	4	4	0.35
7	Concrete	10	5	0	5	0.34
1*	Concrete	36	13	11	12	0.28
10*	Carpentry	24	4	15	5	0.20
11	Plumbing	5	5	0	0	0.08

*Bilingual crew

DATA ANALYSIS AND FINDINGS

The research team focused the data analysis on evaluating the potential impacts of actor attributes on their degree of centrality and betweenness in the networks. Data from all crews were aggregated and statistical analyses were performed on the resulting dataset. Because the data were aggregated, we do not believe that the differences in work type and exposure to hazards among the work crews will influence the internal or external validity of the subsequent analyses. The actual statistical methods we used were dependent on the characteristics (e.g., normality) of the dataset associated with each attribute. The specific statistical methods employed are described and justified below. Results are reported based upon a threshold p-value of 0.10. It should be noted that a p-value of 0.05 is typically regarded as strong evidence for a statistical inference. A p-value between 0.05 and 0.10 can be considered suggestive. The results should be read in light of this interpretation. These thresholds are appropriate for exploratory and contextual social studies (Ramsey and Schafer 2002).

Finding 1: Suggestive evidence that multi-lingual work crews have safety performance that is 51% (0.98 OSHA recordable injuries per 200,000 worker-hours) worse than crews where only one language is spoken (p-value = 0.10).

One of the primary research questions was: Is there a statistical difference between the safety performances of crews where all workers are fluent in a common language (unilingual) and those where at least 20% of the crew members are not fluent in the predominant language (multi-lingual)? In all crews studied, the predominant language was English. In fact, on all multilingual crews, all training, signage, and safety resources, and pre-task safety meetings were provided in

English only. Of the 14 crews studied, three were multilingual (crews 1, 4, and 10) and the remaining 11 were unilingual.

Although the sample size for the multilingual crew was small, we had enough degrees of freedom to perform a two-sample test. Because the datasets were normal but not of equal size or variance, the research team used the Mann-Whitney test to measure the difference in safety performance between the two groups. The test revealed that the average RSP value for the multilingual and unilingual worker crews was 0.34 and 0.514, respectively (p-value = .10). This was not surprising because the two crews with the lowest RSP were multilingual crews. The findings provide moderate evidence that language barriers in safety knowledge exchange may be a contributing reason why Hispanic workers sustain disproportionately high rates of injuries. Because several networks for bilingual workers were shown (e.g., Figure 3) in subsequent sections, a representative network for a unilingual work crew is shown in Figure 2. In comparison, visual representations of networks for multilingual crews are provided in Figure 3. As one can see, unilingual work crews tended to be comparatively well distributed with a higher degree of density. Once the network analyses were complete, we transitioned to analyzing the impacts of individual worker attributes on their positions within the crew networks.

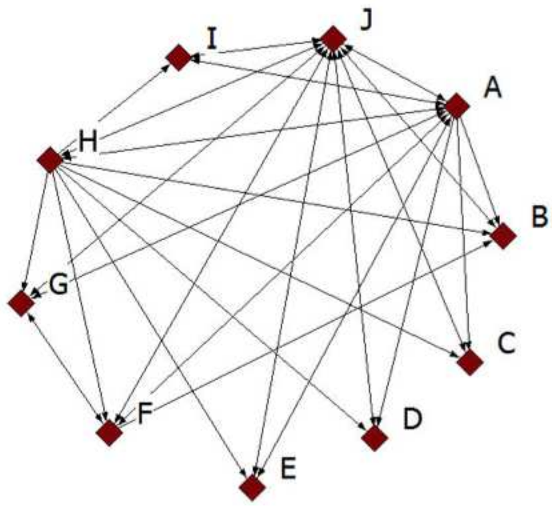


Figure 2 – Network for Crew 9 (unilingual crew work)

Finding 2: Strong evidence that bilingual workers (cultural barrier spanners) play a critical role in safety knowledge exchange in crews where more than one language is spoken (p-value < 0.001)

Literature and theory support the proposition that bilingual workers will serve as cultural barrier spanners in the networks. If this is the case, one would expect bilingual workers to have higher values for their in-centrality, out-centrality, in-betweenness, and out-betweenness. To explore this hypothesis, we divided the actors from all crews into two groups: bilingual workers (i.e., those workers who spoke English and Spanish fluently) and unilingual workers (i.e., those workers who could only speak English or Spanish fluently). Since a disproportionate number of managers were bilingual as previously discussed, managers were removed from the two-sample test. Additionally, since the samples were of unequal size (108 unilingual workers and 28 bilingual workers), normally distributed, and the variances were not approximately equal, the Mann-Whitney two-sample test was used.

The test revealed that bilingual workers have, on average, out centrality scores that are 2.4 times greater than unilingual workers (p-value < 0.01) and out betweenness scores that are 1.86 times greater (p-value $= 0.10$). The statistics for this comparison are provided in Table 2. Interestingly, these findings mean that bilingual actors *provide* a significant amount of the safety knowledge in the network but do not necessarily *receive* a disproportionate amount of knowledge. Thus, they fill structural holes that are known to cause deficiencies in networks.

Table 2 – Two-sample tests for a comparison of unilingual versus bilingual workers

SNA Metric	Unilingual (n=108)	Bilingual (n=28)	Difference	p-value
Average out centrality	0.132	0.312	0.180	0.006
Average out betweenness	0.025	0.041	0.017	0.100
Average in centrality	0.084	0.127	0.043	0.428
Average in betweenness	0.001	0.006	0.006	0.329

These findings are strongly supported by the visual analysis of the networks of the three multilingual work crews (Combined in Figure 3). One can see that the highest performing multilingual crew (Crew 4) had a core cluster of bilingual workers who were densely connected to one another with critical, redundant ties to the unilingual workers. Although the other two crews have a visible core of bilingual actors, the ties to the unilingual workers are not always redundant resulting in structural holes.

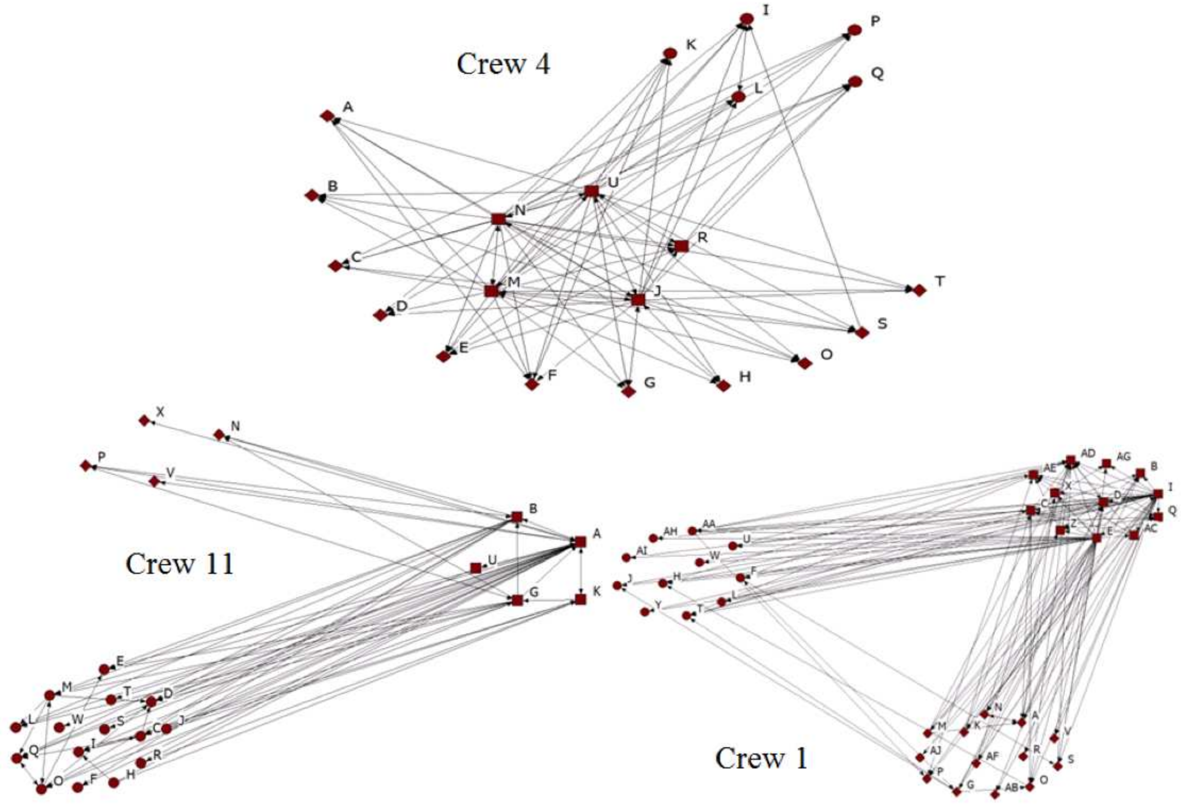


Figure 3 – Networks for multilingual crews (squares represent bilingual workers, diamonds represent English-only-speaking workers, and the circles represent Spanish-only-speaking workers)

Finding 3 (Minor Finding)– Suggestive evidence that workers less than 35 years of age have a higher degree of centrality in the crew networks than do workers who are older than 35 years of age (p-value 0.11)

One might presume that older workers would serve a more central role in a safety network because of their experience and wisdom. To determine the potential influence of actor age on centrality and betweeness, we employed two analytical procedures. Because managers and workers were both included in these analyses, we started by creating Pearson/Spearman correlation matrices to visually identify potential covariance between age and other actor attributes. These matrices showed no relationship between age and any other individual attribute.

Once the test for covariance was complete, researchers performed a simple linear regression on the normally distributed dataset. The regression showed that there was no linear, exponential, or logarithmic relationship within the data so we performed a second test on a dichotomized dataset. Because approximately half of the actors were 35 years old or younger, the data were divided into two samples (e.g., <= 35 and > 35 years of age). Boxplots confirmed that the samples were normally distributed and had approximately equal variance, for an example see Figure 4. Therefore, a t-test was performed for each SNA metric. The results of these statistical tests are shown in Table 3.

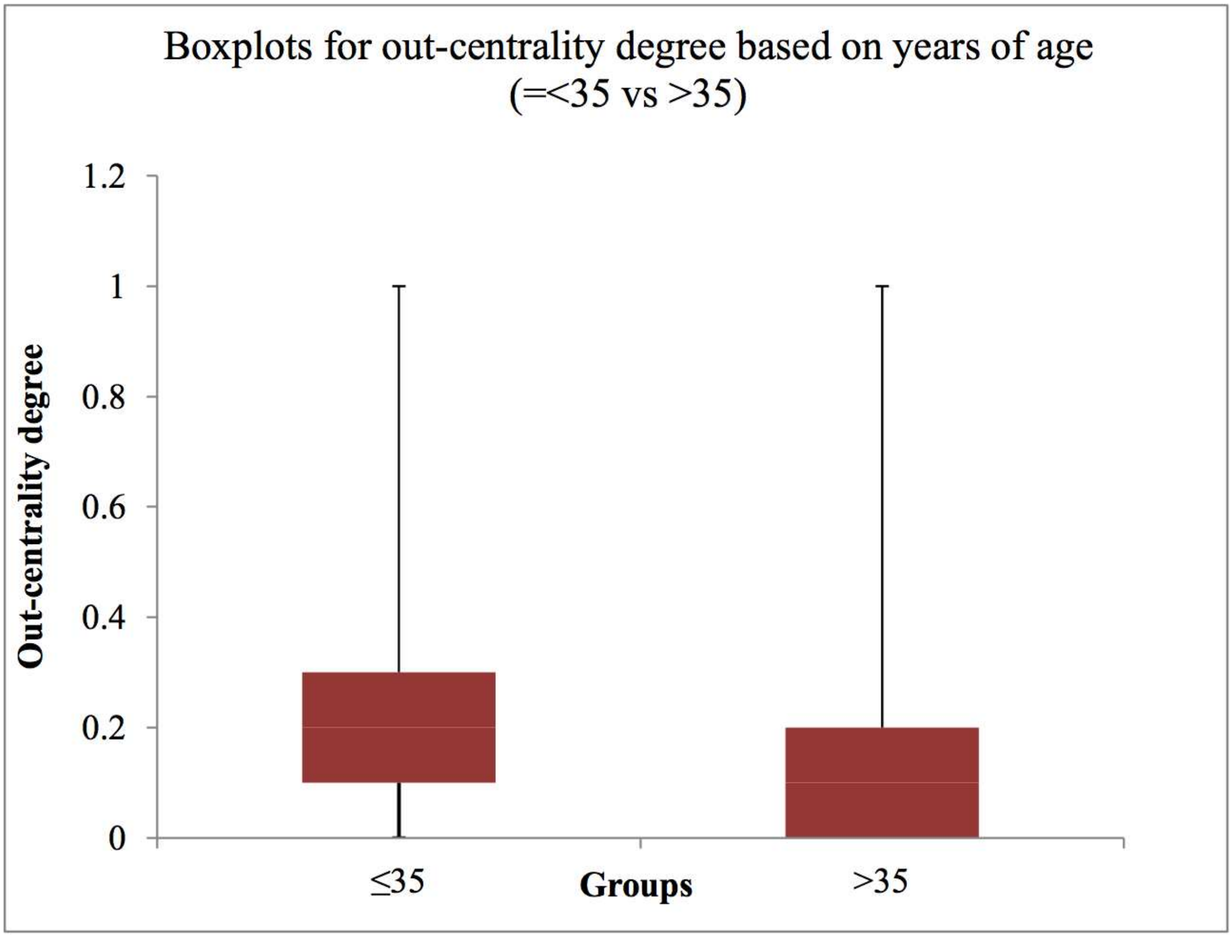


Figure 4 – Box Plot of out-centrality degree based on crew members' ages (=<35 vs >35)

Another interesting relationship existed among the actors who are 25 years old or younger (n=16) and workers who are 56 years old or older (n=6). The findings indicate that the younger workers may have an average out centrality measure of 0.36, which is 15 times greater than the older workers who had an average measure of 0.02 (p-value = 0.045). In fact, of all of the age groups studied, the youngest age bracket (25 years old or younger) had the highest average centrality measure (See Table 4). This suggestive finding was surprising as we originally postulated that older, more experienced workers would be highly central to knowledge exchange.

Table 3 – Two-sample tests for a comparison of younger workers and older workers for a dichotomized dataset

SNA Metric	Workers <= 35 years (n=79)	Workers > 35 years (n=82)	Difference	p-value
Average out centrality	0.218	0.139	0.079	0.108
Average out betweenness	0.032	0.026	0.005	0.753
Average in centrality	0.105	0.088	0.018	0.637
Average in betweenness	0.004	0.000	0.004	0.222

Table 4 – SNA centrality scores for worker age brackets

	Age Bracket				
	< 25	**26 to 35**	**36 to 45**	**46 to 55**	**> 55**
n	16	63	45	31	6
Average	36%	18%	10%	22%	2%
Variance	0.152	0.095	0.061	0.128	0.002

The authors depict two networks that provide some insight regarding the respective roles of older and younger workers. A relatively large and a relatively small network are shown in Figure 5. In both of these networks, workers over the age 35 (depicted by squares) tended to have very few connections to one another and were mostly connected to management. Workers under the age of 35 (depicted by circles), on the other hand, have many connections with one another and account for a large proportion of the overall network density.

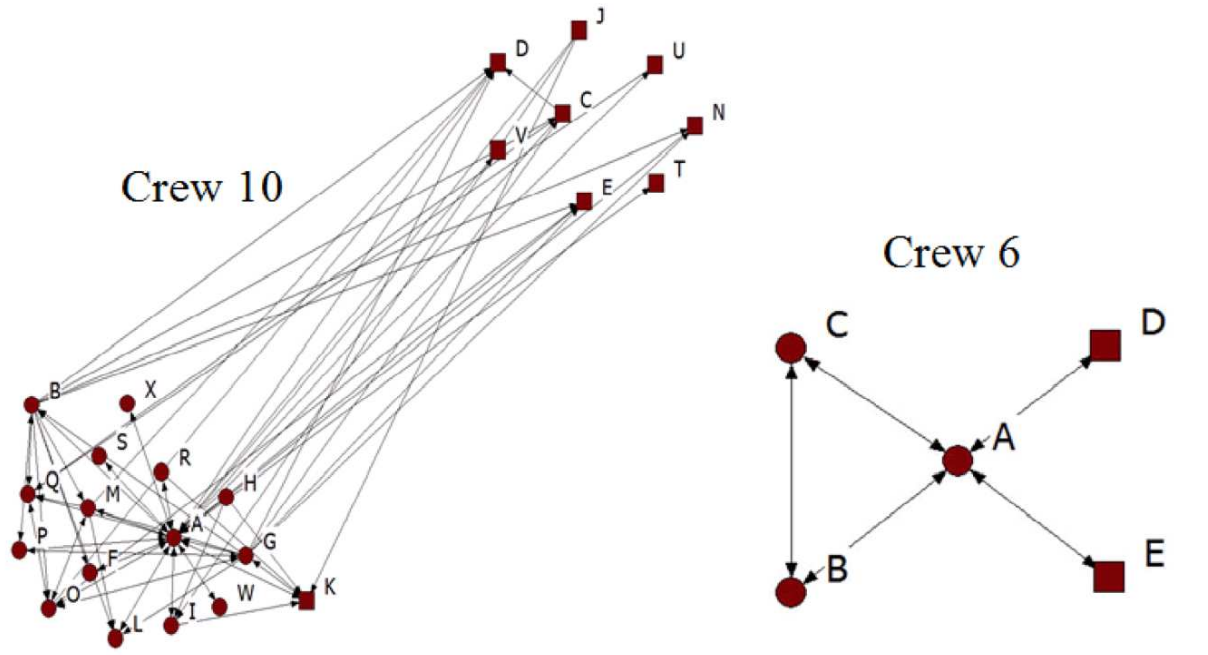


Figure 5 – Networks showing network position dichotomized by age (Circles represent =< 35 years of age and squares represent >35 years of age)

Finding 4: Strong evidence that managers play an important role in the exchange and diffusion of safety knowledge regardless of language proficiency (p-value < 0.001)

In this research, a 'crew' included only workers and field-level managers who work daily with one specific crew. Thus, the dataset associated with position included only two groups: laborers and field-level managers. In order to determine the difference in SNA metrics, a two-sample test was appropriate. Because the dataset for each SNA metric included outliers, researchers used the Wilcoxon Rank Sum test. As indicated in Table 5, the managers, on average, played a very central role to knowledge exchange in their small networks. In fact, the SNA metrics were 3 to 20 times higher for the managers than the laborers. This finding is not surprising because managers must serve the role of integrator and facilitator in the crew for all forms of knowledge and managers are often promoted based on their competencies and leadership potential. Two networks are shown in Figure to visually depict the typical role that managers play as central members of a network. Typically, managers both provide and receive safety information from a large number of workers. As shown in crew 15, the manager is the only member of the crew who receives or provides safety-related information.

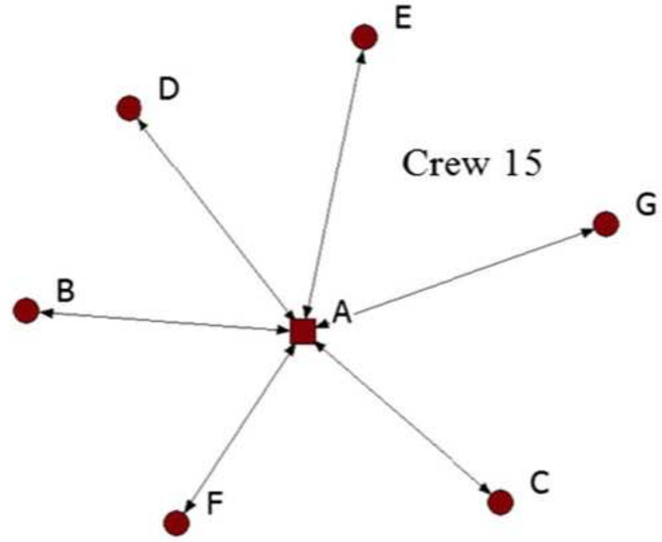


Figure 6 - Networks showing network position by position in the organization (squares represent managers and circles represent field workers)

Table 5 – Two-sample tests for a comparison of field managers and workers

SNA Metric	Field worker (n=136)	Field Manager (n=25)	Difference	p-value
Average out centrality	0.134	0.394	0.260	<0.001
Average out betweenness	0.012	0.124	0.112	<0.002
Average in centrality	0.061	0.294	0.233	<0.003
Average in betweenness	0.000	0.011	0.010	0.021

Finding 5: No statistical evidence that the role of a worker is influenced by the number of years of experience, years with the company, years in the trade, or level of safety training (p-value for all comparisons > 0.20).

In addition, the authors performed similar analyses to those mentioned above for all attributes including number of years of experience in the industry, years in the trade, years with the organization, and safety training. None of these attributes showed any correlation or statistical significance in the dataset. Although we originally hypothesized that more experienced and better trained workers would serve more central roles in the networks, these hypotheses were found to be false. That said, more experienced or better trained workers may provide higher quality or more important safety knowledge than their less experienced or less knowledgeable counterparts. Future studies should investigate the quality and usefulness of safety knowledge exchange as this data was not collected or analyzed in this research.

Limitations

The research team considers this study to be exploratory because SNA was used for the first time to investigate the impact of personal attributes (e.g., age, language proficiency) on an individual's safety knowledge exchange position within a small crew. The study includes several limitations that must be recognized. Because the dataset included only small work crews on building projects in the Denver Metropolitan region of the US, we can only generalize the findings to this population. Also, we assumed that all connections resulted in the same level of quality of safety knowledge exchange regardless of communication mode. In other words, we did not request information on the content or usefulness of the knowledge exchanged among connections. A further study is suggested that includes such data as it would elucidate the potential impacts on both quality and quantity of relationships.

In addition to those limitations to the study as a whole, there are two limitations to Finding 1 because of the nature of crew comparisons. First, the findings are based on the Relative Safety Performance (RSP) metric, which in its calculation depends on an approximation of the subject crew's relative performance within the organization. Although we are confident that project managers are capable of estimating this value for their crews, the RSP values are, inherently, approximations. Thus, the findings are limited to the extent to which the approximations are accurate. Second, we included 14 crews that were working in different projects and aggregated all data from all crews to perform analyses on personal attributes. Consequently, most findings relate to the sample as a whole and not to any particular trade or organization. Differences in trade safety performance on a national scale reported by the Center for Construction Research and Training (2007) is important because it poses a threat to the external validity of the comparisons made among networks. We strongly suggest that Finding 1 be considered suggestive only and that future research is conducted to determine its validity in a more consistent dataset.

Conclusions and Recommendations

The major contribution of this study was the investigation of safety knowledge exchange at the crew level using social network analyses. Past researchers have focused a great deal of attention on knowledge exchange and cooperation in large groups (Morton et al. 2006; Katsanis, 2006; Comu et al. 2011; Javernick-Will, 2011) but very few have studied small networks (e.g., crews).

Additionally, only two other studies attempted to model safety knowledge exchange using SNA (Fang et al. 2010; Alsamadani et al., 2012).

The findings of the present study indicate that there are strong relationships between actor attributes and their SNA metrics. In fact, workers under the age of 35, bilingual workers, and those in management roles tend to have centrality and betweenness scores that are statistically higher than their counterparts. Although these findings may be intuitive, the magnitudes of the relationships are surprising.

Another suggestive finding was that unilingual work crews have safety performance that is 51% better than multilingual work crews. This can be important because the number of Hispanic workers is expected to increase (BLS, 2012) and we observed that all training, hazard communication, and safety signage was provided in English only on all projects observed. The authors believe that action is necessary to better integrate workers within bilingual work crews by employing, recognizing, and rewarding cultural barrier spanners and that employers must take steps to provide safety training and other communications in all languages that are represented.

The research team suggests future research on construction safety knowledge exchange in several areas. First, safety knowledge exchange among different trades is warranted given the fact that most building construction projects involve concurrent work performed by multiple trades. Second, it is important to understand the safety knowledge exchange among the project owner's representatives, the design team, the general contractor, trades, and vendors because many past researchers (e.g., Gambatese et al. 1997) have shown the preconstruction decisions impacts on construction safety. Such networks could help identify strength, weaknesses, and potential areas for improvement. Finally, we suggest that the safety research community consider using SNA as a method to empirically measure safety knowledge exchange because it provides useful output and visual depictions of crew safety dynamics with data that are reasonable to obtain.

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REFERENCES

Alsamadani, R., Hallowell, M., and Javernick-Will, A. (2012). “Measuring and modeling safety communication in small work crews in the US suing social network analysis.” *Construction Management and Economic,* 31(6): 568-579.

Arndt, V., Rothenbacher, D., Daniel, U., Zschendelein, B., and Brenner, H. (2004). “All cause and cause specific mortality in a cohort of 20,000 construction workers; results from a 10 year follow up.” *Occupational and Environmental Medicine,* 61: 419-425.

Baum, J. A. C., Calabrese, T., and Silverman, B. S. (2000). “Don’t go it alone: alliance network composition and startup’ performance in Canadian technology.” *Strategic Management Journal,* 21, 267-294.

Bentley, T. A., and Haslam, R. A. (2001). “A comparison of safety practices used by managers of high and low accident rate postal delivery offices.” *Safety Science,* 37, 19-37.

Borgatti, S. P., and Everett, M.G. (2006). “A graph-theoretic framework for classifying centrality measures.” *Social Networks,* 28(4), 466-484.

Burt, R. S. (1995). *Structural holes: the social structure of competition,* Harvard University Press.

Chen, P., Partington, D., and Maoshan, Q. (2009). “Cross-cultural understanding of construction project managers’ conceptions of their work.” *Journal of Construction Engineering and Management,* 135(6), 477-487.

Chinowsky, P. S., Diekmann, J., and Galotti, V. (2008). “Social network model of construction.” *Journal of Construction Engineering and Management,* 134(10), 804-812.

Cigularov, K. P., Chen, P. Y., and Rosecrane, J. (2010). “The effects of error management climate and safety communication on safety: A multi-level study.” *Accident Analysis and Prevention,* 42, 1498-1506.

Comu, S., Unsal, H. I., and Taylor, J. E. (2011). “Dual impact of cultural and linguistic diversity on project network performance.” *Journal of Management in Engineering,* 27 (3), 179-187.

CPWR - The Center for Construction Research and Training. (2007). Construction Chart Book the U.S. Construction Industry and its Workers. 4th ed. Silver Spring, MD: CPWR - The Center for Construction Research and Training.

Cramton, C. D., and Hinds, P. J. (2005). “Subgroup dynamics in internationally distributed teams: Ethnocentrism or cross-national learning?” *Research in organizational behavior,* An annual series of analytical essays and critical reviews, 26. , Oxford, U.K., 231–263.

Cross, R. L., and Parker, A. (2004). “The hidden power of social networks: understanding how work really gets done in organizations.” *Harvard Business School Press*, 213(13).

Cross, R., and Prusak, L. (2002). “The people who make organizations go-or stop.” *Harvard Business Review*, 80(6), 104-112.

Di Marco, M. K., Taylor, J. E. (2010). “The impact of cultural boundary spanners on global project network performance.” Working Paper No 1004.

European Working Conditions Observatory. (2011). Immigration and Accident at Work. CESIS, Portugal. Retrieved April 11, 2012, from http://www.eurofound.europa.eu/ewco/2011/10/PT1110029I.htm

Fang, D., Huang, J., and Fong, P. S. W. (2010). “Sharing construction safety knowledge through social networks.” Proceedings of W099- Special Track 18th CIB World Building Congress, Salford, United Kingdom, May 10-13, 2010.

Freeman, L. C. (1977). “A set of measures of centrality based on betweenness. Sociometry,” 40**,** 35–41.

Gambatese, J.A., Behm, M., and Hinze, J. W. (1997). “Tool to design for construction worker safety.” *Journal of Architecture Engineering*, 3(1), 32-41.

Geletkanycz, M. A., and Hambrick, D. C. (1997). “The external ties of top executives: implications for strategic choice and performance.” *Administrative Science Quarterly*, 42, 654-681.

Hallowell, M. R. (2011). "Safety knowledge management in American constructin organizations." *Journal of Management in Engineering,* in press.

Haythornthwaite, C. (1996). "Social network analysis: an approach and technique for the study of information exchange." *Libr. Inf. Sci. Res.*, 18(4): 323-342.

Hofmann, D. A., and Morgeson, F. P. (1999). "Safety related behavior as a social exchange: the role of perceived organizational support and leader member exchange." *Journal of Applied Psychology*, 59 (2), 286-296.

Jaselskis, E., Anderson, S., and Russel, J. (1996). "Strategies for achieving excellence in construction safety performance." *Journal of Construction Engineering and Management*, 122(1), 61-70.

Javernick-Will, A. (2011) "Knowledge-sharing connections across geographical boundaries in global intra-firm networks". *Engineering Project Organizations Journal*, 1:4, 239-253.

Katsanis, C. J. (2006). *Network* Organizations: Structural and Strategic Implications, *Proceedings of the 2nd Specialty Conference on Leadership and Management in Construction*, May2006, Louisville, CO: PM Publishing, 108-115.

Levina, N., and Vaast, E. (2008). "Innovating or doing as told? Status differences and overlapping boundaries in offshore collaboration." *Management Information Systems Research Center*, 32(3), 307-332.

Loosemore, M., and Andonakis, N. (2007). “Barriers to implementing OHS reforms- the experience of small subcontractors in the Australian construction industry.” *International Journal of Project Management,* 25, 579-588.

Lu, Y. (2006). “Toward the micro and macro-level consequences of international justice in cross-cultural joint ventures.” *Human Relations Journal,* 59(8), 1019-1047.

Marsden, P. V., and Hurlbert, J. S. (1988). “Social resources and mobility outcomes: a replication and extension.” *Social Forces,* 66, 1038-1059.

Mattila, M., Hyttinen, M., and Rantanen, E. (1994). “Effective supervisory behavior and safety on building site.” *International Journal of Industrial Ergonomics,* 13, 85-93.

Morton, S.C., Dainty, A.R., Burns, N.D., Brookes, N.J., and Backhouse, C.J. (2006). Managing

Relationships to Improve Performance: A Case Study in the Global Aerospace Industry, *International Journal of Production Research*, 44(16).

Nayak, N., and Taylor, J. (2009). “Offshore outscoring in global design networks.” *Journal of Engineering Management*, 16(6), 18-22.

Niskanen, T. (1994). “Safety climate in the road administration.” *Safety Science*, 17, 237-255.

Nooy, Wouter de., Marver, A., and Batagelj, B. (2011). Exploratory social network analysis with Pajek, Cambridge University Press, Cambridge, Mass.

Ozorhon, B., Arditi, D., Dikmen, I., and Birgonul, M. T. (2008). "Implications of culture in performance of international construction joint ventures." *Journal of Construction Engineering and Management,* 134(5), 177-184.

Parker, S. K., Axtell, C. M., and Turner, N. (2001). "Designing a safer workplace: importance of job autonomy, communication quality, and supportive supervisors." *Journal of Occupational Health Psychology,* 6(3), 211-228.

Pew Hispanic Center. (2012). The Demographics of the Jobs Recovery. Washington, Dc. Retrieved June 24, 2012, from http://www.pewhispanic.org/files/2012/03/PHC-Labor-report-FINAL_3-21-12.pdf

Pryke, S.D. (2004). "Analysis construction project coalition: exploring the application of social network analysis." *Construction Management and Economy,* 22(8), 787-797.

Rajendran, S., Gambatese, J. A., and Behm, M. G. (2009). "Impact of green building design and construction on worker safety and health." *Journal of Construction Engineering and Management,* 135(10), 1058-1066.

Ramsey, F. L. and Schafer, D. W. (2002). "The statistical sleuth, a course in methods of data analysis." *Second Edition,* Belmont, CA: Duxbury Press.

Sawacha, E., Naoum, S., and Fong, D. (1999). "Factors affecting safety performance on construction sites." *International Journal of Project Management,* 17(5), 309-315.

Schein, E. H. (1965). *Organizational psychology,* Prentice-Hall, Englewood Cliffs, New Jersey.

Simard, M., and Marchand, A. (1994). “The behavior of first-line supervisors in accident prevention and effectiveness in occupational safety.” *Safety Science*,17, 169-185.

Smith, M. J., Cohen, H. H., Cohen, A. (1978). “Characteristics of a successful safety program.” *Journal of Safety Research*, 10, 5-15.

U.S. Bureau of Labor Statistics. (2011). Hispanic Population of the United States. BLS Washington, DC. Retrieved March 7, 2012, from http://www.bls.gov/news.release/pdf/cfoi.pdf

U.S Department of Labor. (2011). Occupational Safety and Health Administration. Retrieved October 31, 2011, from http://www.osha.gov/dte/outreach/construction/index.html

Van Dyck, C., Frese, M., Baer, M., and Sonnentag, S. (2005). “Organizational error management culture and its impact on performance.” *Journal of Applied Psychology*, 6, 1228-1240.

Vecchio-Sadus, A. M. (2007). “Enhancing safety culture through effective communication.” *Safety Science Monitor*, (11) 3, 1-10.

Wasserman, S., and Faust, K. (1994). *Social network analysis*, Cambridge University Press, Cambridge, Mass.

Zohar, D. (1980). “Safety climate in industrial organizations: theoretical and applied implications.” *Journal of Applied Psychology*, 65, 96-102.

CHAPTER 4

Understanding the Safety Challenges Faced by Hispanic Construction Workers: An Exploratory Study using Photovoice

OBSERVED PROBLEM

Although the construction industry in the United States (US) accounts for 6% of all workers, it accounts for more than 16% of all occupational fatalities (Bureau of Labor Statistics 2012). Within this disproportionately dangerous industry, Hispanic workers are injured at significantly higher rates. In fact, the Center for Construction Research and Training (2013) reported that the fatality rate for Hispanic workers is 12.4 per 100,000 workers while the non-Hispanic workers fatality rate is 10.5. One of the cultural factors that may contribute to the disproportionate injury rate for Hispanic workers is a barrier in communication when Spanish-only speaking workers are the minority on a worksite or within a crew. According to the Center for Construction Research and Training (2013), 42% of Hispanic construction workers report that they do not speak English even at a proficient level. In addition to communication barriers, other factors may contribute to high injury rates such as the job tasks that Hispanic workers are required to perform; risk perception and tolerance; opportunities; social problems; healthcare; and patterns of communication.

The issue of safety for Hispanic workers is becoming more important as the proportion of Hispanic workers continues to increase in the US. Currently, Hispanic workers account for 23% of the US construction workforce and 30% of Colorado construction workforce (Pew Hispanic Center 2012). The percentage of Hispanic US citizens is expected to increase to 128 million by 2060 (Bureau of the Census 2011). Consequently, the number of Hispanic construction workers in construction is expected to increase proportionally, with Hispanic workers accounting for over 25% of all workers. According to the U.S Bureau Labor Statistics (2011), the breakdown of Hispanic workers region of origin is as follows: 66% are Mexican, 20% are Central American, and 16% are South American. Further, Hispanic workers account for 69% of the construction workforce in Texas, 56% in New Mexico, and 30% in Colorado (CPS, 2001 and PHC, 2012).

RESEARCH OBJECTIVES

The present study aims to identify cultural barriers that impact occupational safety for Hispanic workers by exploring their experiences in small construction crews in the US. Accordingly, our research question is ***What cultural challenges do Hispanic construction workers face that may contribute to a disproportionate injury rate?*** We will focus on the challenges and opportunities that the workers *perceive* to be related to culture, which is defined as a set of shared characteristics within a country, community, or workers in a particular field. Characteristics may be linked to language, religion, cuisine, values, gender roles, norms, social structure, art, or music (House et. al., 2004). The overall objective of this research proposal is to have a better ***understanding*** of the safety challenges by Hispanic construction workers. The term ***understanding*** means identify and capture pictures of existing safety challenges. Thereafter, seek in details why these challenges exist and what possible solutions can be proposed to conquer these challenges. Lastly, discuss how to deliver the issues and solutions to the audiences and policy makers. Although researchers and theoreticians have hypothesized that particular cultural barriers exist for Hispanic workers, none have collected data directly from the workers themselves. Addressing this knowledge gap will form an essential foundation for future inquiry and will assist practitioners with strategic management of multicultural work teams.

RESEARCH FRAMEWORK

According to the US Management and Budget Office (1997), the demographic Hispanic refers to an individual who comes from Cuba, Mexico, Puerto Rico, South or Central America, or other Spanish culture or origin, regardless of race. Previous studies have identified a number of cultural characteristics that lead Hispanic workers to communicate and behave differently from members of other cultures in the US (Torres, 2008). As indicated, researchers have yet to perform a detailed or rigorous investigation of the safety-related challenges that Hispanic workers face from the perspective of the workers. To address this knowledge gap we propose an exploratory study that involves exploratory interviews and targeted interviews using photovoice. The unit of analysis for all three phases will be with workers in multicultural crews, including Hispanic and non-Hispanic workers. Our overarching multi-phase approach is illustrated in Figure 1 below. As one can see, the knowledge gained in each phase is used to inform the subsequent phases to yield valid and reliable results.

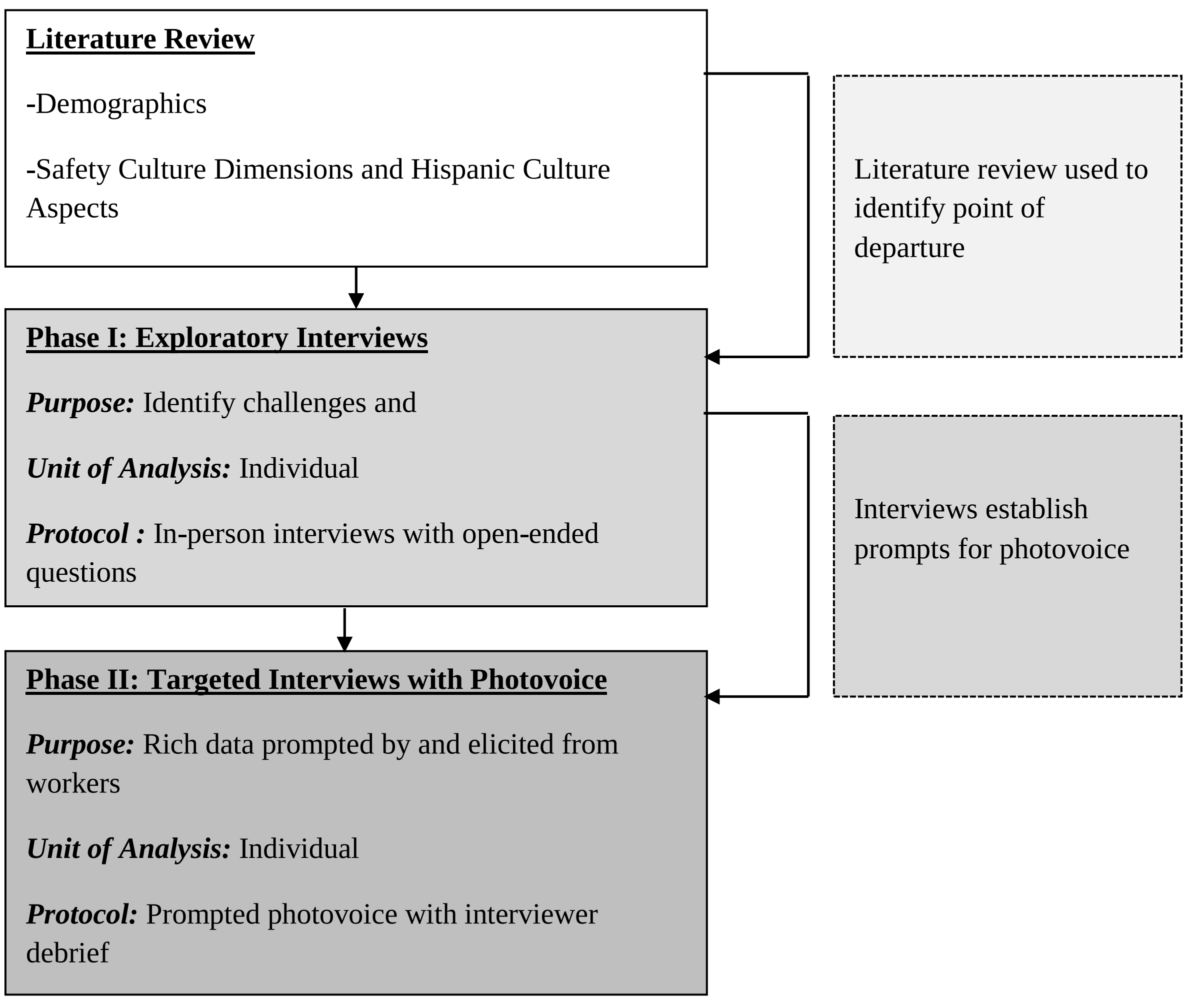

Figure 1 – An internally validated research plan aimed at longitudinally refining knowledge

EXISTING KNOWLEDGE

This study builds upon and extends a large knowledge base in safety communication, safety of Hispanic workers, safety culture, and includes the first use of photovoice in construction research. This section includes a review of salient literature in each of these areas and a statement of the limitations in the knowledge base addressed by this research plan.

Construction safety communication

Communication is defined as a pipeline where the information is transferred from one individual to another (Axley, 1984). Communication can be viewed as the process of transmitting both verbal and nonverbal messages between two or among many individuals and can include experiences, beliefs, and thoughts (Queralt, 1994). In a construction project, parties must develop two-way communication to meet objectives and respond to change. Poor communication at the crew level can result in improper reactions to the management decisions. It has been found that effective communication between managers and workers about project activities is an important driver of project success (Thamhain and Wilemon, 1986; Harper et al., 1997; Tan-Wilhelm et al., 2000). Additionally, Thamhain (1992) found the communication problems are one of the top five factors behind poor project performance.

In multicultural situations, communication difficulties may stem from the fact that individuals have different expectations of behavior, perceptions of the environment, understanding of information being communicated, and risk tolerances (Albert 1986). Consequently, the differences in cultural background among workers may create barriers to effective site safety. Nevertheless, effective safety communication is a vital element to maintain a high safety performance. Open discussion and frequent communication between employees and supervisors can be indicators that distinguish work crews with low accident rates from those with high rates (Smith et al., 1978; Zohar, 1980; Alsamadani et al., 2012). Additionally, effective supervisors discuss safety concerns with employees and provide immediate feedback about safety behavior and performance to those employees (Mattila et al. 1994).

Communication specialists have found that the language accounts for between 35% and 40% of all communication while the rest is non-verbal (Birdwhistell, 1970). In addition to speaking different languages, individuals from different cultures often have different non-verbal communication behaviors and patterns, which can create additional barriers. A lack of awareness of non-verbal communication enhances misunderstanding and fear in social and occupational settings (Baker et al. 1996; Guarnaccia and Rodriquez 1996). Therefore, it is very important to study non-verbal communication, particularly as it applies to safety.

Limitations in the body of knowledge and key points of departure

Although researchers have recently studied patterns in verbal safety communication, none have investigated this topic from the perspective of the workers. Additionally, there is a dearth of knowledge related to nonverbal communication. This study addresses this knowledge gap by exploring safety experiences of Hispanic workers and will include observations and perceptions of non-verbal safety communication. Focusing on Hispanic workers helps to address the practical issue of a trending increase in Hispanic workers in the US and a disproportionate injury rate for this group.

Communication challenges for Hispanic workers

During the last 15 years injury rates have been increasing for Hispanic workers (Lavy et al., 2010) while the overall injury rates have been decreasing (Center for Construction Research and Training 2013). There are many reasons that this phenomenon has occurred. For example, Jaselskis (2004) found the miscommunication between American and Hispanic employees has been proven to be one of the main causes of accidents in the construction sector. Along with the language barrier, difficulty of Hispanic workers in understanding English has been cited as a reason for inadvertent violations of safety rules and best practices (Loden and Rosener, 1991). Furthermore, Anderson et al. (2000) notes that, because most of the construction safety standards and programs are generally written and presented in English, Hispanic workers often do not receive safety information during training, on signs, or during ad hoc presentations. To address this issue, Sapir (2004) proposed that employers should provide Hispanic workers with an effective training program that is tailored to their language and other aspects of culture. Another recommendation is that Hispanic workers and supervisors should come up with common vocabulary and glossary (bilingual document) used on construction jobsites (Sanders, 2007).

Recent research has been conducted to better understand the role of language in safety-related knowledge exchange within small work crews in the US (Alsamadani et al. 2012; 2013). The studies revealed that unilingual work crews have safety performance that is 51% better than multilingual work crews (p-value = 0.10); bilingual workers play a more central role than unilingual workers when more than one language is spoken (p-value < 0.001); and managers play an important role in the exchange and diffusion of safety knowledge regardless of language proficiency (p-value < 0.001). Most importantly, SNA metrics show that these language boundary spanners often form the core of a network that connects disparate groups of individuals. On the other hand, crews with relatively weak safety performance tend to have clear and disparate sub-networks distinguished by language and high rates of turnover. Such characteristics are of concern because individual actors are not able to effectively warn one another of uncontrolled hazardous exposures or work in transition.

Limitations in the body of knowledge and key points of departure

Research on safety challenges for Hispanic workers is limited to knowledge of communication and signage, a form of non-verbal communication. Knowledge of other dimensions of safety culture such as values, perceptions, risk tolerance, personal values, and formation and role of interpersonal relationships is clearly needed. This study will be the first exploration of this topic, which will add rich knowledge that will help US contractors to better understand the culture of Hispanic workers and the role of this culture in site safety management.

Dimensions of Safety Culture

There is a wealth of research into the topic of safety culture. Although researchers are equivocal in the exact dimensions of safety culture, a comprehensive report published by MacAfee (2012) found the following common dimensions:

Patterns of behavior and norms - Safety culture requires a mutual relationship between psychological and behavioral factors focused on consistent behaviors and attitudes (Cooper, 2000). Provost and Sexton (2005) claim that behavioral norms are more important at the crew level than individual or organizational levels.

Shared values and beliefs- Shared values is a core safety culture dimension because it defines why a specific behavior is desired. Specifically, sharing beliefs about hazards has been shown to be an important element that drives positive safety culture at the organizational (Cooper, 2000), crew (Choudary et al., 2007), and worker levels (Guldenmund , 2000).

Risk tolerance- In order to have consistently strong adherence to safety protocol, it is important that workers accurately perceive and tolerate risk at acceptable levels (Guldenmund 2000). Such personal appreciation of risk is a main driver of behavior (Cox and Cheyne, 2000).

Management commitment- Chaudhry et al. (2007) considered several aspects of management commitment such as the allocation of time and resources toward safety risk assessment committee meetings. O'toole (2002) defined this dimension as the management's knowledge of safety issues, beliefs toward high safety standards, and established actions toward these goals.

Technical practices and risk assessment- Sawacha et al. (1999) and Chaudhry et al. (2007) identified that, in addition to soft skills, organizations must have robust methods to identify, analyze, and respond to safety risks. These include risk registers, job hazard analyses, protocols, and others.

Organizational structure- Is related to roles, responsibilities, and communication flows in which they have significant influence on safety performance (Sawach et al., 1999). Others linked this dimension to the relationship and the communication flows between management and employees.

Social practices and workers involvement- According to O'Toole (2000) employees must be involved in safety management activities, safety committees, rule-making, and investigations. Rather than a top-down approach, Mohammed (2003) suggests driving safety decisions from the bottom-up because it encourages adherence to and appreciation of safety protocol.

Competencies- This dimension is related to employees' general knowledge and abilities that are typically driven by training. Mearns and Flin (1999) and Cox and Cheyne (2000) considered competencies as a dimension of safety culture because they define a common knowledge within the organization upon which all employees draw.

Assumptions- Worker assumptions and expectations with respect to incentives and disincentives, instructions, competing objectives (e.g., productivity), and instructions are all important attributes of safety culture Guldenmund (2000).

Limitations in the body of knowledge and key points of departure

Although the domain of construction safety culture has reached maturity, the role and impact of the culture associated with specific ethnic groups (Hispanic) and interactions among ethnic groups (Hispanic and Caucasian) remains unknown. This is a clear issue for research need since anthropology research has shown that there are distinct and unique characteristics of Hispanic culture that have implications to the occupational environment. This study will investigate this important dimension of safety culture.

Aspects of Hispanic Culture

La Familia - Hispanics reflect an ethnically diverse population with race and color ranging from Black to Caucasian, variations which are due to the mixing of Spanish, Indian, African, and European people. Regardless of the national origins, Hispanics show a strong collectivism aspect that supports the family life. Previous studies reported the importance of the family as the most salient and empirically supported characteristic of the Hispanic culture. The fundamental aspect of the family consists of three or four generations of relatives and horizontal relationships among siblings, cousins, and other individuals who are considerably valuable on the daily and weekly interaction (Falicov 1999). This family relationship often extends to Hispanics who are not members of the immediate family but with whom a Hispanic person interacts frequently. Such relationships result in patterns of trust, communication, and even action that is different from the typical expectations of an all-Caucasian group. Mańin and Mańin (1991) have found Hispanics demonstrate a higher interaction frequency and attachment with their extended families. In addition, Hispanics of Mexican descent call their families for help, marital behaviors, friendships, and voting (Martinelli, 1993).

Personalismo - Another aspect of Hispanic culture with direct implications to the occupational environment, personalismo, which relates to personal dignity and worthiness. Personalismo focuses on the importance of the person and the inner qualities that formed the uniqueness of the person or worthiness, notwithstanding the gender or social status (Ramos-McKay et al. 1988). The level of Personalismo can influence the occurrence of truly free discussion and respect for individuals who hold different positions or with different levels of experience and expertise. Hispanics feel more comfortable and encourage developing respected, valued, warm, and friendly relationships, they expect to shake and hug the others in the context of informal interaction (Santiago-Rivera et al., 2002; and Paniagua, 1998). Another study by Gloria and Castellanos (2007) found that personalismo is a major factor interpersonal interaction in encouraging and supporting Hispanic students' achievements.

Job Perception - Smith et al. (2006) notes that Hispanic workers often consider themselves as primary supporters for their families; accordingly, they are highly engaged in self-exposure of dangerous work. Other studies have found that Hispanics concern about supporting not only their families but distant relatives as well (Sanders, 2007). As a result, Allen (1991) and others have established that foreign-born Hispanic workers have different values and perceptions toward work ethic, family, and loyalty. For instance, desperation and fear of obtaining a high salary job, inability to comprehend job policies, and apprehension of retribution can all be contributing factors for high fatality rates among Hispanic construction workers. Previous research has found that Hispanic workers believe managers or authorities are not questionable, even if they are ruling wrong or unsafe works (Stakes 2006). Such beliefs can have significant impacts on the behavior of Hispanic workers.

Limitations in the body of knowledge and key points of departure

As noted, there is no literature that has directly investigated the relationship between specific aspects of Hispanic culture on safety within an organization, despite the fact that these deeply embedded characteristics have powerful implications for safety. Perhaps even more importantly, research is needed to investigate the interactions among ethnic cultures and the impact on safety perception, comprehension, collaboration, and behavior. This study directly addresses these knowledge gaps through a comprehensive and internally validated investigation of the relationship among cultures and construction safety.

WORK PLAN

Phase I: Exploratory Interviews

Research goals

The primary goal of this phase is to identify cultural barriers faced by Hispanic workers that will be used as prompts for deep investigations in the subsequent phase. Cultural interpretation can be shaped through a holistic perspective, contextualization, and non-judgmental views of reality. In this phase, attention will be paid to the emic (e.g. how participants imagine and explain things) perspective since this phase is exploratory. This method will focus on participants' perspective of reality to describe existing situations and behaviors. With emic perspective, we expect to recognize and accept multiple realities that are important to understand why people act and think in the different ways during field work. In addition to our primary aim, we will also seek to determine the relationship between those challenges and Hispanic cultural aspects such as job-perception, *LaFamilia and Personalismo*.

Number of interviews

Sampling in this exploratory research is different from sampling in typical research design. The focus in a pseudo-ethnographic approach is on generating themes, categories, or theories about specific group of people. Previous interview studies similar in structure to ours have had a sample size ranged from 30 to 50 interviewees (Morse, 1994; and Bernard, 2000). Therefore, the intention in this phase is to conduct the ethnographic interview study with at least a total of 30 Hispanic and 10 non-Hispanic construction workers in Denver Metropolitan area.

Interview protocol

We must first gain an entry or access to the participants and build cooperation and trust by establishing interpersonal relationships (Berg, 1998). Previous researchers experienced challenges with bridging relationships and trust between researchers and participants. Two approaches can be considered to build a trust between researchers and participants. First, having a social identity as a member of participant group is important. To address this, we will ensure that the student conducting the research is Hispanic and has had some construction field experience. This will instill a sense that researchers have credibility and knowledge in the interview (Hogg and Terry, 2000). Secondly, an experienced Hispanic student will ensure that the researcher is not rejected culturally by the participants (Wolf, 1991). Another study by Whyte (1984) suggested the researcher to find a common characteristic with participants to overcome any difficulty in bridging the relationship with them; for example, learning to speak Spanish language proficiently (See figure 2.)

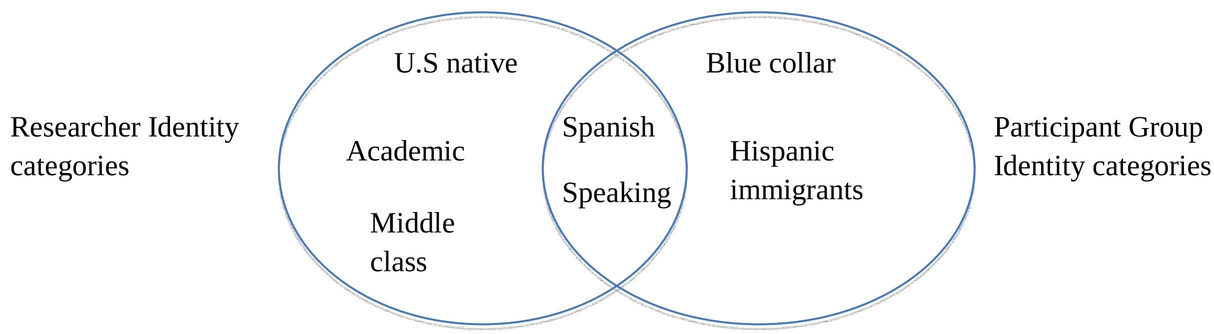

Figure 2. Matching of researcher and participant characteristics approach.

The key to effective pseudo-ethnographic interviews is to establish a series of friendly easygoing conversation that allow the researcher to introduce their questions naturally and assist the participants in their response. Such conversation can be viewed through the greeting (e.g. “Hi, “It’s good to see you”, and clear goals and objective of the interview (e.g. “Let’s talk about the challenges of working with non-Hispanic group of workers”). If there is a lack of clear goals or objectives, participants often attempt to change the subject, end the conversation, or simply satiate the interviewer. Furthermore, we will avoid repetition and questions about other persons. Alternatively, expressing interest and taking turns helps to establish friendly conversation. Additionally, leaving the conversation in a positive note that shows the participant the positive impact that they have made and the importance of their participation. For example, interviews may end with statements like “you did a great job today and thank you for your help” (Spradley 1979).

Designing interview questions (open-ended vs. close ended)

It has been found that asking open-ended questions is preferred, especially if the researchers seek a full expression and opinion from the participants. Unlike close-ended questions, open-ended questions have no suggested answers, which means the participants can answer the questions in their own words instead of merely obligated to select an answer from a predetermined set of responses (Foddy, 1993). Further, open-ended questions approach is appropriate if the researchers are looking for qualitative instead of quantitative information or provided text responses. We will employ open-ended questions because we believe that there is more to be explained than can be assumed from the current knowledge base.

Data collection

We will start by contacting representatives from ongoing building construction projects in the Denver Metropolitan area. Before administrating interview, we will discuss the objectives of study and the interview protocol with prospective participants, the safety manager, and the superintendent. Since this study deals with humans subjects, each participant will be asked to provide informed consent. Once the introduction is provided, our bilingual research team will interview participants individually. To ensure that all details are captured, our team of at least two researchers will take notes. When allowed, we will record the interview.

Data analysis

First, a proficient Spanish speaker will help the research team to transcribe all tape recording and notes in English. The team then will use NVIVO queries to automatically code sources based on the words or phrases they contain. The first analytical step will be to record all responses with the assistance of at least one other coder to minimize biases. Second, the reviewers will develop categories of responses. For example, if the question that directed to the safety manager about suggestions on ways to enhance Hispanics' effective safety communication, the categories might include something like "open and clear discussion" or "employ a lesson-learned safety program." The third step is labeling each response with one or a number of categories (e.g., coding). The best way to accomplish this step is in an excel sheet by sorting all responses in one column and category(s) that developed from the previous step.

In the fourth step the research team will break the data into specific subcategories. For instance, "open and clear discussion" could be under "socializing with others". Or, "employ a lesson-learned safety program" and "immediate feedback and correction" could be both under "action needed at workplace." Once coded, responses and refined the categories can be analyzed using relative frequencies. Finally, the fifth step will be to identify the patterns and trends and determine what patterns in responses have emerged within and among question responses for the respondents representing the three organizational levels.

Phase II: Targeted Interviews with Photovoice

We expect that the initial interviews will yield a robust list of cultural barriers that can be investigated in greater detail. The goal of the second phase will be to use photovoice to understand the details associated with each barrier, including the context in which they exist and their relationships to other cultural or organizational characteristics.

Overview of Photovoice

Photovoice was originally created by Wang and Burris (1997) and has been applied in many research studies that engaged society in community-based participatory research (CBPR). The fundamental characteristic of this technique is that the participants are asked to take photos related to the theme and then discuss, in detail, the specifics associated with their photographs. Photovoice is usually conducted with a group of people with limited power due to language proficiency, race, social economic status, ethnicity, gender, or other aspects (Wang and Burris 1997). It is a method of self-directed interviews that are particularly beneficial for underserved groups.

Wang (1999) argued that the photovoice discussion between the researcher and the participants builds a deep understanding of how society and policies affect the motivations, decisions, and actions of the participants. Photovoice can be used as qualitative research method, in particular as an assessment tool in cases such as changing a group of people's opinions about themselves, publicizing the group's situation and problem, assessing the community's activities, and evaluating an intervention program (Freedman et al. 2013).

Similar technique called photo elicitation, which was found by the photographer and researcher John Collier in 1957, proposed using picture interview as the solution to existing issues. Unlike the Photovoice technique, researchers of photo elicitation in cultural studies take photographs of a group of individuals doing their normal activities. After that, interview those individuals to define how they interpret the activities depicted in the pictures (Curry and Strauss 1986; Snyder and Ammons 1993).

Application of Photovoice

Although photovoice has yet to be used in construction research, the technique has been successfully implemented and validated in other fields. For example, researchers in the healthcare industry have used photovoice to investigate youth-driven substance abuse (Brazg et al. 2010); HIV in rural African American communities (Corbie-Smith et al. 2010); the risk of sexual transmitted diseases among African American, Latino, and Caucasian homosexual men (Rhodes et al. 2011); unemployment behavior of individuals with HIV/AIDS (Hergenrather et al. 2006); understanding health issues in rural Guatemala (Cooper and Yarbrough, 2010); identifying and exploring community health and disability priorities (Hergenrather et al. 2009); and clinical nutrition and dietetic scheme (Martin et al. 2010). The results were used to inform policy makers who made subsequent changes to health promotion strategy.

Photovoice has also been employed broadly to study: factors influencing elementary school student behavior including attendance, citizenship, pre-requisite skills, and social changes (Claudia et al. 2006); the impact of cultural diversity on social life of the Latino community in North Carolina (Streng et al. 2004); and the influence of support-learning projects for mothers with learning disabilities in the U.K (Booth and Booth 2003). In only one study in the occupational safety and health domain photovoice was used to evaluate health and safety hazards for custodians (Flum et al. 2010)

Selection of Photovoice for this Study

Photovoice is not a widely used approach in construction engineering and management research and, to our knowledge, has not been utilized in any construction safety research study. With a steady growing population of Hispanic construction workers in the US, safety related issues for these individuals are becoming increasingly important, especially in multicultural construction organizations (Alsamadani et al. 2012). We believe that Photovoice will allow us to explore safety-related challenges that Hispanic workers face by studying them within context and from the perspective of the workers. This technique is especially effective because it does not impose prior assumptions with the selection of interview questions; rather, participants direct the conversation through the photographs that they take based on very general prompts.

Photovoice will be used to validate the findings from the first phase and to obtain deep and rich examples of safety challenges from the perspective of the workers. Photovoice will enable workers to express their experiences and perceptions with both words and images. Unlike other social science research methods, Photovoice incorporates creativity, fun, and collaboration in a way that encourages participation. For example, in the past, Photovoice gave an opportunity to low-income women in Winnipeg, Manitoba and Saskatoon, Saskatchewan to express ideas about poverty and public policy in words and images. The women as a result were able to raise awareness of the realities of living in poverty and prompt actions to improve the conditions of women's lives in these areas (Palibroda et al., 2009).

Size of Photovoice group or participants

Determining the sample size needed in a photovoice study depends on the timeline, goals, budget, and availability and accessibility of participants. Although several Photovoice research studies had a group size that ranged from 10 to 242 participants (see Table 1), a group of 10 to 20 Photovoice participants has been found as adequate for a homogenous sample (Wang 1999). In order to study various crew structures, crew sizes, geographic locations, and other demographics, the size of the photovoice sample must increase proportionally with a stratified sampling method. This group size allows participants to feel safe to share and take part in discussions. A group of 10 to 20 individuals is proper for this study where we expect to have only two to three bilingual facilitators. A smaller group will help to ensure that individuals feel listened to and are responded to in a sensitive and respectful way. In this proposal, the researchers aim to study six different groups from three different trades working on an ongoing building construction project in Denver metropolitan area. Additionally, the researchers will conduct the study only on multi cultural groups (Hispanic and non-Hispanic) where the Hispanic participants must have a minimum of six years work experience in the construction industry in the US since more than 50% of immigrant construction workers entered the US between 1995 and 2007 (CPWR 2013). This rule will ensure that Hispanic participants have sufficient knowledge and experience about the issue that needs to be addressed.

Table 1 Photovoice group size from previous studies

Authors	Number of participants in each group
Booth and Booth, 2003	16
Streng *et al.*, 2004	10
Wang *et al.*, 2004	41
Hergenrather *et al.*, 2006	11
Flum *et al.*, 2010	66
Brazg *et al*., 2011	170

Photovoice Protocol

There are several methods that have been used to conduct a Photovoice. Palibroda et al. (2009) and Wang (1999) suggested seven step process (see figure 3), which help to accomplish research objectives similar to those stated in this proposal. We will follow this protocol.

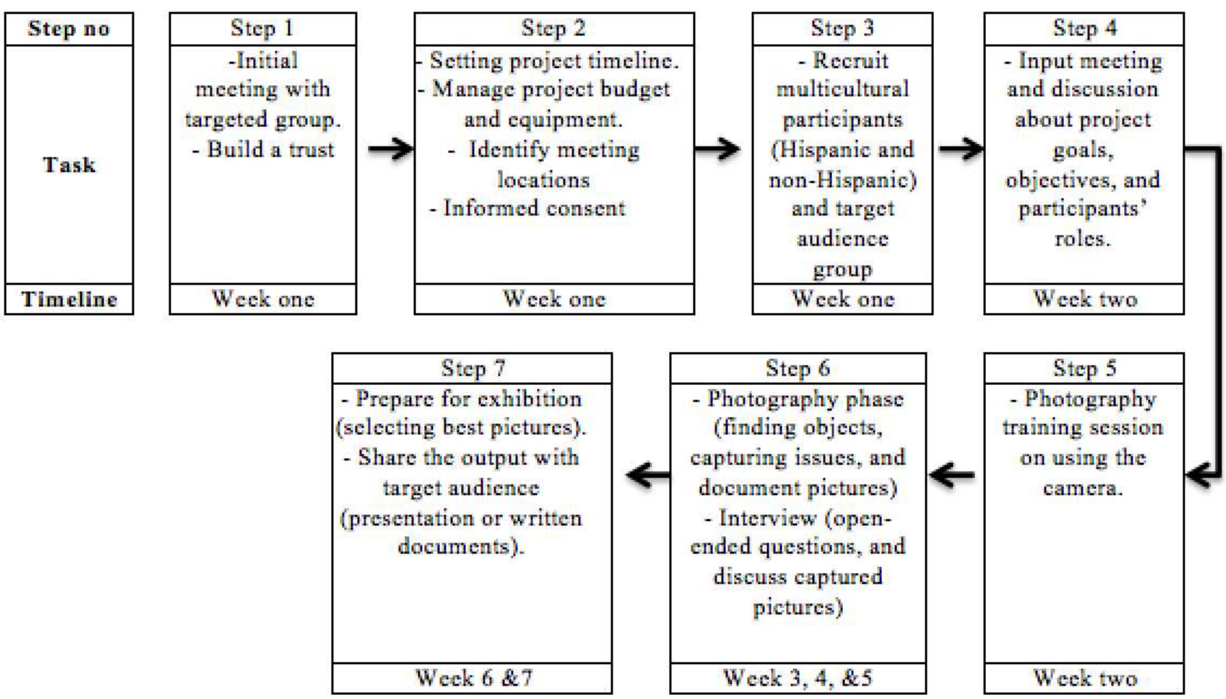

Figure 3 - Photovoice main steps

Step 1: Connecting and consulting with the community or targeted group

A community may initially feel hesitant to participate in this study. To overcome this issue, we will build trust with each crew by explaining the goals of the study, explaining the Photovoice process, informing them of the positive impact that they can have on others, and informing them of their rights to confidentiality. We will also implement the aforementioned methods of trust building. Building a strong relationship between the community and researchers is vital to obtaining complete, valid, and unbiased results.

Step 2: Planning for a Photovoice project

Once the community members are informed about Photovoice and trust has been built, the project details will be established. Planning includes setting a project timeline, managing the budget and equipment, and specifying a location for meetings. It is important for the Photovoice facilitator to consider possible logistical and cultural barriers that may arise. For example, to minimize potential cultural barriers, the primary researcher for this study will be a Hispanic student with construction and safety knowledge. Our facilitator will work with participants to overcome challenges.

To manage the project budget effectively, we will purchase bulk disposable cameras, which cost approximately $7.00 each. Pictures can be printed and converted to digital images for approximately $3.00 per roll. Thus, we will budget for $10.00 per participant, with a total expected cost of approximately $1,500. This cost is very low compared to the expected benefits.

Similar to other human subject's research, Photovoice must conform to ethical guidelines that offers significant benefits and ensures the participants or individuals are not harmed. We will obtain an institutional review board (IRB) certificate prior to conducting any research. Specifically, we will ensure that participants are fully informed and consent is obtained. As noted by Wang and Redwood-Jones (2001), the act of taking photographs of human subjects will require that all individuals who may be photographed to also provide informed consent. Additionally, depending on the site characteristics, the facilitator may also need to obtain safety training and certification. To address this requirement and to show participants commitment to the project, the student researcher will participate in safety training and planning meetings whenever feasible.

Step 3: Recruiting participants

Recruiting participants and target audience groups is a fundamental part of the Photovoice process. The recruiting process will be on a volunteer basis and based contacts with industry professionals. We will build a diverse group with members from different cultural backgrounds and life experiences to acquire a broad perspective. Further, we will ensure that participants have first-hand knowledge and experience about the issue that needs to be addressed. For example, non-Hispanic workers must have been or currently are members of a multi-cultural crew with Hispanic members. Participants will also be informed that the project may need a long-term commitment and they should be enthusiastic and willing to work as a group. Although the interviews will be conducted with individuals, groups will be targeted to form holistic models of the crew dynamics.

Step 4: Input meeting and discussion (project timeline, rules, goals, objectives)

Since Photovoice involves many participants and frequent meetings, it’s important to be well organized. At the initial stage the project timeline will be finalized with specific dates and duration for each step and meeting. This will be done with input from participants and project managers and will be sensitive to the project schedule. During this input meeting we will also establish guidelines and rules for the Photovoice group. As suggested by Wang (1999) we will:

a- Establish the photographers’ role as experts;

b- Discuss importance of informing each other about the community issues; and

c- Discuss the potential of influencing the public policy or policy makers.

The benefit of this step is to allow the group members to ask questions, share concerns and ideas, understand the research and project goals, aware of possible risks, and understand the possible outcomes before the formal process begins.

Although our goal is for all participants to continue with the project to the last day, we recognize the potential for attrition. This initial step helps to minimize attrition as it establishes clear project goals that the participants help shape and also establishes the participants as subject matter experts who are critical to the success of the project.

Step 5: Photography training and practice

During the group meetings, a knowledgeable photographer will conduct basic photography training. In this introductory session, we will provide instruction on how to use the camera and best practices that encourage self-expression and creativity. The research team will ensure all participants are using the same kind of camera to have consistency in the photographic quality. Before starting the Photovoice phase, it is a good idea to discuss with participants the issues of concern that have been selected from the exploratory interview phase. Some participants can be unsure about what exactly to capture; therefore, a professional photographers are highly recommended to be involved in the pre-photography discussion. Participants can learn from them how to use the camera to represent their ideas and symbolic experiences. This discussion is intended to prompt the participants to take better pictures that express the strengths and the addressed issues from the interview phase.

Step 6: Photography phase and interview

Once the instructions have been given, the photovoice phase will begin. Each participant will be asked to capture a maximum of 25 pictures (Flum et al., 2010). Once all participants done with capturing their 25 pictures, we will immediately process the film and prepare hard copies of all pictures for further discussion in the next meeting. In order to simplify the data analysis process, we will ask each participant to pick between 6 and 10 most significant pictures. This approach will help also to eliminate duplicate pictures (Flum et al., 2010).

Once the photos have been taken, we will ask the participants to answer a set of questions called "*SHOWeD*" for each selected picture (see figure 4). *SHOWeD*, developed by Wang and Burris (1997), has been used in different previous Photovoice research. For this project, the questions were slightly modified for the purposes. In addition to the interview questions, the participants may write captions to the selected pictures to explain why they chose the subject, their purpose, how they feel about the pictures, and the connections between the pictures and workplace or community issues. This will give an opportunity to the participants to clarify the meaning of their pictures and perceptions of issues and concerns within their organizations. Through the regular meetings, all participants will have an opportunity to share and look at others' pictures.

There are three important aspects of this process (Wang and Burris, 1997):

a- Selecting photographs (pictures): this process allows the participants to choose pictures that they think reflect their safety strength and struggles. They are asked to choose the best pictures that can be evidence and representative of their experiences;

b- Contextualization: through a dialogue with other participants and Photovoice research team, the individuals are assumed to deliver their voice and tell stories about what pictures mean to them; and

c- Codifying: this process allows the research team and Photovoice facilitators identify and sort data into categories of issues, themes, or theories. For example, when examining the issue of Hispanic workers and language barrier, themes that may arise include reachability to upper level managers, or availability of signs written in Spanish.

Once the data have been collected, we will conduct a thematic analysis considering all "*SHOWeD*" responses, captions, and facilitators' field notes. A draft summary report then will be generated in collaboration with participant that reports the salient themes. The final step in the analysis is to present the summary report that includes themes, pictures, captions, and notes to the participants for final approval. This final report can be then used as a tool for exhibition and sharing session with target audience and policy makers.

"*SHOWeD*" form

Participant name: ____
Title of picture: ____
Description of picture : ____

S	Describe what do you **S**ee here?
H	What is actually **H**appening here? (Describe what is the unseen story behind the picture?"
O	What does this picture tell us about your **O**rganization?
W	**W**hy does this issue or challenge exist?
e	How could this picture **E**ducate people or the audience?
D	What changes can we **D**o about it?

Figure 4 - "*SHOWeD*" form

Step 7: Photovoice sharing and exhibition

During the data analysis step, participants will have decided which photographs they would like include in the exhibit. Also, they will have approved captions and written for each photo. In the exhibition, photographs and captions will be enlarged and mounted for visual display. We will ensure that the elements of the display offer compelling results to inform and educate audiences.

Depending on the target audience, there will be different goals of sharing Photovoice findings. For instance, sharing photographs can offer a true version of experience that can capture attention and support toward existing issues. Further, sharing and exhibition may address and bring attention about specific policy and lead decision makers to change that policy.

INTELLECTUAL CONTRIBUTIONS

The primary contribution of this study is a rich understanding of the cultural and intercultural factors that affect the safety of Hispanic construction workers in the US. Although past research has provided theoretical models and proposed barriers, this study will investigate deeply from the perspective of the workers. Additionally, this study introduces a new method to construction engineering and management research, photovoice. Photovoice has advantages over other types of assessment because it allows subjects not to assess the issues and concerns and gives them an opportunity to define potential solutions (Wang and Pies, 2008). In construction, Photovoice contributes positively as a tool to increase the individuals’ understanding and awareness of their strengths and struggles. Also, Photovoice arms the community or the organization with good information and willingness to inform others with passion to improve the existing situation for better work environment.

PRACTICAL CONTRIBUTIONS

Understanding the challenges faced by Hispanic workers is an incredibly important aspect of managing crews in regions of the US with diverse populations. For example, according to the Pew Research Center (2012) over 30% of construction workers in Colorado are Hispanic and the vast majority work in multilingual work crews. Thus, understanding the barriers that they face and their perceptions of safety culture will help managers to better relate to their workforce, better target safety programs to address cultural challenges, and acknowledge personal difficulties that some disadvantaged workers may face. Consequently, this research has the potential to positively benefit over 1 million Hispanic construction workers in the US, who are currently injured and killed at a disproportionate rate.

REFERENCES

Albert, R.D. (1986). “Communication and attributional difference between Hispanics and Anglo-Americans.” In Y.Y. Kim(Ed.), *International and intercultural communication annual, Vol. X. Interethnic communication: Current research* (pp. 42-59). Beverly Hills, CA: Sage.

Allen, G. (1991). “Valuing cultural diversity, industry woos a new workforce.” *Communication World*, 8(6), 14–17.

Alsamadani, R., Hallowell, M., and Javernick-Will, A. (2012). “Measuring and modeling safety communication in small work crews in the US suing social network analysis.” *Construction Management and Economic,* **31(6): 568-579**

Alsamadani, R., Hallowell, M., Javernick-Will, A., and Cabello, J. (2013). "Relationship among language proficiency, communication patterns, and safety performance in small work crews in the US." *Journal of Construction Engineering and Management,* 139(9): 1125-1134.

Anderson, J. T., Hunting, K. L., and Welch, L. S. (2000). "Injury and employment patterns among Hispanic construction worker." *Journal of Occupational Environmental Medicine,* 42, 176-186.

Anschuetz, L., and Rosenbaum, S. (2003). "Ethnographic interviews guide design of Ford vehicles website." *The Association for Computing Machinery.*

Axley, S. (1984). "Managerial and organizational communication in terms of the conduit metaphor." *Academy of Management Review,* 9, 428-437.

Baker, D., Parker, R. M., Williams, M. V., Coates, W. C., and Pitkins, K. (1996). "Use and effectiveness of interpreters in an emergency department." *Journal of the American Medical Association,* 275(10), 783-789.

Bernard, H. R. (2000). *Social Research Methods*. Thousand Oaks, CA: Sage.

Berg, B. 1998. *Qualitative research methods for the social sciences*. Boston: Allyn and Bacon.

Birdwhistell, R. L. (1970). *Kinesics and context.* Philadelphia, PA: University of Pennsylvania Press.

Booth, T., Booth, W. (2003). "In the frame: Photovoice and mothers with learning difficulties." *Disability and Society,* 18(4), 431-442.

Brazg, T., Bekemeier, B., Spigner, C., and Huebner, C. E. (2011). “Our community in focus: the use of Photovoice for youth-driven substance abuse assessment and health promotion.” *Health Promotion Practice*, 12(4), 502-511.

Carlson, E. D., Engebreston, J., and Chamberlin, R. M. (2006). “Photovoice as a social process of critical consciooesness.” *Qualitative Health Research*, 16(6), 836-852.

Castellanos, J., & Gloria, A. M. (2007). “Research considerations and theoretical application for best practices in higher education: Latina/os achieving success. *Journal of Hispanic Higher Education*, 6, 378-396

Claudia, M., Jean, S., Relebohile, M., and Callistus Bheka, N. (2006). “Why we don’t go to school on Friday: on youth participation through photo voice in rural KwaZulu-Natal.” *McGill Journal of Education*, 41(3), 267-282.

Cooper, C. M., and Yarbrough. S. P. (2010). “Tell me—show me: using combined focus group and Photovoice methods to gain understanding of health issues in rural Guatemala.” *Qualitative Health Research*, 20(5), 644-653.

Cooper, M.D. (2000). “Towards a model of safety culture.” *Safety Science* 36, 111–136.

Corbie-Smith, G., Adimora, A. A., Youmans, S., Muhammad, M., Blumenthal, C., Ellison, A., Akers, A., Council, B., Thigpen, Y., Wynn, M., and Lioyd. S. W. (2011). “Project grace: a strategy approach to development of a community-academic partnership to address HIV in rural African American communities.” *Health Promotion Practice*, 12(2), 293-302.

Cordeiro, P. A., and Carspecken, P. F. (2006). “How minority of the minority succeed: a case study of twenty Hispanic achievers.” *International Journal of Qualitative Studies in Education*, 6(4), 277-290.

Cox, S.J., Cheyne, A.J. (2000). “Assessing safety culture in offshore environment.” *Safety Science* 34, 111-129.

CPWR - The Center for Construction Research and Training. (2007). Construction Chart Book the U.S. Construction Industry and its Workers. 4th ed. Silver Spring, MD: CPWR - The Center for Construction Research and Training.

CPWR - The Center for Construction Research and Training. (2013). Construction Chart Book the U.S. Construction Industry and its Workers.54th ed. Silver Spring, MD: CPWR - The Center for Construction Research and Training.

Curry, T. J., and Strauss, R. (1986). “A little pain never hurt anybody: a photo-essay on the normalization of sport injuries.” *Sociology of Sport Journal*, 11(2): 192-208.

Dickie, V. A. (2003). “Establishing worker indintity: a study of people in craft work.” *American Journal of Occupational Therapy*, 57(3), 250-261.

Dongping, F., Yang, C., & Wong, L. (2006). “Safety climate in construction industry: A case study in Hong Kong.” . *Journal of Construction Engineering & Management, 132*(6), 573-584.

Elwood, W. N., Dayton, C. A., and Richard, A. J. (1995). “Ethnography and illegal drug users: the efficacy of outreach as HIV prevention.” *Communication Studies*, 46(3-4), 261-275.

Falicov, C.J. (1999). *Latino families in therapy: A guide to multicultural practice*. New York: Guilford Press.

Fetterman, D. M. (2010). Ethnography: step by step. Thousand Oaks, CA: Sage Publications.

Flum, M. R., Siqueira, C. E., DeCaro, A., and Redway, S. (2010). "Photovoice in the workplace: a participatory method to give voice to workers to identify health and safety hazards and promote workplace change, a study of university custodians." *American Journal of Industrial Medicine*, 53(11), 1150-1158.

Foddy, W. (1993). "Constructing questions for interviews and questionnaires: theory and practice in social research." Cambridge: Cambridge University Press.

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

Guarnaccia, P., and Rodriguez, O. (1996). "Concepts of culture and their role in the development of culturally competent mental health services." *Hispanic Journal of Behavioral Science*, 18(4), 419-443.

Hallowell, M. R., & Gambatese, J. A. (2009). "Construction safety risk mitigation." *Journal of Construction Engineering & Management, 135*(12), 1316- 1323.

Hammersly, M. & Atkinson, P. (2007), Ethnography: Principles in Practice (3rd ed). London: Routledge

Harper, A. C., Cordery, J. L., de Klerk, N. H., Sevastos, P., Geelhoed, E., Gunson, C., Robinson, L., Sutherland, M., Osborn, D., and Colquhoun, J. (19979). "Curtin industrial safety trial: managerial behavior and program effectiveness." *Safety Science*, 24, 173-179.

Hergenrather, K. C., Rhodes, S. D., and Clark, G. (2006). "Windows to work: exploring employment-seeking behaviors of persons with HIV/AIDS through Photovoice." *AIDS Education and Prevention*, 18(3), 242-258.

Hergenrather, K. C., Rhodes, S. D., Cowan, C. A., Bardhoshi, G., and Pula, S. (2009). "Photovoice as community-based participatory research: a qualitative review." *American Journal of Health Behavior*, 33(6), 686-698.

Hogg, M., and Terry, D. (2000). "Social identity and self-categorization processes in organizational contexts." *Academy of Management Review (*25),121-40.

Houst, R. J., Hanges, P. J., Javidan, M., Dorfman, P. W., and Gupta, V. (2004). *Culture, Leadership, and Organizations.* Sage

Jaselskis, E. (2004). Developing an effective construction training program for Hispanic supervisors and craft workers, Center for Transportation Research and Education (CTRE)— Project 03-132, Iowa State University Report.

Johnson, J. 1975. *Doing field research*. Free Press: New York.

Keyton, J., and Shockley-Zalabak, P. (2006). Case studies for organizational communication: Understanding communication processes (2nd ed.). Los Angeles, CA: Roxbury.

La Belle, T. J. (1982). "Formal, nonformal and informal education: a holistic perspective on lifelong learning." *International Review of Education*, 28(2), 159-175.

Larkey, L. K., Hecht, M. L., Miller, K., and Alatorre, C. (2001). "Hispanic cultural norms for health-seeking behaviors in the face of symptoms." *Health Education Behavior*, 28(1), 65-80.

Lavy, S., Aggarwal, C., and Porwal, V. (2010). "Fatalities of Hispanic workers: safety initiatives taken by U.S. construction companies to address linguistic and cultural issues." *International Journal of Construction Education and Research*, 6(4), 271-284.

LeCompte, M. D. (2002). "The transformation of ethnographic practices: past and current challenges." *Qualitative Research*, 2(3), 283-299.

LeCompte, M.D., & Schensul, J.J. (1999). *Designing and conducting ethnographic research.* Walnut Creek, CA: AltaMira.

Lett, J. (1990). Emics and etics: Notes on the epistemology of anthropology. In T.N. Headland, K.L. Pike, & M.

Levin, B. (1993). English verb classes and alternations: A preliminary investigation. Chicago, IL: University of Chicago Press.

Loden, M. & Rosener, J. B. (1991). Workforce America: Managing employee diversity as a vital resource. New York, NY: McGraw-Hill.

Mar´ın, G. & Mar´ın, B. V. (1991). Research with Hispanic populations. Newbury Park,

CA: Sage.

Martinelli, P. C. (1993). Mexican American identity: An interdisciplinary approach. In

M. E. Bernal & P. C. Martinelli (Eds.), Mexican American identity (pp. 19-31).

Martin, N., Garcia, A. C., and Leipert, B. (2010). “Photovoice and its potential use in nutrition and dietetic research.” *Canadian Journal of Dietetic Practice and Research*, 71(2), 93-97.

Matilla, M., Hyttinen, M. and Rantanen, E. (1994). “Effective supervisory behavior and safety at building site.” *International Journal of Industrial Ergonomic*, 13, 85-93.

Maton, K. I. (1993). “A bridge between cultures: linked ethnographic-empirical methodology for culture anchored research.” *American Journal of Community Psychology,* 21(6), 747-773.

May, S. K. (Ed.). (2006). Cases in organizational communication: Ethical perspective and practices. Thousand Oaks, CA: Sage.

Mearns, K., Flin, R. (1999). “Assessing the state of organizational safety- culture or climate?” *Current Psychology*, 18 (1) , 5-17.

Morse, J. M. (1994). Designing funded qualitative research. *Handbook of qualitative research* (2nd ed., pp.220-35). Thousand Oaks, CA: Sage.

Nail, L. (2002). “Illuminating problems, defining processes, and improving outcomes: the essence of oncology nursing research.” *Oncology Nursing Forum,* 29(6), 941-947.

O’Connor, T. (2002). Reaching Spanish-speaking workers and employers with occupational safety and health information, National Council for Occupational Safety and Health, Washington, DC: National Academy of Science.

O'Toole, M. (2002). "The relationship between employees' perceptions of safety and organizational culture." *Journal of Safety Research*, 33, 231–243.

Office of Management and Budget. (1997). "Revisions to the Standards for the Classification of Federal Data on Race and Ethnicity." http://www.Caucasianhouse.gov/omb/fedreg_1997standards.

Palibroda, B., Krieg, B., Murdock, L., and Havelock, J. (2009). "A practical guide to Photovoice: sharing pictures, telling stories and changing communities." *Prairie Women's Health Network.* Winnipeg, MB.

Paniagua, F.A. (1998). Assessing and treating culturally diverse clients (2nd ed.).

Thousand Oks, CA: Sage.

Parrado, E. A., McQuiston, C., and Flippen, C. A. (2005). "Participatory survey research: integrating community collaboration and quantitative methods for the study of gender and HIV risks amon Hispanic Migrants." *Sociological Methods and Research*, 2(34), 204-239.

Pew Hispanic Center. (2012). The Demographics of the Jobs Recovery. Washington, Dc. Retrieved June 24, 2012, from http://www.pewhispanic.org/files/2012/03/PHC-Labor-report-FINAL_3-21-12.pdf

Pronovost, P., Sexton, B. (2005) "Assessing safety culture: guidelines and recommendations." BMJ Quality & Safety 14, 231-233.

Freedman, D., Pitner, R., Power, M. C. F., and Anderson, T. P. (2013). "Using photovoice to devlope a grounded theory of socio-environmental attributes influencing the health of community environments." *The British Journal of Social Work*, 43(2), 1-21.

Grahame, P. R. (1998). "Ethnography, institutions, and social organization of knowledge, *Human Studies*, 21, 347-360.

Queralt, M. (1996). *The social environment and human behavior. A diversity perspective*. Needham Heights, MA: Allyn & Bacon.

Ramos-McKay, J.M., Comaz-Díaz, L. & Rivera, L.A. (1988). Puerto Ricans. In L. Comas-Díaz, L & Griffith, E.E.H. (Eds.), *Clinical guidelines in cross-cultural mental health* (pp. 204-232). New York: John Wiley & Sons.

Rhodes, S.D., Hergenrather, K. C., Vissman, A. T., Stowers, J., Davis, A. B., Hannah, A., Alonzo, J., and Marsiglia, F. F. (2011). "Boys must be men, and men must have sex with women: a quantitative CBPR study to explore sexual risk among African American, Latino, and Caucasian gay and MSM." *American Journal of Men Health*, 5(2), 140-151.

Sanders, S. S. (2007). Hispanic workers safety: understanding culture improves training and prevents fatalities. Professional Safety, 52(2), 34–40.

Santiago-Rivera, A. L., Arredondo, P., and Gallardo-Cooper, M. (2002). Counseling Latinos and la familia: A practical guide. Thousand Oaks, CA: Sage Publications.

Sapir, E. (2004). An Introduction to The Study of Speech. Mineola, NY: Dover Publication.

Smith, D. E. (1999). Writing the social: theory, critique, and investigation. Toronto: University of Toronto Press.

Smith, D. E. (2006). Institutional Ethnography as Practice. Rowman and Littlefield Publishers, Inc.

Smith, M. J., Cohen, H. H., Cohen, A. (1978). "Characteristics of a successful safety program." *Journal of Safety Research*, 10, 5-15.

Smith, S. M., Perry, T., & Moyer, D. (2006). Creating a safer workplace. Professional Safety,

51(12), 20–25.

Snyder, E. E., and Ammons, R. (1993). " Baseball's emotion work: getting psyched to play." *Qualitative Sociology*, 16(2): 111-132.

Spradley, J. P. (1979). The ethnographic interview. New York: Holt, Rinehart & Winston.

Stakes, V. (2006). Bridging the safety gap with Hispanic workers. Contractor Magazine, 53(9), 30–94.

Streng, J., Rhodes, S., Ayala. G., Eng, E., Arceo, R., and Phipps, S. (2004). "Realidad Latina: Latino adolescents, their school, and university use Photovoice to examine and address influence of immigration." *Journal of Interprofessional Studies*, 18(4), 403-415.

Sypher, B. D. (1997). Case studies in organizational communication 2. New York, NY: Guilford.

Tan-Wilhelm, D., Witte, K., Liu, W. Y., Newman, L. S., Jansen, A., Ellison, C., Yancey, A., Sanderson, W., and Henneberger, P. K. (2000). "Impact of a worker notification program:

assessment of attitudinal and behavioral outcomes." *American Journal of Industrial Medicine.* 37, 205-213.

Thamhain, H. J., (1992). *Engineering Management managing Effectively in Technology-Based Organizations.* John Wiley and Sons, Inc., New York, N.Y.

Thamhain, H. J., and Wilemon, D. L. (1986). "Criteria for controlling project according to plan." *Project Management Journal*, (2), 75-81.

Torres, J. B. (2008). "Communication patterns and direct social work practice with Latinos in the U.S." *Journal of Human Behavior in the Social Environment.* 3(2), 23-42.

US Bureau of Labor Statistics. (2011). Hispanic Population of the United States. BLS Washington, DC, available at http://stats.bls.gov/news.release/pdf/osh.pdf.

Wang, C. (1999). "A participatory action research strategy applied to women's health." *Journal of Women's Health*, 8(2), 185-192.

Wang, C. 2003. "Using Photovoice as a participatory assessment and issue selection tool: A case study with the homeless in Ann Arbor." In M. Minkler and H. Wallerstein. Eds. *Commu- nity-based participatory action research for health*. San Fran- cisco: Jossey-Bass.

Wang, C., Morrel-Samuels, S., Hutchison, P., Bell, L., and Pestronk, R. M. (2004). "Flint Photovoice: community-building among youth, adults, and policy makers." *American Journal of Public Health*, 94(6), 911-913.

Wang, C., and Burris, M. A. (1997). "Photovoice: Concept, methodology, and use for participatory needs assessment." *Health Education & Behavior*, 24 (3), 369-387.

Wang, C., and Pies, C. A. (2008). Using Photovoice for participatory assessment and issue selection: Lessons from a family, maternal, and child health department. In M. Minkler, & N. Wallerstein (Eds.), Community-based participatory research for health: From process to outcomes. San Francisco, CA: Jossey-Bass.

Wang, C., and Redwood-Jones, Y. (2001). "Photovoice ethics: perspectives from Flint Photovoice." *Health Education and Behavior*, 28(5), 560-572.

Wolf, D. 1991. High-risk methodology: Reflections on leaving an outlaw society. In*Experiencing fieldwork: An inside view of qualitative research*, edited by W. Shaffir and R. Stebbins, 211-23. Newbury Park, CA: Sage.

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

CHAPTER 5

CONCLUSIONS

Contributions

The two papers in this dissertation improve understanding of how small construction organization members share safety knowledge within their organizations (intra-organization) through network analysis and visualization. The first paper presents an exploratory study that measured, analyzed, and provided visual interpretation of the safety communication patterns of over ten construction crews. The second paper investigated the relationships between the organization members' attributes and their positions and roles within their networks. The subsequent proposal outlines a strategy to identify, in great detail, safety challenges for Hispanic construction workers using Photovoice, a research method new to the construction engineering and management field. Figure 1 depicts the research questions and contributions of this dissertation.

Chapter	***Research Questions***	***Contributions***
Ch.2	How do patterns in safety communication among crewmembers relate to safety performance?	✓ Determine differences between high and low safety performance crews ✓ Visualize communication patterns of small crews
Ch.3	What are the relationships between personal attributes & position in safety networks? What is the role of bilingual workers, managers, and experienced workers?	✓ Identify characteristics of language barrier spanners and central actors ✓ Visualize safety communication patterns of unilingual and multi-lingual crews
Ch.4	What safety challenges do Hispanic construction workers face and how can they be overcome as the proportion of Hispanic workers continues to increase?	✓ Determine unforeseen safety challenges for Hispanic workers at workplace ✓ Identify possible solutions from Hispanic workers to overcome or mitigate those challenges

Figure 1. Overview of research questions and contributions.

Contributions to theory

This dissertation builds upon past research that showed the importance of safety communication for achieving strong safety performance. According to Smith et al. (1978) and Zohar (1980) construction organizations that facilitate open safety communication and encourage direct communication between workers and their supervisors are distinguished by low incident rates. Additionally, immediate feedback and correction of unsafe behaviors was found to be a major driver for safety (Smith et al. 1978). Finally, other studies claimed communication as one of the top 10 management practices that influence safety performance (Hofmann and Morgeson 1999; Sawacha et al. 1999; Bentley and Haslam 2001).

In Chapter 2 the patterns of safety communication were modeled and measured using social network analysis. First, various modes of safety communication are identified and classified as formal and informal communication. Formal modes include written communication, toolbox talks, safety training, and communication from upper management and informal modes include ad hoc communication among workers. The analysis also includes the frequency with which workers use the different safety communication modes, classified as: (1) more than once a day; (2) once a day; (3) once a week; (4) bi-weekly; and (5) once a month.

Using social network analysis (SNA) metrics, the data were analyzed to determine the safety communication patters that distinguish high performing crews for the first time. We found that networks with high-density values have significantly lower safety records. The details of this analysis are provided in Chapter 2. The main intellectual contribution of this portion of the study was that we identified the safety communication patterns of relatively high performing crew networks for the first time. Specifically, high performing crews used informal communication patterns constantly and every formal method of safety communication at least once a month. Methodologically, this was the first use of SNA to study safety communication and one of the first uses of crew-level data for SNA in construction.

Chapter 3 built upon and deviated from the results presented in Chapter 2 to study the relationship among crewmember characteristics, their position in the network, and their SNA metrics. The main contribution of this portion was the inclusion of personal attributes such as age, position, years of experience, safety education (OSHA class and training), attitude toward safety, and language proficiency as predictors of network location and metrics. Not surprisingly, there was strong statistical evidence ($p < 0.001$) that bilingual workers and managers have higher degree of centrality and betweenness than their counterparts. Additionally, there was suggestive evidence that multilingual work crews have worse safety performance (RIR) than unilingual work crews and young construction workers (under 35) have higher degree of centrality and betweenness than older workers. This result was a surprise and prompted a proposal to better understand the cultural issues that Hispanic workers face with respect to construction safety.

Chapter 4 builds upon the results found in Chapter 3 to better understand the safety challenges faced by Hispanic construction workers in multilingual work crews in the U.S. The intellectual contribution of this work is to set a protocol for using Photovoice with construction workers for the first time. Specifically, this proposal seeks workers perspectives to nominate the most significant challenges Hispanic workers encounter at workplace through ethnographic interview. Photovoice involves empowering the disadvantaged group to express their concerns through photographs and focus group meetings that are focused on specific prompts that were identified in exploratory interviews. Collectively, these three chapters will yield to important knowledge advancements that are directed toward improving safety performance for Hispanic workers and small crews.

Contributions to practice

The results of this research provide leading indicators of safety performance that managers can use to alert when potential weaknesses exist. Additionally, the process of building and viewing SNA sociograms gives practitioners a meaningful visualized image of the actual communication network. Such information can help them to identify patterns (e.g. isolated or disconnected workers and subgroup "cluster" of workers in the network).

The research also provides practitioners with important information about the predictors of network position based upon the personal attributes of members of the construction crew. This new knowledge helps managers to build well-structured networks upon complementary attributes. For example, multilingual crews should not be without a young bilingual worker who has the best chance of serving as a language barrier spanner who links otherwise disparate sub-networks of unilingual workers.

Limitations and suggestions for future research

The chief limitation of this dissertation is the use of a new safety metric to compare relative crews safety performance. In Chapters 2 and 3, a metric was developed called relative safety performance (RSP) for crew comparison. The RSP metric is calculated based on crew's relative performance rate. The weakness of this method lies in the need for safety managers to the performance of the crew relative to the other crews in the organization. Although these individuals are capable to provide better estimated relative performance values for their crews, the computed RSP values are, essentially, approximated and limited to the accuracy of relative performance values.

To address this final limitation an internal check was performed to see if different results would have been obtained if the traditional safety metric, recordable injury rate (RIR), was used in lieu of the RSP in the statistical analyses. Accordingly, the order of the crews Table 1 in Chapter 2 were restructured. A comparison of Tables 1 and 2 reveal only a very small change where crew 8 and crew 4 switch positions. Despite this change, no statistical analyses or results changed.

Table 1. Relative safety performance (RSP) summary (high to low)

Crew No	Trade	Crew size	RIR	Percentile Rating	Safety performance	Percent of Maximum Performance
5	Drywall	10	2.8	85%	0.304	1.000
9	Carpentry	5	3.9	90%	0.231	0.760
6	General	12	4.1	90%	0.220	0.723
7	Drywall	5	4.4	95%	0.216	0.711
2	Glazing	7	5.4	90%	0.167	0.549
4	HVAC	7	6.8	95%	0.140	0.460
3	HVAC	5	6.8	95%	0.140	0.460
8	Carpentry	6	5.4	75%	0.139	0.458
1	Electrical	5	12.1	100%	0.083	0.272

Table 2. Safety performance (RIR) summary (low to high)

Crew No	Trade	Crew size	RIR
5	Drywall	10	2.8
9	Carpentry	5	3.9
6	General	12	4.1
7	Drywall	5	4.4

2	Glazing	7	5.4
8	Carpentry	6	5.4
3	HVAC	5	6.8
4	HVAC	7	6.8
1	Electrical	5	12.1

Therefore, the findings in Chapter 2 will remain unchanged. The top performing crews receive weekly formal safety communication from upper-level managers and have informal weekly safety communication. However, the statement of finding 3 needs to be revised to "in comparison, only one crew from low performing crews had connections among members when data were dichotomized for monthly training communication." Please see the revised version of Table 3 (this table corresponds with Table 4 in Chapter 2).

Table 3. Network density degrees for safety training on a monthly basis for high and low performing crews

	Crew	**Network Density**
Top Crews	5	20%
	6	16%
	9	20%
Bottom Crews	4	16%
	3	0%
	1	0%

Similarly, the analysis and results from Chapter 3 remain the same when RIR is used. The only change is the order of the participant crews since they are ranked according to the crews' recordable injury rates. Table 4 in this chapter shows the original crew analysis and Table 5 shows the adjusted analysis. Despite this change, the analysis remained the same.

Table 4. Crew Analysis (RSP)

Crew no	Trade	Size	Number of workers fluent in			Relative safety performance
			English	Spanish	Bilingual	
13	Sheet metal	9	8	0	1	1.00
14	Plumping	10	9	0	1	0.66

6	Landscaping	5	0	4	1	0.57
4*	Drywall	21	11	5	5	0.54
5	Electrical	7	7	0	0	0.51
9	Cleaning	5	0	4	1	0.48
12	Electrical	6	5	0	1	0.47
3	HVAC	5	0	2	3	0.40
8	Electrical	10	8	0	2	0.36
2	Concrete	8	0	4	4	0.35
7	Concrete	10	5	0	5	0.34
1*	Concrete	36	13	11	12	0.28
10*	Carpenter	24	4	15	5	0.20
11	Plumping	5	5	0	0	0.08

* Bilingual crew

Table 5. Crew Demographics (RIR)

Crew no	Trade	Size	Number of workers fluent in			Recordable injury rate
			English	Spanish	Bilingual	
13	Sheet metal	9	8	0	1	0.86
14	Plumping	10	9	0	1	1.16
6	Landscaping	5	0	4	1	1.50
4*	Drywall	21	11	5	5	1.60
5	Electrical	7	7	0	0	1.60
12	Electrical	6	0	4	1	1.63
9	Cleaning	5	5	0	1	1.80
3	HVAC	5	0	2	3	1.90
2	Concrete	8	8	0	2	2.20
7	Concrete	10	0	4	4	2.50
8	Electrical	10	5	0	5	2.50
1*	Concrete	36	13	11	12	3.10
10*	Carpentry	25	4	15	5	4.55
11	Plumping	5	5	0	0	5.88

* Bilingual crew

There are several other limitations and recommendations for future research. First, the focus of this dissertation is limited to the State of Colorado because all participating crews worked in this region and were reasonable accessible to the research team. Further studies are recommended for other regions such as New Mexico and Texas where multilingual crews are likely due to high Hispanic populations. Second, all crews were actively working on building commercial and residential construction projects. In the future study, infrastructure construction projects, energy projects, and others can be considered. Third, although 63 participants across nine crews were included in Chapter 2 and 161 participants from 14 different construction organizations in Chapter 3, future research is suggested to expand the number of crew and participants to have more reliable statistical results. Fourth, this dissertation includes the analysis of crews from 9 different trades. Further researchers may segregate the data based on the crew's trade and present the results accordingly. Finally, this dissertation did not test the quality and usefulness of safety-related knowledge exchange. Future researchers may collect data with explanation of quality and quantity of relationship (knowledge exchange) focused on how useful or vital the information is to safety achievement.

What I learned and future research

In this dissertation I studied social network analysis (SNA) and showed how SNA can be linked to the information science. I also learned SNA is a broad strategy for investigating social structures. However, in order to have fully understand of social phenomena, SNA researchers must consider primarily the relationships between actors and the individual characteristics. This dissertation has showed that SNA can be utilized as a useful technique in construction safety knowledge exchange field. More specifically in multi-primes and multicultural work crews projects.

A typical example where SNA can investigate the safety knowledge exchange is the Saudi Arabia construction industry. In Saudi Arabia, construction projects have increased rapidly over the past decade attracting construction companies from all over the world. Regardless this fact, Berger (2008) has found 25% of contractors did not provide a necessary safety orientation to new workers; 25% did not provide personal protective equipment (PPE); and 38% did not have formal safety training program. In fact, construction safety has not been regulated by any government agency, which lead to the fact the concept of safety doesn't exist among construction contractors. According to the General Organization of Social Insurance in Saudi Arabia (GOSI, 2011) the annual average injury rate of the construction industry from 2004 to 2010 was relatively high at 3413 per 100,000 employees and the annual fatality rate was 28.3 per 100,000 employees. Most of the these accidents were caused by the worker's safety culture due to the fact that 91% of the construction workers were migrants from (e.g. Pakistan, Bangladesh, and Egypt) (MOL 2012). The above situation suggests the need for a future study to investigate and identify the impacts of critical cultural aspects on implementing effective safety communication and safety program using social network analysis (SNA) technique.

References

Bentley, T. A., and Haslam, R. A. (2001). "A comparison of safety practices used by managers of high and low accident rate postal delivery offices." *Safety Science,* 37, 19-37.

Berger, H. (2008). Study finds safety poor on KSA sites, ArabianBusiness.com, accessed on November 10, 2013. http://www.arabianbusiness.com/507489-study-finds-safety-poor-on-ksa-sites.

Chinowsky, P. S., Diekmann, J., and Galotti, V. (2008). "Social network model of construction." *Journal of Construction Engineering and Management,* 134(10), 804-812.

Fang, D., Huang, J., and Fong, P. S. W. (2010). "Sharing construction safety knowledge through social networks." Proceedings of W099- Special Track 18th CIB World Building Congress, Salford, United Kingdom, May 10-13, 2010.

Hofmann, D. A., and Morgeson, F. P. (1999). "Safety related behavior as a social exchange: the role of perceived organizational support and leader member exchange." *Journal of Applied Psychology*, 59 (2), 286-296.

Kingdom of Saudi Arabia, General Organization of Social Insurance. (2011). "Annual statistics reports." Accessed on November 10, 2013. http://www.gosi.gov.sa/portal/web/guest/statistics

Loosemore, M., and Andonakis, N. (2007). "Barriers to implementing OHS reforms- the experience of small subcontractors in the Australian construction industry." *International Journal of Project Management*, 25, 579-588.

Ministry of Labor, Kingdom of Saudi Arabia. (2012). Annual Labor Statistics. Retrieved October 31, 2013, from http://portal.mol.gov.sa/ar/Statistics/Documents/الكتاب الاحصائي السنوي لعام 2012م.pdf.

Sawacha, E.., Naoum, S., and Fong, D. (1999). "Factors affecting safety performance on construction sites." *International Journal of Project Management*, 17(5), 309-315.

Smith, M. J., Cohen, H. H., Cohen, A. (1978). “Characteristics of a successful safety program.” *Journal of Safety Research*, 10, 5-15.

Taylor, J.E. and Bernstein, P.G. (2009) “Paradigm trajecto- ries of building information modeling practice in project networks.” *Journal of Management in Engineering*, 25(2), 69–76.

Zohar, D. (1980). “Safety climate in industrial organizations: theoretical and applied implications.” *Journal of Applied Psychology*, 65, 96-102.

BIBLIOGRAPHY

Albert, R.D. (1986). "Communication and attributional difference between Hispanics and Anglo-Americans." In Y.Y. Kim(Ed.), *International and intercultural communication annual, Vol. X. Interethnic communication: Current research* (pp. 42-59). Beverly Hills, CA: Sage.

Allen, G. (1991). "Valuing cultural diversity, industry woos a new workforce." *Communication World*, 8(6), 14–17.

Alsamadani, R., Hallowell, M., and Javernick-Will, A. (2012). "Measuring and modeling safety communication in small work crews in the US suing social network analysis." *Construction Management and Economic,* **31(6): 568-579**

Alsamadani, R., Hallowell, M., Javernick-Will, A., and Cabello, J. (2013). "Relationship among language proficiency, communication patterns, and safety performance in small work crews in the US." *Journal of Construction Engineering and Management,* 139(9): 1125-1134.

Anderson, J. T., Hunting, K. L., and Welch, L. S. (2000). "Injury and employment patterns among Hispanic construction worker." *Journal of Occupational Environmental Medicine*, 42, 176-186.

Anschuetz, L., and Rosenbaum, S. (2003). "Ethnographic interviews guide design of Ford vehicles website." *The Association for Computing Machinery.*

Arndt, V., Rothenbacher, D., Daniel, U., Zschendelein, B., and Brenner, H. (2004). "All cause and cause specific mortality in a cohort of 20,000 construction workers; results from a 10 year follow up." *Occupational and Environmental Medicine*, 61: 419-425.

Axley, S. (1984). "Managerial and organizational communication in terms of the conduit metaphor." *Academy of Management Review*, 9, 428-437.

Baker, D., Parker, R. M., Williams, M. V., Coates, W. C., and Pitkins, K. (1996). "Use and effectiveness of interpreters in an emergency department." *Journal of the American Medical Association*, 275(10), 783-789.

Baum, J. A. C., Calabrese, T., and Silverman, B. S. (2000). "Don't go it alone: alliance network composition and startup' performance in Canadian technology." *Strategic Management Journal*, 21, 267-294.

Bentley, T. A., and Haslam, R. A. (2001). "A comparison of safety practices used by managers of high and low accident rate postal delivery offices." *Safety Science*, 37, 19-37.

Berger, H. (2008). Study finds safety poor on KSA sites, ArabianBusiness.com, accessed on November 10, 2013. http://www.arabianbusiness.com/507489-study-finds-safety-poor-on-ksa-sites

Bernard, H. R. (2000). *Social Research Methods*. Thousand Oaks, CA: Sage.

Berg, B. 1998. *Qualitative research methods for the social sciences*. Boston: Allyn and Bacon.

Birdwhistell, R. L. (1970). *Kinesics and context.* Philadelphia, PA: University of Pennsylvania Press.

Booth, T., Booth, W. (2003). “In the frame: Photovoice and mothers with learning difficulties.” *Disability and Society,* 18(4), 431-442.

Borgatti, S. P., and Everett, M.G. (2006). “A graph-theoretic framework for classifying centrality measures.” *Social Networks,* 28(4), 466-484.

Boud, D., Rooney, D., and Solomon, N. (2009). “Talking up learning at work: Cautionary tales in co-opting everyday learning.” *International Journal of Lifelong Education,* 28(3), 323-334.

Brazg, T., Bekemeier, B., Spigner, C., and Huebner, C. E. (2011). “Our community in focus: the use of Photovoice for youth-driven substance abuse assessment and health promotion.” *Health Promotion Practice,* 12(4), 502-511.

Burt, R. S. (1995). *Structural holes: the social structure of competition,* Harvard University Press.

Carlson, E. D., Engebreston, J., and Chamberlin, R. M. (2006). “Photovoice as a social process of critical consciooesness.” *Qualitative Health Research,* 16(6), 836-852.

Castellanos, J., & Gloria, A. M. (2007). “Research considerations and theoretical application for best practices in higher education: Latina/os achieving success. *Journal of Hispanic Higher Education,* 6, 378-396

Chen, P., Partington, D., and Maoshan, Q. (2009). “Cross-cultural understanding of construction project managers’ conceptions of their work.” *Journal of Construction Engineering and Management,* 135(6), 477-487.

Chinowsky, P. S., Diekmann, J., and Galotti, V. (2008). “Social network model of construction.” *Journal of Construction Engineering and Management,* 134(10), 804-812.

Chinowsky, P. S., Diekmann, J., and O’Brien, J. (2010). “Project organizations as social networks.” *Journal of Construction Engineering and Management,* 136(4), 452-458.

Cigularov, K. P., Chen, P. Y., and Rosecrane, J. (2010). “The effects of error management climate and safety communication on safety: A multi-level study.” *Accident Analysis and Prevention,* 42, 1498-1506.

Claudia, M., Jean, S., Relebohile, M., and Callistus Bheka, N. (2006). “Why we don’t go to school on Friday: on youth participation through photo voice in rural KwaZulu-Natal.” *McGill Journal of Education,* 41(3), 267-282.

Comu, S., Unsal, H. I., and Taylor, J. E. (2011). “Dual impact of cultural and linguistic diversity on project network performance.” *Journal of Management in Engineering,* 27(3), 179-187.

Cooper, C. M., and Yarbrough. S. P. (2010). "Tell me—show me: using combined focus group and Photovoice methods to gain understanding of health issues in rural Guatemala." *Qualitative Health Research*, 20(5), 644-653.

Cooper, M.D. (2000). "Towards a model of safety culture." *Safety Science* 36, 111–136.

Corbie-Smith, G., Adimora, A. A., Youmans, S., Muhammad, M., Blumenthal, C., Ellison, A., Akers, A., Council, B., Thigpen, Y., Wynn, M., and Lioyd. S. W. (2011). "Project grace: a strategy approach to development of a community-academic partnership to address HIV in rural African American communities." *Health Promotion Practice,* 12(2), 293-302.

Cordeiro, P. A., and Carspecken, P. F. (2006). "How minority of the minority succeed: a case study of twenty Hispanic achievers." *International Journal of Qualitative Studies in Education*, 6(4), 277-290.

Cox, S.J., Cheyne, A.J. (2000). "Assessing safety culture in offshore environment." *Safety Science* 34, 111-129.

CPWR - The Center for Construction Research and Training. (2007). Construction Chart Book the U.S. Construction Industry and its Workers. 4th ed. Silver Spring, MD: CPWR - The Center for Construction Research and Training.

CPWR - The Center for Construction Research and Training. (2013). Construction Chart Book the U.S. Construction Industry and its Workers.54th ed. Silver Spring, MD: CPWR - The Center for Construction Research and Training.

Cramton, C. D., and Hinds, P. J. (2005). "Subgroup dynamics in internationally distributed teams: Ethnocentrism or cross-national learning?" *Research in organizational behavior*, An annual series of analytical essays and critical reviews, 26. , Oxford, U.K., 231–263.

Cross, R., and Prusak, L. (2002). "The people who make organizations go-or stop." *Harvard Business Review,* 80(6), 104-112.

Cross, R. L., and Parker, A. (2004). "The hidden power of social networks: understanding how work really gets done in organizations." *Harvard Business School Press,* 213(13).

Curry, T. J., and Strauss, R. (1986). "A little pain never hurt anybody: a photo-essay on the normalization of sport injuries." *Sociology of Sport Journal*, 11(2): 192-208.

Daft, R., and Lewin, A. (1993). "Where are the theories for the 'new' Organizational forms? an editorial essay." *Organization Science*, 4(4), 1-6.

De Mare, G. (1989). "Communicating: the key to establishing good working relationships." *Price Waterhouse Review*, 33, 30-37.

Di Marco, M. K., Taylor, J. E. (2011). "The impact of cultural boundary spanners on global project network performance." *Engineering Project Organization Journal*, 1(1), 27-39.

Dickie, V. A. (2003). “Establishing worker indintity: a study of people in craft work.” *American Journal of Occupational Therapy*, 57(3), 250-261.

Dongping, F., Yang, C., & Wong, L. (2006). “Safety climate in construction industry: A case study in Hong Kong.” . *Journal of Construction Engineering & Management*, *132*(6), 573-584.

Elwood, W. N., Dayton, C. A., and Richard, A. J. (1995). “Ethnography and illegal drug users: the efficacy of outreach as HIV prevention.” *Communication Studies*, 46(3-4), 261-275.

Emmitt, S. and Gorse, C. (2003). “Construction communication.” Blackwell Publishing Ltd.

European Working Conditions Observatory. (2011). Immigration and Accident at Work. CESIS, Portugal. Retrieved April 11, 2012, from http://www.eurofound.europa.eu/ewco/2011/10/PT1110029I.htm

Falicov, C.J. (1999). *Latino families in therapy: A guide to multicultural practice*. New York: Guilford Press.

Fang, D., Huang, J., and Fong, P. S. W. (2010). “Sharing construction safety knowledge through social networks.” Proceedings of W099- Special Track 18th CIB World Building Congress, Salford, United Kingdom, May 10-13, 2010.

Fetterman, D. M. (2010). Ethnography: step by step. Thousand Oaks, CA: Sage Publications.

Flum, M. R., Siqueira, C. E., DeCaro, A., and Redway, S. (2010). “Photovoice in the workplace: a participatory method to give voice to workers to identify health and safety hazards and promote workplace change, a study of university custodians.” *American Journal of Industrial Medicine*, 53(11), 1150-1158.

Foddy, W. (1993). “Constructing questions for interviews and questionnaires: theory and practice in social research.” Cambridge: Cambridge University Press.

Freedman, D., Pitner, R., Power, M. C. F., and Anderson, T. P. (2013). “Using photovoice to devlope a grounded theory of socio-environmental attributes influencing the health of community environments.” *The British Journal of Social Work*, 43(2), 1-21.

Freeman, L. C. (1977). “A set of measures of centrality based on betweenness. Sociometry,” 40, 35–41.

Gambatese, J.A., Behm, M., and Hinze, J. W. (1997). “Tool to design for construction worker safety.” *Journal of Architecture Engineering,* 3(1), 32-41.

Geletkanycz, M. A., and Hambrick, D. C. (1997). “The external ties of top executives: implications for strategic choice and performance.” *Administrative Science Quarterly*, 42, 654-681.

Grahame, P. R. (1998). “Ethnography, institutions, and social organization of knowledge, *Human Studies*, 21, 347-360.

Guarnaccia, P., and Rodriguez, O. (1996). "Concepts of culture and their role in the development of culturally competent mental health services." *Hispanic Journal of Behavioral Science,* 18(4), 419-443.

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

Hale, A. R. (1984). "Is safety training worthwhile?." *Journal of Occupational Accidents,* 6, 17-33.

Hallowell, M. R., & Gambatese, J. A. (2009). "Construction safety risk mitigation." *Journal of Construction Engineering & Management*, *135*(12), 1316- 1323.

Hallowell, M. R. (2011). "Safety knowledge management in American constructin organizations." *Journal of Management in Engineering,* in press.

Hammersly, M. & Atkinson, P. (2007), Ethnography: Principles in Practice (3rd ed). London: Routledge

Harper, A. C., Cordery, J. L., de Klerk, N. H., Sevastos, P., Geelhoed, E., Gunson, C., Robinson, L., Sutherland, M., Osborn, D., and Colquhoun, J. (19979). "Curtin industrial safety trial: managerial behavior and program effectiveness." *Safety Science*, 24, 173-179.

Havold, J. I. (2005). "Measuring occupational safety: from safety culture to safety orientation." *Policy and Practice in Health and Safety,* 1, 85-105.

Hawe, P., and Ghali, L. (2008). "Use of social network analysis to map the social relationships of staff and teachers at school." *Health Education Research,* 23 (1): 62-69.

Haythornthwaite, C. (1996). "Social network analysis: an approach and technique for the study of information exchange." *Social Science,* 18(4), 323-342.

Hergenrather, K. C., Rhodes, S. D., and Clark, G. (2006). "Windows to work: exploring employment-seeking behaviors of persons with HIV/AIDS through Photovoice." *AIDS Education and Prevention,* 18(3), 242-258.

Hergenrather, K. C., Rhodes, S. D., Cowan, C. A., Bardhoshi, G., and Pula, S. (2009). "Photovoice as community-based participatory research: a qualitative review." *American Journal of Health Behavior,* 33(6), 686-698.

Hofmann, D. A., and Morgeson, F. P. (1999). "Safety related behavior as a social exchange: the role of perceived organizational support and leader member exchange." *Journal of Applied Psychology*, 59 (2), 286-296.

Hogg, M., and Terry, D. (2000). "Social identity and self-categorization processes in organizational contexts." *Academy of Management Review (*25),121-40.

Houst, R. J., Hanges, P. J., Javidan, M., Dorfman, P. W., and Gupta, V. (2004). *Culture,* *Leadership, and Organizations.* Sage

Hurst, N. W., Young, S., Donald, I., Gibson, H., and Muyselaar, A. (1996). "Measures of safety management performance and attitudes to safety at major hazard sites." *Journal of Loss Prevention in the Process Industries*, 9(2), 161-172.

Huang, X., and Hinze, J. (2006). "Owner's role in construction safety." *Journal of Construction Engineering and Management*, 123(2), 164-173.

Jaselskis, E., Anderson, S., and Russel, J. (1996). "Strategies for achieving excellence in construction safety performance." *Journal of Construction Engineering and Management,* 122(1), 61-70.

Jaselskis, E. (2004). Developing an effective construction training program for Hispanic supervisors and craft workers, Center for Transportation Research and Education (CTRE)— Project 03-132, Iowa State University Report.

Javernick-Will, A. N., and Levitt, R. E. (2010). "Mobilizing institutional knowledge for international projects." *Journal of Construction Engineering and Management*, 136(4), 430-441.

Javernick-Will, A. N. (2011). "Motivating knowledge sharing in engineering and construction organizations: the power of social motivations." *Journal of Management in Engineering.*,in press.

Javernick-Will, A. (2011) "Knowledge-sharing connections across geographical boundaries in global intra-firm networks". *Engineering Project Organizations Journal,* 1:4, 239-253.

Johnson, J. (1975). *Doing field research*. Free Press: New York.

Katsanis, C. J. (2006). *Network* Organizations: Structural and Strategic Implications, *Proceedings of the 2nd Specialty Conference on Leadership and Management in Construction*, May2006, Louisville, CO: PM Publishing, 108-115.

Keyton, J., and Shockley-Zalabak, P. (2006). Case studies for organizational communication: Understanding communication processes (2nd ed.). Los Angeles, CA: Roxbury.

Kingdom of Saudi Arabia, General Organization of Social Insurance. (2011). "Annual statistics reports." Accessed on November 10, 2013. http://www.gosi.gov.sa/portal/web/guest/statistics

La Belle, T. J. (1982). "Formal, nonformal and informal education: a holistic perspective on lifelong learning." *International Review of Education*, 28(2), 159-175.

Larkey, L. K., Hecht, M. L., Miller, K., and Alatorre, C. (2001). "Hispanic cultural norms for health-seeking behaviors in the face of symptoms." *Health Education Behavior*, 28(1), 65-80.

Lavy, S., Aggarwal, C., and Porwal, V. (2010). "Fatalities of Hispanic workers: safety initiatives taken by U.S. construction companies to address linguistic and cultural issues." *International Journal of Construction Education and Research,* 6(4), 271-284.

LeCompte, M. D. (2002). “The transformation of ethnographic practices: past and current challenges.” *Qualitative Research,* 2(3), 283-299.

LeCompte, M.D., & Schensul, J.J. (1999). *Designing and conducting ethnographic research.* Walnut Creek, CA: AltaMira.

Lett, J. (1990). Emics and etics: Notes on the epistemology of anthropology. In T.N. Headland, K.L. Pike, & M.

Levin, B. (1993). English verb classes and alternations: A preliminary investigation. Chicago, IL: University of Chicago Press.

Levina, N., and Vaast, E. (2008). “Innovating or doing as told? Status differences and overlapping boundaries in offshore collaboration.” *Management Information Systems Research Center,* 32(3), 307-332.

Loden, M. & Rosener, J. B. (1991). Workforce America: Managing employee diversity as a vital resource. New York, NY: McGraw-Hill.

Loosemore, M., and Andonakis, N. (2007). “Barriers to implementing OHS reforms- the experience of small subcontractors in the Australian construction industry.” *International Journal of Project Management,* 25, 579-588.

Lu, Y. (2006). “Toward the micro and macro-level consequences of international justice in cross-cultural joint ventures.” *Human Relations Journal,* 59(8), 1019-1047.

Mar´ın, G. & Mar´ın, B. V. (1991). Research with Hispanic populations. Newbury Park, CA: Sage.

Marsden, P. V., and Hurlbert, J. S. (1988). “Social resources and mobility outcomes: a replication and extension.” *Social Forces,* 66, 1038-1059.

Martin, N., Garcia, A. C., and Leipert, B. (2010). “Photovoice and its potential use in nutrition and dietetic research.” *Canadian Journal of Dietetic Practice and Research,* 71(2), 93-97.

Matilla, M., Hyttinen, M. and Rantanen, E. (1994). “Effective supervisory behavior and safety at building site.” *International Journal of Industrial Ergonomic,* 13, 85-93.

Maton, K. I. (1993). “A bridge between cultures: linked ethnographic-empirical methodology for culture anchored research.” *American Journal of Community Psychology,* 21(6), 747-773.

May, S. K. (Ed.). (2006). Cases in organizational communication: Ethical perspective and

practices. Thousand Oaks, CA: Sage.

March, J. G., and Simon, H. A. (1958). Organizations, Wiley, New York, NY.

Martinelli, P. C. (1993). Mexican American identity: An interdisciplinary approach. In

Mearns, K., Flin, R. (1999). “Assessing the state of organizational safety- culture or climate?” *Current Psychology*, 18 (1) , 5-17.

Ministry of Labor, Kingdom of Saudi Arabia. (2012). Annual Labor Statistics. Retrieved October 31, 2013, from http://portal.mol.gov.sa/ar/Statistics/Documents/الكتاب الاحصائي السنوي لعام 2012م.pdf.

Moreno, J. L. (1960). “The sociometry reader.” *The Free Press*, Glencoe.

Morris, M. (1993). “Epidemiology and social networks: modeling structures diffusion.” *Sociological Methods Research*, 2(1), 99-126.

Morse, J. M. (1994). Designing funded qualitative research. *Handbook of qualitative research* (2nd ed., pp.220-35). Thousand Oaks, CA: Sage.

Morton, S.C., Dainty, A.R., Burns, N.D., Brookes, N.J., and Backhouse, C.J. (2006). ManagingRelationships to Improve Performance: A Case Study in the Global Aerospace Industry, *International Journal of Production Research*, 44(16).

M. E. Bernal & P. C. Martinelli (Eds.), Mexican American identity (pp. 19-31).

Nail, L. (2002). “Illuminating problems, defining processes, and improving outcomes: the essence of oncology nursing research.” *Oncology Nursing Forum*, 29(6), 941-947.

National Safety Council. (2001). Injury facts. Itasca, III

National Safety Council. (2002). Injury facts. Itasca, III

National Safety Council. (2003). Injury facts. Itasca, III

Nayak, N., and Taylor, J. (2009). “Offshore outscoring in global design networks.” *Journal of Engineering Management*, 16(6), 18-22.

Niskanen, T. (1994). “Safety climate in the road administration.” *Safety Science*, 17, 237-255.

Nooy, Wouter de., Marver, A., and Batagelj, B. (2011). Exploratory social network analysis with Pajek, Cambridge University Press, Cambridge, Mass.

O’Connor, T. (2002). Reaching Spanish-speaking workers and employers with occupational safety and health information, National Council for Occupational Safety and Health, Washington, DC: National Academy of Science.

O’Toole, M. (2002). “The relationship between employees’ perceptions of safety and organizational culture.” *Journal of Safety Research*, 33, 231–243.

Office of Management and Budget. (1997). "Revisions to the Standards for the Classification of Federal Data on Race and Ethnicity." http://www.Caucasianhouse.gov/omb/fedreg_1997standards.

Ozorhon, B., Arditi, D., Dikmen, I., and Birgonul, M. T. (2008). "Implications of culture in performance of international construction joint ventures." *Journal of Construction Engineering and Management*, 134(5), 177-184.

Palibroda, B., Krieg, B., Murdock, L., and Havelock, J. (2009). "A practical guide to Photovoice: sharing pictures, telling stories and changing communities." *Prairie Women's Health Network.* Winnipeg, MB.

Paniagua, F.A. (1998). Assessing and treating culturally diverse clients (2nd ed.). Thousand Oks, CA: Sage.

Parker, S. K., Axtell, C. M., and Turner, N. (2001). "Designing a safer workplace: importance of job autonomy, communication quality, and supportive supervisors." *Journal of Occupational Health Psychology,* 6(3), 211-228.

Parrado, E. A., McQuiston, C., and Flippen, C. A. (2005). "Participatory survey research: integrating community collaboration and quantitative methods for the study of gender and HIV risks amon Hispanic Migrants." *Sociological Methods and Research*, 2(34), 204-239.

Pew Hispanic Center. (2012). The Demographics of the Jobs Recovery. Washington, Dc. Retrieved June 24, 2012, from http://www.pewhispanic.org/files/2012/03/PHC-Labor-report-FINAL_3-21-12.pdf

Pronovost, P., Sexton, B. (2005) "Assessing safety culture: guidelines and recommendations." BMJ Quality & Safety 14, 231-233.

Pryke, S.D. (2004). "Analysis construction project coalition: exploring the application of social network analysis." *Construction Management and Economy,* 22(8), 787-797.

Queralt, M. (1996). *The social environment and human behavior. A diversity perspective*. Needham Heights, MA: Allyn & Bacon.

Rajendran, S., Gambatese, J. A., and Behm, M. G. (2009). "Impact of green building design and construction on worker safety and health." *Journal of Construction Engineering and Management,* 135(10), 1058-1066.

Ramos-McKay, J.M., Comaz-Díaz, L. & Rivera, L.A. (1988). Puerto Ricans. In L. Comas-Díaz, L & Griffith, E.E.H. (Eds.), *Clinical guidelines in cross-cultural mental health* (pp. 204-232). New York: John Wiley & Sons.

Ramsey, F. L. and Schafer, D. W. (2002). "The statistical sleuth, a course in methods of data analysis." *Second Edition,* Belmont, CA: Duxbury Press.

Ressler, S. (2006). “Social network analysis as an approach to combat terrorism: past, present, and future research.” *Homeland Security Affairs,* 2(2).

Rhodes, S.D., Hergenrather, K. C., Vissman, A. T., Stowers, J., Davis, A. B., Hannah, A., Alonzo, J., and Marsiglia, F. F. (2011). “Boys must be men, and men must have sex with women: a quantitative CBPR study to explore sexual risk among African American, Latino, and Caucasian gay and MSM.” *American Journal of Men Health,* 5(2), 140-151.

Sanders, S. S. (2007). Hispanic workers safety: understanding culture improves training and prevents fatalities. Professional Safety, 52(2), 34–40.

Santiago-Rivera, A. L., Arredondo, P., and Gallardo-Cooper, M. (2002). Counseling Latinos and la familia: A practical guide. Thousand Oaks, CA: Sage Publications.

Sapir, E. (2004). An Introduction to The Study of Speech. Mineola, NY: Dover Publication.

Sawacha, E.., Naoum, S., and Fong, D. (1999). “Factors affecting safety performance on construction sites.” *International Journal of Project Management*, 17(5), 309-315.

Schein, E. H. (1965). *Organizational psychology,* Prentice-Hall, Englewood Cliffs, New Jersey.

Scott, J. (1991). Social network analysis: A handbook, Saga, London.

Seashore, S. E. (1977). Group cohesiveness in the industrial work group, Institute for Social Research, University of Michigan, Ann Arbor.

Shimmin, S., Corbett, J., and McHugh, D. (1980). “Human behavior: some aspects of risk-taking in the construction industry.” *Institute of Civil Engineering.* London, UK, 13-22.

Silve, C. A., Sousa, J. M. C., Runkler, T. A., and Sa da Costa, J. M. G. (2008). “Distributed supply chain management using ant colony optimization.” *European Journal of Operational Research,* 10, 1016-1026.

Simard, M., and Marchand, A. (1994). “The behavior of first-line supervisors in accident prevention and effectiveness in occupational safety.” *Safety Science,*17, 169-185.

Smith, D. E. (1999). Writing the social: theory, critique, and investigation. Toronto: University of Toronto Press.

Smith, D. E. (2006). Institutional Ethnography as Practice. Rowman and Littlefield Publishers, Inc.

Smith, M. J., Cohen, H. H., Cohen, A. (1978). “Characteristics of a successful safety program.” *Journal of Safety Research*, 10, 5-15.

Smith, S. M., Perry, T., & Moyer, D. (2006). Creating a safer workplace. Professional Safety, 51(12), 20–25.

Snyder, E. E., and Ammons, R. (1993). “ Baseball’s emotion work: getting psyched to play.”

Qualitative Sociology, 16(2): 111-132.

Son, J.W., and Rojas, E.M. (2011). “Evolution of collaboration in temporary project teams: an agent-based modeling and simulation approach.” *Journal of Construction Engineering and Management*, 137(8), 1943-1944.

Spradley, J. P. (1979). The ethnographic interview. New York: Holt, Rinehart & Winston.

Stakes, V. (2006). Bridging the safety gap with Hispanic workers. Contractor Magazine, 53(9), 30–94.

Streng, J., Rhodes, S., Ayala. G., Eng, E., Arceo, R., and Phipps, S. (2004). “Realidad Latina: Latino adolescents, their school, and university use Photovoice to examine and address influence of immigration.” *Journal of Interprofessional Studies*, 18(4), 403-415.

Sypher, B. D. (1997). Case studies in organizational communication 2. New York, NY: Guilford.

Tan-Wilhelm, D., Witte, K., Liu, W. Y., Newman, L. S., Jansen, A., Ellison, C., Yancey, A., Sanderson, W., and Henneberger, P. K. (2000). “Impact of a worker notification program: assessment of attitudinal and behavioral outcomes.” *American Journal of Industrial Medicine*. 37, 205-213.

Taylor, J.E. and Bernstein, P.G. (2009) “Paradigm trajecto- ries of building information modeling practice in project networks.” *Journal of Management in Engineering*, 25(2), 69–76.

Thamhain, H. J., (1992). *Engineering Management managing Effectively in Technology-Based Organizations.* John Wiley and Sons, Inc., New York, N.Y.

Thamhain, H. J., and Wilemon, D. L. (1986). “Criteria for controlling project according to plan.” *Project Management Journal*, (2), 75-81.

The National Institute and for Occupational Safety and Health (NIOSH) and Center for Disease Control and Prevention (CDC). (1998). Assessing occupational safety and health training. Retrieved October 31, 2011, from http://www.cdc.gov/niosh/pdfs/98-145.pdf

The New Hampshire Department of Labor. (2010). A guide for developing a written safety program and lab 600 rules. Concord, NH. Retrieved November 14, 2011, from http://www.labor.state.nh.us/ST-WrittenSafetyProgram.pdf

Torres, J. B. (2008). “Communication patterns and direct social work practice with Latinos in the U.S.” *Journal of Human Behavior in the Social Environment.* 3(2), 23-42.

U.S. Bureau of Labor Statistics. (2002). Workplace injuries and illnesses in 2002. BLS Washington, DC. Retrieved April 11, 2010, from http://stats.bls.gov/news.release/pdf/osh.pdf

U.S. Bureau of Labor Statistics. (2008). Hispanic Population of the United States. BLS Washington, DC. Retrieved April 11, 2010, from http://stats.bls.gov/news.release/pdf/osh.pdf

U.S. Bureau of Labor Statistics. (2011). Hispanic Population of the United States. BLS Washington, DC. Retrieved November 1, 2011, from http://www.bls.gov/news.release/pdf/cfoi.pdf

U.S. Census Bureau. (2006). United States Census Bureau. Retrieved April 11, 2010, from http://www.census.gov/econ/census02/guide/INDRPT23.HTM

U.S Department of Labor. (2004). Occupational Safety and Health Administration. Retrieved October 31, 2011, from http://www.osha.gov/recordkeeping/new-osha300form1-1-04.pdf

U.S Department of Labor. (2008). Workplace injuries and illnesses in 2007. Retrieved October 31, 2011, from http://www.bls.gov/iif/oshwc/osh/os/osnr0030.pdf

U.S Department of Labor. (2011). Occupational Safety and Health Administration. Retrieved October 31, 2011, from http://www.osha.gov/dte/outreach/construction/index.html

Van Dyck, C., Frese, M., Baer, M., and Sonnentag, S. (2005). "Organizational error management culture and its impact on performance." *Journal of Applied Psychology*, 6, 1228-1240.

Vecchio-Sadus, A. M. (2007). "Enhancing safety culture through effective communication." *Safety Science Monitor*, (11) 3, 1-10.

Wagner, D. M. (1987). "Transactive memory: a contemporary analysis of the group mind." *Theories of Group Behavior*, 185-208.

Wang, C. (1999). "A participatory action research strategy applied to women's health." *Journal of Women's Health*, 8(2), 185-192.

Wang, C. 2003. "Using Photovoice as a participatory assessment and issue selection tool: A case study with the homeless in Ann Arbor." In M. Minkler and H. Wallerstein. Eds. *Commu- nity-based participatory action research for health*. San Fran- cisco: Jossey-Bass.

Wang, C., and Burris, M. A. (1997). "Photovoice: Concept, methodology, and use for participatory needs assessment." *Health Education & Behavior*, 24 (3), 369-387.

Wang, C., Morrel-Samuels, S., Hutchison, P., Bell, L., and Pestronk, R. M. (2004). "Flint Photovoice: community-building among youth, adults, and policy makers." *American Journal of Public Health*, 94(6), 911-913.

Wang, C., and Pies, C. A. (2008). Using Photovoice for participatory assessment and issue selection: Lessons from a family, maternal, and child health department. In M. Minkler, & N. Wallerstein (Eds.), Community-based participatory research for health: From process to outcomes. San Francisco, CA: Jossey-Bass.

Wang, C., and Redwood-Jones, Y. (2001). "Photovoice ethics: perspectives from Flint Photovoice." *Health Education and Behavior*, 28(5), 560-572.

Wasserman, S., and Faust, K. (1994). Social network analysis, Cambridge University Press, Cambridge, Mass.

Wolf, D. 1991. High-risk methodology: Reflections on leaving an outlaw society. In*Experiencing fieldwork: An inside view of qualitative research*, edited by W. Shaffir and R. Stebbins, 211-23. Newbury Park, CA: Sage.

Wyer, R.S. (1966). “Effects of incentive o perform well, goup aractioin, and group acceptance on conformity in judgmental task.” *Journal of Personality and Social Psychology*, 4(1), 21-26.

Zohar, D. (1980). “Safety climate in industrial organizations: theoretical and applied implications.” *Journal of Applied Psychology*, 65, 96-102.

Appendices

Appendix 1: Social Network Analysis metrics scores of the five communication modes for nine work crews, form Alsamadani et al. 2013a (Chapter 2)

Communication modes		SNA metric	Crew number								
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Formal communication	Provide information	Density	5%	29%	0%	29%	10%	14%	20%	0%	10%
		Centrality -out	25%	83%	0%	83%	100%	95%	100%	0%	19%
		Centrality- in	25%	25%	0%	6%	1%	9%	6%	0%	50%
		Betweenness	0%	6%	0%	0%	0%	0%	0%	0%	0%
	Receive information	Density	45%	21%	0%	62%	0%	16%	35%	0%	40%
		Centrality -out	69%	92%	0%	44%	0%	32%	81%	0%	44%
		Centrality- in	38%	53%	0%	25%	0%	57%	50%	0%	75%
		Betweenness	44%	0%	0%	5%	0%	1%	75%	0%	13%
Informal communication	Provide information	Density	30%	31%	0%	55%	80%	19%	0%	0%	30%
		Centrality -out	40%	81%	0%	53%	10%	90%	0%	0%	88%
		Centrality- in	29%	22%	0%	14%	10%	16%	0%	0%	25%
		Betweenness	0%	6%	0%	1%	0%	11%	0%	0%	50%
	Receive information	Density	20%	38%	15%	43%	80%	14%	0%	0%	0%
		Centrality -out	69%	72%	13%	67%	10%	33%	0%	0%	0%
		Centrality- in	38%	14%	75%	28%	10%	46%	0%	0%	0%
		Betweenness	0%	3%	0%	20%	0%	7%	0%	0%	0%
Training	Provide information	Density	0%	0%	0%	20%	10%	14%	0%	0%	0%
		Centrality -out	0%	0%	0%	86%	100%	95%	0%	0%	0%
		Centrality- in	0%	0%	0%	8%	1%	9%	0%	0%	0%
		Betweenness	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Receive information	Density	20%	7%	0%	12%	10%	9%	0%	7%	20%
		Centrality -out	69%	31%	0%	53%	1%	40%	0%	16%	69%
		Centrality- in	6%	31%	0%	33%	100%	27%	0%	40%	38%
		Betweenness	17%	0%	0%	21%	0%	1%	0%	0%	0%

Appendix 1 continued: Social Network Analysis metrics scores of the five communication modes for nine work crews, form Alsamadani et al. 2013a (Chapter 2)

Communication modes		SNA metric	Crew number								
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Written Communication	Provide information	Density	0%	14%	0%	0%	1%	11%	0%	0%	0%
		Centrality -out	0%	100%	0%	0%	11%	99%	0%	0%	0%
		Centrality- in	0%	3%	0%	0%	11%	0%	0%	0%	0%
		Betweenness	0%	0%	0%	0%	0%	11%	0%	0%	0%
	Receive information	Density	0%	19%	0%	0%	0%	2%	0%	7%	25%
		Centrality -out	0%	94%	0%	0%	0%	10%	0%	16%	63%
		Centrality- in	0%	17%	0%	0%	0%	22%	0%	40%	31%
		Betweenness	0%	0%	0%	0%	0%	0%	0%	0%	0%
Toolboox talk	Provide information	Density	40%	0%	5%	55%	9%	14%	15%	17%	20%
		Centrality -out	44%	0%	25%	53%	89%	95%	75%	100%	100%
		Centrality- in	44%	0%	25%	14%	2%	9%	12%	4%	6%
		Betweenness	8%	0%	0%	1%	0%	0%	0%	0%	0%
	Receive information	Density	30%	10%	20%	57%	9%	11%	20%	0%	40%
		Centrality -out	25%	28%	6%	50%	2%	49%	5%	0%	44%
		Centrality- in	56%	47%	100%	50%	89%	49%	69%	0%	75%
		Betweenness	0%	0%	0%	21%	0%	0%	25%	0%	13%

Appendix 2: Social Network Analysis metrics scores for 161 participants based-attributes, form Alsamadani et al. 2013b (Chapter 3)

Participant no	Language	Position	Age	Years of experience			**Safety education**	SNA metric scores			
				Industry	Current employer	Trade		Out centrality	Out betweenness	In centrality	In betweenness
1	English	Field manager	30	9.00	4.00	4.00	Safety training	100.00%	50.00%	83.33%	0.00%
2	English	Field worker	37	15.00	1.00	15.00	Safety training	0.00%	0.00%	0.00%	0.00%
3	English	Field worker	32	15.00	4.00	4.00	Safety training	16.67%	0.00%	0.00%	0.00%
4	English	Field worker	27	0.25	0.25	0.25	Safety training	16.67%	0.00%	0.00%	0.00%
5	English	Field worker	25	4.00	0.75	0.75	OSHA classes & training	16.67%	0.00%	0.00%	0.00%
6	English	Field worker	40	4.00	2.00	3.00	Safety training	0.00%	0.00%	0.00%	0.00%
7	English	Field worker	31	6.00	0.25	5.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
8	English	Field worker	29	6.00	4.00	6.00	OSHA classes & training	5.00%	0.00%	10.00%	0.26%
9	English	Field worker	35	15.00	0.50	15.00	Safety training	0.00%	0.00%	10.00%	0.26%
10	English	Field worker	35	15.00	2.00	15.00	OSHA classes & training	5.00%	0.00%	5.00%	0.00%
11	English	Field worker	36	16.00	0.33	16.00	Safety training	0.00%	0.00%	5.00%	0.00%
12	English	Field worker	47	15.00	0.25	15.00	OSHA classes & training	10.00%	0.00%	5.00%	0.00%
13	English	Field worker	36	26.00	8.00	21.00	OSHA classes & training	5.00%	0.26%	10.00%	0.26%
14	English	Field worker	45	24.00	0.25	22.00	Safety training	5.00%	0.00%	5.00%	0.00%
15	English	Field worker	49	26.00	0.25	26.00	Safety training	10.00%	0.00%	0.00%	0.00%
16	Spanish	Field worker	37	15.00	1.00	4.00	OSHA classes & training	5.00%	0.13%	5.00%	0.00%
17	E &S	Field worker	49	24.00	1.00	29.00	OSHA classes & training	100.00%	7.37%	20.00%	0.00%
18	Spanish	Field worker	32	6.00	4.00	4.00	Safety training	0.00%	0.00%	5.00%	0.00%
19	Spanish	Field worker	30	10.00	2.00	2.00	Safety training	5.00%	0.00%	5.00%	0.00%
20	E &S	Field worker	51	23.00	1.00	23.00	Safety training	100.00%	2.37%	5.00%	0.00%
21	E &S	Field worker	41	14.00	0.66	14.00	Safety training	100.00%	0.00%	5.00%	0.00%
22	English	Field worker	45	8.00	0.50	8.00	OSHA classes & training	0.00%	0.00%	5.00%	0.00%
23	Spanish	Field worker	28	8.00	1.50	10.00	Safety training	5.00%	0.00%	10.00%	0.26%
24	Spanish	Field worker	37	3.00	3.00	3.00	OSHA classes & training	0.00%	0.00%	10.00%	0.00%
25	E &S	Field worker	25	8.00	2.00	2.00	Safety training	10.00%	0.00%	10.00%	0.00%
26	English	Field worker	34	10.00	0.50	10.00	OSHA classes & training	10.00%	0.00%	5.00%	0.00%
27	English	Field worker	47	11.00	1.00	11.00	Safety training	0.00%	0.00%	5.00%	0.00%
28	E &S	Field worker	38	15.00	0.33	15.00	OSHA classes & training	100.00%	4.61%	5.00%	0.00%
29	E &S	Field manager	30	9.00	4.00	4.00	Safety training	100.00%	0.00%	100.00%	0.00%
30	E &S	Field worker	19	8.00	3.00	3.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%

Appendix 2 continued: Social Network Analysis metrics scores for 161 participants based-attributes, form Alsamadani et al. 2013b (Chapter 3)

Participant no	Language	Position	Age	Years of experience			Safety education	SNA metric scores			
				Industry	Current employer	Trade		Out centrality	Out betweenness	In centrality	In betweenness
31	E &S	Field worker	28	1.00	1.00	1.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
32	Spanish	Field worker	34	1.00	1.00	1.00	Safety training	0.00%	0.00%	0.00%	0.00%
33	Spanish	Field worker	27	5.00	2.00	2.00	Safety training	0.00%	0.00%	0.00%	0.00%
34	English	Field manager	30	8.50	8.50	8.50	OSHA classes & training	8.57%	1.18%	0.64%	0.08%
35	E &S	Field worker	36	7.00	3.00	15.00	OSHA classes & training	8.57%	0.34%	0.64%	0.00%
36	E &S	Field manager	46	30.00	2.00	30.00	Safety training	8.57%	0.59%	0.64%	0.34%
37	E &S	Field worker	42	14.00	8.00	14.00	OSHA classes & training	5.71%	0.00%	0.95%	0.08%
38	E &S	Project manager	27	4.00	4.00	4.00	OSHA classes & training	100.00%	0.00%	0.00%	0.00%
39	Spanish	Field worker	20	1.00	1.00	1.00	OSHA classes & training	5.71%	0.21%	0.00%	0.00%
40	English	Field worker	27	1.00	1.00	1.00	OSHA classes & training	5.71%	2.52%	0.00%	0.00%
41	Spanish	Field worker	46	9.00	1.50	3.00	Safety training	2.86%	0.00%	0.00%	0.00%
42	E &S	Field manager	49	28.00	9.00	28.00	OSHA classes & training	100.00%	7.69%	0.32%	0.00%
43	Spanish	Field worker	46	10.00	5.00	10.00	OSHA classes & training	2.86%	5.00%	0.00%	0.00%
44	English	Field worker	27	4.00	4.00	4.00	Safety training	0.00%	0.00%	0.00%	0.00%
45	Spanish	Field worker	47	20.00	15.00	20.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
46	English	Field manager	52	34.00	1.00	34.00	OSHA classes & training	2.86%	0.00%	0.00%	0.00%
47	English	Field worker	34	4.00	4.00	4.00	OSHA classes & training	8.57%	1.00%	0.00%	0.00%
48	English	Field worker	40	10.00	1.50	10.00	OSHA classes & training	5.71%	0.00%	5.40%	0.00%
49	English	Field worker	50	30.00	1.00	10.00	Safety training	2.86%	0.00%	0.00%	0.00%
50	E &S	Field worker	48	30.00	1.00	25.00	Safety training	0.00%	0.00%	0.32%	0.08%
51	English	Field worker	57	40.00	25.00	40.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
52	English	Field manager	57	35.00	7.00	35.00	OSHA classes & training	0.00%	0.00%	0.32%	0.08%
53	Spanish	Field worker	49	7.00	2.00	7.00	OSHA classes & training	2.86%	0.00%	0.32%	0.00%
54	Spanish	Field worker	36	18.00	3.00	18.00	Safety training	2.86%	0.00%	0.00%	0.00%
55	English	Field worker	38	20.00	6.00	18.00	Safety training	0.00%	0.00%	0.00%	0.00%
56	Spanish	Field worker	38	12.00	3.50	12.00	Safety training	0.00%	0.00%	0.00%	0.00%
57	E &S	Field manager	31	9.00	5.00	9.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
58	Spanish	Field worker	46	20.00	11.00	20.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
59	E &S	Field worker	57	26.00	20.00	26.00	OSHA classes & training	0.00%	0.00%	0.32%	0.17%
60	Spanish	Field worker	36	6.00	6.00	6.00	OSHA classes & training	8.57%	0.00%	0.00%	0.00%

Appendix 2 continued: Social Network Analysis metrics scores for 161 participants based-attributes, form Alsamadani et al. 2013b (Chapter 3)

Participant no	Language	Position	Age	Years of experience			Safety education	SNA metric scores			
				Industry	Current employer	Trade		Out centrality	Out betweenness	In centrality	In betweenness
61	English	Field worker	52	30.00	2.00	30.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
62	E &S	Field worker	43	3.00	3.00	3.00	Safety training	5.71%	0.00%	0.00%	0.00%
63	E &S	Field manager	28	10.00	5.00	10.00	Safety training	8.57%	2.98%	2.86%	0.00%
64	E &S	Field manager	33	15.00	3.00	12.00	Safety training	8.57%	0.17%	0.95%	0.00%
65	English	Field worker	53	25.00	15.00	25.00	OSHA classes & training	2.86%	0.00%	0.00%	0.00%
66	E &S	Field worker	38	5.00	5.00	5.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
67	Spanish	Field worker	45	9.00	9.00	9.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
68	Spanish	Field worker	52	30.00	2.00	30.00	Safety training	0.00%	0.00%	0.00%	0.00%
69	English	Field worker	36	16.00	8.00	16.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
70	English	Field manager	44	23.00	8.00	23.00	Safety training	12.50%	10.71%	0.00%	0.00%
71	English	Field worker	50	10.00	1.50	24.00	Safety training	25.00%	0.00%	0.00%	0.00%
72	English	Field worker	52	15.00	8.00	15.00	OSHA classes & training	25.00%	3.57%	12.50%	0.00%
73	E &S	Field worker	40	10.00	1.00	2.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
74	English	Field worker	33	3.50	0.03	3.50	OSHA classes & training	12.50%	0.00%	0.00%	0.00%
75	English	Field worker	29	9.50	0.03	4.50	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
76	English	Field worker	47	16.00	0.50	16.00	OSHA classes & training	25.00%	0.00%	0.00%	0.00%
77	English	Field manager	43	18.00	2.50	10.00	OSHA classes & training	12.50%	10.71%	100.00%	0.00%
78	English	Field worker	26	0.04	0.04	0.04	Safety training	12.50%	10.71%	0.00%	0.00%
79	English	Field worker	19	3.00	3.00	3.00	OSHA classes & training	100.00%	0.00%	20.00%	0.00%
80	English	Field worker	42	4.00	4.00	4.00	Safety training	0.00%	0.00%	40.00%	0.00%
81	English	Field worker	23	4.00	1.00	4.00	OSHA classes & training	100.00%	0.00%	0.00%	0.00%
82	E &S	Field worker	24	5.00	1.00	5.00	OSHA classes & training	20.00%	0.00%	40.00%	0.00%
83	English	Field worker	30	6.00	5.00	6.00	Safety training	20.00%	0.00%	40.00%	0.00%
84	English	Field worker	20	3.00	1.00	3.00	OSHA classes & training	20.00%	0.00%	20.00%	0.00%
85	English	Field worker	38	19.00	0.50	19.00	Safety training	11.11%	0.69%	55.56%	0.00%
86	English	Field worker	40	20.00	0.02	20.00	Safety training	11.11%	0.00%	11.11%	0.00%
87	E &S	Field worker	31	9.00	0.05	8.00	OSHA classes & training	22.22%	0.00%	0.00%	0.00%
88	English	Field worker	34	6.00	1.00	6.00	OSHA classes & training	22.22%	0.00%	11.11%	2.78%
89	English	Field worker	23	5.00	5.00	5.00	OSHA classes & training	22.22%	0.00%	11.11%	0.00%
90	English	Field worker	53	32.00	5.00	32.00	Safety training	22.22%	0.00%	11.11%	0.00%

Appendix 2 continued: Social Network Analysis metrics scores for 161 participants based-attributes, form Alsamadani et al. 2013b (Chapter 3)

Participant no	Language	Position	Age	Years of experience			Safety education	SNA metric scores			
				Industry	Current employer	Trade		Out centrality	Out betweenness	In centrality	In betweenness
91	English	Field worker	42	7.00	1.50	6.00	Safety training	11.11%	11.11%	11.11%	0.00%
92	English	Field worker	19	0.50	0.50	0.50	OSHA classes & training	11.11%	50.00%	0.00%	0.00%
93	English	Field worker	34	10.00	1.00	10.00	Safety training	11.11%	20.83%	0.00%	0.00%
94	English	Field manager	49	30.00	1.00	26.00	Safety training	100.00%	82.64%	88.89%	0.00%
95	Spanish	Field worker	38	10.00	8.00	8.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
96	Spanish	Field worker	51	20.00	7.00	7.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
97	E &S	Field worker	39	20.00	9.00	20.00	OSHA classes & training	100.00%	0.00%	100.00%	0.00%
98	E &S	Field manager	44	25.00	11.00	25.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
99	E &S	Field worker	26	8.00	3.00	3.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
100	E &S	Field worker	39	18.00	6.00	18.00	Safety training	0.00%	0.00%	0.00%	0.00%
101	Spanish	Field worker	50	20.00	1.00	20.00	Safety training	0.00%	0.00%	0.00%	0.00%
102	Spanish	Field worker	24	3.00	3.00	3.00	Safety training	100.00%	0.00%	100.00%	0.00%
103	E &S	Field manager	28	9.00	1.00	9.00	OSHA classes & training	100.00%	0.00%	100.00%	0.00%
104	Spanish	Field worker	34	3.00	1.00	3.00	Safety training	0.00%	0.00%	0.00%	0.00%
105	Spanish	Field worker	31	3.00	1.00	3.00	Safety training	0.00%	0.00%	0.00%	0.00%
106	Spanish	Field worker	63	10.00	1.00	10.00	Safety training	0.00%	0.00%	0.00%	0.00%
107	Spanish	Field worker	53	1.00	1.00	1.00	Safety training	0.00%	0.00%	0.00%	0.00%
108	E &S	Field manager	32	6.00	6.00	6.00	OSHA classes & training	100.00%	0.00%	100.00%	25.00%
109	Spanish	Field worker	26	4.00	4.00	4.00	OSHA classes & training	0.00%	0.00%	25.00%	0.00%
110	Spanish	Field worker	30	3.00	1.00	3.00	OSHA classes & training	25.00%	8.33%	0.00%	0.00%
111	Spanish	Field worker	27	1.00	1.00	1.00	1	25.00%	0.00%	0.00%	0.00%
112	Spanish	Field worker	41	2.00	2.00	2.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
113	English	Field worker	37	15.00	12.00	12.00	OSHA classes & training	4.17%	9.72%	1.85%	0.00%
114	English	Field manager	50	20.00	14.00	14.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
115	E &S	Field worker	33	7.00	4.00	7.00	OSHA classes & training	2.78%	0.00%	0.00%	0.00%
116	English	Field manager	60	41.00	18.00	30.00	OSHA classes & training	0.00%	0.00%	1.85%	0.00%
117	E &S	Field manager	54	35.00	19.00	35.00	OSHA classes & training	12.50%	31.25%	1.85%	0.00%
118	E &S	Field worker	33	10.00	9.00	10.00	Safety training	2.78%	0.00%	0.00%	0.00%
119	English	Field worker	60	38.00	20.00	34.00	OSHA classes & training	11.11%	0.00%	0.00%	0.00%
120	E &S	Field manager	46	30.00	12.00	30.00	Safety training	9.72%	25.67%	24.07%	0.00%

Appendix 2 continued: Social Network Analysis metrics scores for 161 participants based-attributes, form Alsamadani et al. 2013b (Chapter 3)

Participant no	Language	Position	Age	Years of experience			Safety education	SNA metric scores			
				Industry	Current employer	Trade		Out centrality	Out betweenness	In centrality	In betweenness
121	E &S	Field worker	33	5.00	5.00	5.00	Safety training	4.17%	0.00%	0.00%	0.00%
122	English	Field worker	34	6.00	6.00	6.00	Safety training	4.17%	0.00%	0.00%	0.00%
123	English	Field worker	30	11.00	1.00	1.00	Safety training	100.00%	0.00%	44.44%	0.00%
124	E &S	Field worker	34	3.50	3.50	3.50	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
125	English	Field worker	27	3.50	3.50	3.50	Safety training	0.00%	0.00%	0.00%	0.00%
126	English	Field worker	26	6.00	1.00	6.00	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
127	English	Field worker	38	8.00	1.50	1.50	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
128	English	Field worker	20	2.50	2.50	2.50	Safety training	22.22%	1.39%	0.00%	0.00%
129	English	Field worker	24	5.00	2.00	2.00	Safety training	11.11%	0.00%	0.00%	0.00%
130	English	Field worker	23	2.00	2.00	2.00	Safety training	100.00%	0.00%	0.00%	0.00%
131	E &S	Field worker	32	3.50	0.50	3.50	OSHA classes & training	0.00%	0.00%	0.00%	0.00%
132	English	Field manager	52	33.00	11.00	33.00	OSHA classes & training	100.00%	0.00%	100.00%	0.00%
133	E &S	Field manager	28	9.00	9.00	9.00	Safety training	56.52%	73.49%	0.00%	0.00%
134	E &S	Field worker	23	6.00	6.00	6.00	Safety training	39.13%	9.85%	0.00%	0.00%
135	Spanish	Field worker	41	5.00	5.00	5.00	OSHA classes & training	4.35%	0.00%	0.00%	0.00%
136	Spanish	Field worker	36	15.00	15.00	15.00	OSHA classes & training	4.35%	0.00%	1.63%	0.00%
137	Spanish	Field worker	45	15.00	1.00	15.00	OSHA classes & training	4.35%	0.00%	0.54%	0.00%
138	Spanish	Field worker	28	7.00	1.00	7.00	OSHA classes & training	4.35%	0.00%	4.35%	0.00%
139	E &S	Field worker	32	12.00	3.00	12.00	OSHA classes & training	39.13%	2.93%	0.00%	0.00%
140	Spanish	Field worker	34	11.00	2.00	11.00	OSHA classes & training	8.70%	0.00%	0.00%	0.00%
141	Spanish	Field worker	29	9.00	2.00	9.00	OSHA classes & training	4.35%	0.00%	0.54%	0.00%
142	Spanish	Field worker	36	24.00	12.00	24.00	OSHA classes & training	8.70%	0.00%	0.00%	0.00%
143	E &S	Field worker	46	24.00	12.00	24.00	OSHA classes & training	8.70%	0.00%	2.72%	0.00%
144	Spanish	Field worker	27	1.00	0.08	1.00	OSHA classes & training	4.35%	0.00%	1.63%	0.00%
145	Spanish	Field worker	35	15.00	1.00	15.00	OSHA classes & training	8.70%	4.35%	0.54%	0.00%
146	English	Field manager	43	30.00	3.00	30.00	Safety training	4.35%	0.00%	0.00%	0.00%
147	Spanish	Field worker	27	5.00	5.00	5.00	OSHA classes & training	13.04%	7.61%	1.63%	1.58%
148	English	Field worker	30	10.00	1.00	10.00	OSHA classes & training	13.04%	0.10%	0.00%	0.00%
149	Spanish	Field worker	35	10.00	5.00	10.00	OSHA classes & training	8.70%	1.68%	2.17%	0.99%
150	Spanish	Field worker	32	7.00	2.00	7.00	OSHA classes & training	4.35%	0.00%	0.00%	0.00%

Appendix 2 continued: Social Network Analysis metrics scores for 161 participants based-attributes, form Alsamadani et al. 2013b (Chapter 3)

Participant no	Language	Position	Age	Years of experience			**Safety education**	SNA metric scores			
				Industry	Current employer	Trade		Out centrality	Out betweenness	In centrality	In betweenness
151	Spanish	Field worker	34	3.00	1.00	3.00	OSHA classes & training	4.35%	0.00%	0.00%	0.00%
152	Spanish	Field worker	42	10.00	0.08	10.00	OSHA classes & training	4.35%	0.00%	0.00%	0.00%
153	E &S	Field worker	44	23.00	4.00	23.00	OSHA classes & training	4.35%	0.00%	0.00%	0.00%
154	English	Field worker	36	7.00	1.00	7.00	OSHA classes & training	4.35%	0.00%	0.00%	0.00%
155	Spanish	Field worker	33	6.00	2.00	6.00	OSHA classes & training	4.35%	0.00%	0.00%	0.00%
156	English	Field worker	25	4.00	2.00	4.00	OSHA classes & training	4.35%	0.00%	0.00%	0.00%
157	English	Field manager	32	14.00	7.00	14.00	OSHA classes & training	100.00%	0.00%	0.00%	0.00%
158	English	Field worker	35	12.00	0.06	12.00	Safety training	0.00%	0.00%	25.00%	0.00%
159	English	Field worker	35	14.00	8.00	14.00	Safety training	0.00%	0.00%	25.00%	0.00%
160	English	Field worker	44	25.00	7.00	25.00	Safety training	0.00%	0.00%	25.00%	0.00%
161	English	Field worker	47	26.00	1.00	2.00	Safety training	0.00%	0.00%	25.00%	0.00%

Appendix 3: Social Network Analysis (SNA) metrics glossary

Assume we have the following network (ABCDEFG)

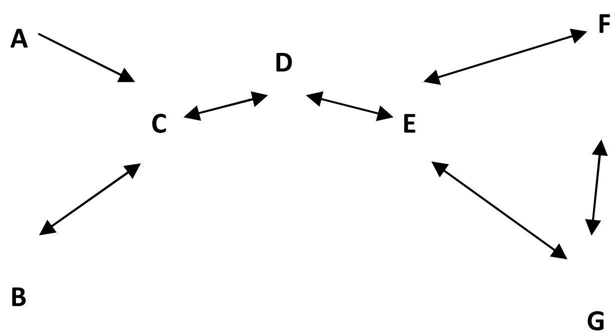

Figure 1. ABCDEFG network

Nodes represent the actors, and ties with arrows represent the connections or (relationships). All outputs of the network analysis were generated by a Social Network Analysis software called (UCINET).

Density

- **Definition**: The total sum of all connections in the network divided by the number of possible connections. The density of any network can show which actors have high levels of social influence.
- **Equation**: $\Delta = \frac{L}{g(g-1)}$ where Δ is the network density, (L) is the number of existing connections in the network, and g is the total number of actors.
- **Example**: the output for network (ABCDEFG) density table

Network	Density	No of Ties
ABCDEFG	0.3095	13.00

Geodesic Distance

- **Definition**: The number of connections (direct and indirect) in the shortest possible path from one specific actor to another specific actor.

- **Equation**: the geodesic distance between actor i and actor k ids equal to the number of connections (ties) on the shortest path between $i\ and\ k$.
- **Example**: for the network (ABCDEFG) the geodesic distance from actor (A) to actor (E) equals (see the output below). The geodesic distance for the whole network is shown below. UCINET also calculates the frequencies of each geodesic distance and their proportions to the total distances.

Distance	**Frequent**	**Proportion %**
1	13	0.361
2	10	0.278
3	7	0.194
4	6	0.167

Average distance (among reachable pairs) = 2.167

Actors	A	B	C	D	E	F	G
A	0	2	1	2	**3**	4	4
B	0	0	1	2	3	4	4
C	0	1	0	1	2	3	3
D	0	2	1	0	1	2	2
E	0	3	2	1	0	1	1
F	0	4	3	2	1	0	1
G	0	4	3	2	1	1	0

Point Centrality

- **Definition**: The number of actors that need to be removed in order for one specific actor to no longer be able to reach another specific actor.
- **Example**: in the network (ABCDEFG) the point centrality from actor (A) to actor (D) is equal to one because actor (C) is only actor need to be removed so actor (A) is no longer able to reach actor (D). The output for the whole network is shown below:

Point Centrality table

Actor	A	B	C	D	E	F	G
A	0	1	1	**1**	1	1	1
B	0	0	1	1	1	1	1
C	0	1	0	1	1	1	1
D	0	1	1	0	1	1	1
E	0	1	1	1	0	2	2
F	0	1	1	1	2	0	2
G	0	1	1	1	2	2	0

Reachability

- **Definition**: The ability of one specific actor to reach another specific actor through the network. If a pair of actors is reachable, a value of "1" would be given; if they are not reachable a value of "0" is given.
- **Example**: the actor (A) can reach actor (C) so it's given a score value equal to one, but actor (C) cannot reach actor (A) then a score value of zero is given. The reachability for the network (ABCDEFG) is shown in the below table:

Actors	A	B	C	D	E	F	G
A	0	1	**1**	1	1	1	1
B	0	0	1	1	1	1	1
C	**0**	1	0	1	1	1	1
D	0	1	1	0	1	1	1
E	0	1	1	1	0	1	1
F	0	1	1	1	1	0	1
G	0	1	1	1	1	1	0

Freeman's Degree Centrality Measures

- **Definition:** The number of direct connections made by one actor with all other actors in the network.

- **Equation:** to compute the standardized degree of centrality use the following equation: C_D (actor x) = $\frac{(c_D \text{ (actor x)})}{(g-1)}$; where c_D (actor x) is the total number of connection that the actor x has (in or out), and (g-1) is the maximum possible number of connections that actor x can have, where g is the total number of network actors.

  The network centralization (in and out) can be computed by the following equation:

  $$Network\ Centralization = \frac{\sum_{i=1}^{g}[C_D\ (n*) - C_D\ (n_i)]}{[(g-2)(g-1)]}$$

  Where C_D (n $*$) is the largest observed value of C_D (n_i) (Wasserman and Faust, 1994)

  Example: the out degree of centrality of actor (D), c_D (actor D) = 2

  The standardized out degree of centrality of actor G, C_D (D)= $\frac{2}{(7-1)} = \frac{2}{6}$ = 0.33 or 33.00%

  The network (out degree) centralization = $\frac{[(3-3)+(3-2)+(3-2)+(3-2)+(3-2)+(3-1)+(3-1)]}{[5*6]} =$

  $$\frac{8}{30} = 0.266667\ or\ 26.6667\ \%$$

Actors	Out Degree	In Degree	NrmOutDeg	NrmInDeg
A	3.0000	3.0000	50.0000	50.0000
B	2.0000	2.0000	33.3333	33.3333
C	2.0000	3.0000	33.3333	50.0000
D	2.0000	2.0000	33.3333	33.3333
E	2.0000	2.0000	33.3333	33.3333
F	1.0000	1.0000	16.6667	16.6667
G	1.0000	0.0000	16.6667	0.0000

Descriptive Statistics	Out Degree	In Degree	NrmOutDeg	NrmInDeg
Mean	1.8571	1.8571	30.9524	30.9524
Std Dev	0.6901	1.0690	11.5011	17.8174
Sum	13.0000	13.0000	216.6667	216.6667
Variance	0.4762	1.1429	132.2751	317.4603
SSQ	27.0000	31.0000	7500.0000	8611.1100
MCSSQ	2.8570	6.8570	793.6510	1904.7620
Minimum	1.0000	0.0000	16.6667	0.0000
Maximum	3.0000	3.0000	50.0000	50.0000
No of Observation	7.0000	7.0000	7.0000	7.0000

Network (out degree) centralization= 26.6667 %

Network (in degree) centralization= 26.6667 %

Closeness Centrality

- **Definition:** The in-closeness centrality is the reciprocal of the summation of the geodesic distance from all actors to reach a specific actor (inFarness) in the network. The out-closeness centrality is the reciprocal of the summation of the geodesic distance from a specific actor to reach all actors (outFarness).
- **Equation:** The in-closeness C_C (x) = $\frac{1}{(\sum \text{geodesic distance from all actors to actor (x)in the network})}$

  The out-closeness C_C (x)= $\frac{1}{(\sum \text{geodesic distance from actor (x) to all actors in the network})}$

The standardized closeness centrality (in or out)= C_C (x) × $(g - 1)$

Example: in the network (ABCDEFG) a total of fifteen connections (geodesic distances) for all actors to reach the actor (D).

The “nCloseness” for actor (D) = $\frac{(7-1)}{15}$ = 40%.

Actors	inFarness	outFarness	inCloseness	outcloseness
A	10.0000	15.0000	60.0000	40.0000
B	11.0000	15.0000	54.5455	40.0000
C	11.0000	17.0000	54.5455	35.2941
D	15.0000	18.0000	40.0000	33.3333
E	15.0000	18.0000	40.0000	33.3333
F	16.0000	21.0000	37.5000	28.5714
G	0.0000	16.0000	0.0000	37.5000

Descriptive Statistics	Out Degree	In Degree	NrmOutDeg	NrmInDeg
Mean	11.1429	17.1429	40.9416	35.4332
Std Dev	5.4598	2.1157	20.0964	4.1212
Sum	78.0000	120.0000	286.5909	248.0322
Variance	29.8095	4.4762	403.8641	16.9842
SSQ	2812.0000	2084.0000	14360.7450	8890.4740
MCSSQ	754.8570	26.8570	1428.3530	101.9050
Minimum	0.0000	15.0000	0.0000	40.0000
Maximum	16.0000	21.0000	37.5000	28.5714
No of Observation	7.0000	7.0000	7.0000	7.0000

Reach Centrality

- **Definition**: The percentage of actors that can be reached by a specific actor through "*n*" number of connections "outReach", it is defined as the summation of reciprocal closeness centrality from a specific actor to all actors, plus one. On the other hand "inReach" is the percentage of actors that reach a specific actor through "*n*" number of connections.
- **Equation**: the "outreach" centrality for actor $i = \sum_{i}^{k=\, i\ to\ g} \frac{1}{n} + 1$,

Where n $is\ the\ total\ number\ of\ connections\ from\ actor\ i\ to\ actor\ k$;
"inReach" centrality for actor i
$=\sum_{k=i\ to\ g}^{i}\frac{1}{n}+\ 1,$ where $n\ is\ the\ total\ number\ of\ connections\ from\ actor\ i\ to\ actor\ k$

- **Example**: the reach centrality of actor (A)= $[1+\frac{1}{2}+\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+\frac{1}{4}]+1 = 3.833$

The normalized reach centrality then can be obtained by dividing by observation value (NormdwReach) $= \frac{3.833}{g} = \frac{3.833}{7} = 0.548$.

The third table shows the proportion of total actors in the network can be reached by a specific actor in *n* connections (1, 2, 3, etc) for example actor (A) can reach **17%** of actors in the networks in one step and **67%** of the network actors in three steps. The last table shows what proportions of other actors can reach a specific actor in *n* connections (1, 2, 3, etc); for example, actor (A) is never reachable by others.

Actors	outReach	inReach	nOutReach	nInreach
A	**3.8330**	1.0000	**0.5480**	0.1430
B	3.3333	3.8330	0.4760	0.5480
C	4.1670	5.1670	0.5950	0.7380
D	4.5000	5.0000	0.6430	0.7140
E	4.8330	5.1670	0.6900	0.7380
F	4.0830	4.3333	0.5830	0.6190
G	4.0830	4.3333	0.5830	0.6190

Descriptive Statistics	outReach	inReach	nOutReach	nInreach
Mean	4.1189	4.1191	0.5883	0.5884
Std Dev	0.4759	1.4648	0.0679	0.2091
Sum	28.8323	28.8336	4.1180	4.1190
Variance	0.2265	2.1458	0.0046	0.0437
SSQ	120.1200	130.6400	2.4500	2.6900
MCSSQ	1.3600	12.8700	0.0300	0.2600
Minimum	3.3333	1.0000	0.4800	0.1400
Maximum	4.8330	5.1700	0.6900	0.7400
No of Observation	7.0000	7.0000	7.0000	7.0000

Proportion of nodes reachable by a node in *n* steps (connections)

	Number of steps (connections) *n*					
Actors	1	2	3	4	5	6
A	**0.17**	0.50	**0.67**	1.00	1.00	1.00
B	0.17	0.33	0.50	0.83	0.83	0.83
C	0.33	0.50	0.83	0.83	0.83	0.83
D	0.33	0.83	0.83	0.83	0.83	0.83
E	0.50	0.67	0.83	0.83	0.83	0.83
F	0.33	0.50	0.67	0.83	0.83	0.83
G	0.33	0.50	0.67	0.83	0.83	0.83

Proportion of nodes that can reach a node in *n* steps (connections)

	Number of steps (connections) *n*					
Actors	1	2	3	4	5	6
A	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
B	0.17	0.50	0.67	1.00	1.00	1.00
C	0.50	0.67	1.00	1.00	1.00	1.00
D	0.33	1.00	1.00	1.00	1.00	1.00
E	0.50	0.67	1.00	1.00	1.00	1.00
F	0.33	0.50	0.67	1.00	1.00	1.00
G	0.33	0.50	0.67	1.00	1.00	1.00

Node Betweenness Centrality

- **Definition:** The number of times a specific actor is on the geodesic path between pairs of actors.
- **Equation**: c_B (x)= $\sum \frac{the\ number\ of\ geodesic\ distance\ between\ y\ and\ z\ through\ actor\ x}{the\ number\ of\ geodesic\ distance\ or\ path\ between\ y\ and\ z}$ where y<z

  The relative node betweeness centrality C_B (x) = $\frac{c_B\,(x)}{(g-1)(g-2)}$
- **Example:** the betweenness centrality for actor E is c_B (E)= $\frac{1}{1}(A\ to\ F)+\frac{1}{1}(A\ to\ G)+\frac{1}{1}(B\ to\ F)+\frac{1}{1}(B\ to\ G)+\frac{1}{1}(C\ to\ F)+\frac{1}{1}(C\ to\ G)+\frac{1}{1}(D\ to\ F)+\frac{1}{1}(D\ to\ G)+\frac{1}{1}(F\ to\ D)+\frac{1}{1}(F\ to\ C)+\frac{1}{1}(F\ to\ B)+\frac{1}{1}(G\ to\ D)+\frac{1}{1}(G\ to\ C)+\frac{1}{1}(G\ to\ B)=14$

  The relative node betweenness centrality C_B (E)= $\frac{14}{6\times5}$ = 0.466667 = 46.667%

Actors	Betweenness	nBetweenness
A	0.000	0.000
B	0.000	0.000
C	13.000	43.333
D	15.000	50.000
E	**14.000**	**46.667**
F	0.000	0.000
G	0.000	0.000

Descriptive Statistics	outReach	inReach
Mean	6.0000	20.0000
Std Dev	7.5056	25.0185
Sum	42.0000	140.0000
Variance	56.3333	625.9263
SSQ	590.0000	6555.5560
MCSSQ	338.0000	3755.5560
Minimum	0.0000	0.0000
Maximum	15.0000	50.0000
No of Observation	7.0000	7.0000

Edge Betweenness Centrality

- **Definition:** The number of times a specific connection falls on the shortest path between pair of actors.
- **Equation:** $c_B\ (i\ to\ j)$=

$$\sum \frac{the\ number\ of\ geodesic\ distance\ between\ y\ and\ z\ through\ connection\ (tie) i\ to\ j}{the\ number\ of\ geodesic\ distance\ or\ path\ between\ y\ and\ z}$$ where y<z

- The relative edge betweenness centrality $C_B\,(i\ to\ j) = \frac{c_B\,(i\ to\ j)}{(g-1)(g-2)}$

- **Example:** the relationship (connection) from actor C to actor D is the mediator for all connections that start from actors A, B, or C to the rest actors. The edge betweenness centrality for the connection (tie) from (C) to (D)= $\frac{1}{1}$ (A to D) + $\frac{1}{1}$ (A to E)+ $\frac{1}{1}$ (A to F)+ $\frac{1}{1}$ (A to G) + $\frac{1}{1}$ (B to D) + $\frac{1}{1}$ (B to E)+ $\frac{1}{1}$ (B to F) + $\frac{1}{1}$ (B to G) + $\frac{1}{1}$ (C to D) + $\frac{1}{1}$ (C to E) + $\frac{1}{1}$ (C to F) + $\frac{1}{1}$ (C to G) = 12

  The relative edge betweenness centrality $C_B\,(C\ to\ D)= \frac{12}{(7-1)(7-2)} = 0.4\ or\ 40\%$

Edge betweenness centrality

	A	B	C	D	E	F	G
A	0	0	6	0	0	0	0
B	0	0	5	0	0	0	0
C	0	6	0	**12**	0	0	0
D	0	0	8	0	12	0	0
E	0	0	0	9	0	5	5
F	0	0	0	0	4	0	1
G	0	0	0	0	4	1	0