Spring 1-1-2010

Quantifying the Effectiveness of Pair-Wise Interactions among Safety Program Elements Through a Cross-Impact Analysis

Matthew Calhoun
Matthew.Calhoun@colorado.edu

QUANTIFYING THE EFFECTIVENESS OF PAIR-WISE INTERACTIONS AMONG SAFETY PROGRAM ELEMENTS THROUGH A CROSS-IMPACT ANALYSIS

Matthew E. Calhoun

B.S., University of Alaska Anchorage

School of Civil Engineering, 2002

A thesis submitted to the Faculty of the

Graduate School of the University of Colorado in

partial fulfillment of the requirements for the degree

of Master of Science from the Department of Civil,

Environmental & Architectural Engineering

2010

This thesis for the Master of Science degree written by

Matthew E. Calhoun

has been approved for the

Department of Civil, Environmental and Architectural Engineering

at the University of Colorado at Boulder

____

Matthew R. Hallowell, committee chair

____

Keith R. Molenaar, committee member

Date______________________________

The final copy of this thesis has been examined by the signatories, and we find that both the content and the form meet acceptable presentation standards of scholarly work in the mentioned discipline above.

ABSTRACT

Calhoun, Matthew E. (M.S., Department of Civil, Environmental & Architectural Engineering)

Quantifying the Effectiveness of Pair-Wise Interactions among Safety Program Elements through a Cross-Impact Analysis

Thesis directed by Assistant Professor Matthew R. Hallowell

The current construction safety and health management strategy is informal and safety program elements are selected without consistency across the industry. This is especially true for small construction companies who typically operate with a limited safety and health management budget. To guide these small construction firms, this study develops a tool to maximize the effectiveness of their current safety program. This study uses the Delphi method to gain consensus among thirteen experts in the field of construction safety and health. The experts quantify the interrelationships of the following highly-effective safety program elements: emergency response planning; first aid facilities; frequent safety inspections; job hazard analyses; project based safety incentives; record keeping and accident analyses; safety and health committees; safety and health orientation; site-specific safety manager; site-specific safety plan; subcontractor selections and compliance; substance abuse programs; training and regular safety meetings; upper management support; and worker participation and involvement. The interrelationships that are quantified determine the percent increase each safety program element has on the effectiveness of the other safety program elements. Through this cross-impact analysis a decision support system is developed that will help construction managers select the most effective safety program elements for their present safety program.

CONTENTS

TABLES

Table

FIGURES

Figure

CHAPTER ONE
INTRODUCTION

1.1 Construction Safety Programs in the U.S.

Year after year the construction industry accounts for a disproportionate injury rate in comparison to other industries. In 2002, the approximated costs (indirect and direct) of construction injuries aggregated a total of $13 billion (BLS 2008). Three years later, occupations within the construction industry accounted for 7% of U.S. workers, but reported 21% of workplace fatalities (U.S. Census Bureau 2006). In 2007, construction accounted for 1,178 fatalities, which resulted in the most deaths of any other U.S. industry sector (BLS 2008). Furthermore, contrary to the overall trend of reduced injury and illness rates in construction, injury rates for employers with 1,000 or more workers have increased from 1.1 per 100 full-time workers in 1994 to 1.4 in 2005 (Center for Construction Research and Training 2008). Despite recent advancements in safety performance, the yearly fatality rate in the American construction industry is still 11.1 fatalities per 100,000 workers and is three times greater than the fatality rate of other developed countries.

The National Occupational Research Agenda (NORA) has been existence since 1996 and was developed by the National Institute for Occupational Safety and Health (NIOSH). The purpose of NORA has been to grow the research framework used to identify critical issues in workplace safety and health. From 2006 to 2008, the NORA Construction Sector Council developed fifteen strategic goals for the “National Construction Agenda” with the effort to find information for being more effective in preventing fatalities, injuries and illnesses in construction. One of the strategic goals is aimed at improving the effectiveness of safety and health management programs in construction and increasing their use in the industry (NORA 2008). To improve the effectiveness of safety programs, first an understanding must be developed about safety program success and the effective safety elements, also identified as injury-prevention strategies, that make up a successful construction safety program.

1.2 Research Motivation

The current construction safety management strategy is informal and safety managers typically select site-specific safety program elements based upon intuition and peer suggestions (Hallowell and Gambatese 2007). This is especially true for small contractors who employ fewer than 20 workers, but represent 80% of the workforce (BLS 2006). One reason that these smaller firms have an informal safety management strategy is these firms operate on limited safety and health budgets and only have the ability to employ a small subset of safety program elements (Hallowell 2007). Unfortunately for these firms, research has found that improving the effectiveness of construction safety programs cannot be the adaptation of another company's safety program (Hinze 2006). To aid these firms, the injury prevention strategies that make up a highly effective safety program need to be analyzed. Recent research has quantified the effectiveness of thirteen highly effective safety program elements in isolation (Hallowell 2008). However, there is a deficient awareness of the interrelationships that exist among these safety program elements. For example, how does one safety program element influence another and vice versa.

1.3 Research Problem Statement

What are the cross-impacts on effectiveness of the following pair-wise interrelationships of the following highly-effective safety program elements: emergency response planning; first aid facilities; frequent safety inspections; job hazard analyses; project based safety incentives; record keeping and accident analyses; safety and health committees; safety and health orientation; site-specific safety manager; site-specific safety plan; subcontractor selections and compliance; substance abuse programs; training and regular safety meetings; upper management support; and worker participation and involvement? These fifteen elements were mentioned as highly effective safety program elements in more than three publications (Hill 2004; Hinze 2006; Findley et al. 2004; Jaselskis et al. 1996; Liska and Goodloe 1993; Hallowell and Gambatese 2009; and Meridian 1994).

If these interrelationships are understood, construction companies can recognize the potential impacts of a new safety program element on their present safety program and also have direction in selecting elements that are central to the success of the program as a whole.

1.4 Research Objectives

The general goal of the investigation is to understand how each highly effective safety program element influences the effectiveness of the other elements. The purpose of quantifying these interrelationships will help construction managers select the most effective safety program elements for their present safety program. To accomplish this, the following specific objectives were as follows:

- Fully investigate the effectiveness of safety programs and their elements

- Create a survey for the cross-impact analysis
- Select a Delphi panel
- Survey the Delphi panel through iteration with the goal of consensus
- Consolidate the results
- Select a validation panel to provide their opinion on the salient results
- Dissemination of results from Delphi and validation panel

1.5 Research Methodology

In order to quantify the interrelationships among the established highly effective safety program elements, a cross-impact analysis was performed. This analysis rated each element on the influence it has on the effectiveness of each of the fourteen other elements. This resulted in 210 relationships that needed to be quantified and required considerable time commitment from the survey participants.

The Delphi method is designed to extract unbiased information that deals with complex problems on uncertain issues through a formalized method of communication of a panel of independent experts (Linestone and Turoff, 1975). In addition, the Delphi method supports achieving consensus with those independent experts in an area of uncertainty where objective data is not possible (Murphy et al. 1998). Finally by using the Delphi method, the inference of any conclusions can be broadened through identifying experts across the globe (Hallowell 2008). All of these characteristics make selecting the Delphi method appropriate to use for identifying and quantifying the interrelationships of high-effective safety program elements.

1.6 Research Contribution

The overall contribution, after the expert panel quantified the interrelationships of the elements, is the quantification of how each highly effective safety program element influences the effectiveness of the other elements. From this increase in knowledge, the most significant interrelationships of construction safety program elements were identified. Finally, the measures of impact of each element on the overall effectiveness of the safety program were identified by total contribution received from the other elements and the total contribution made to the other elements is given. These data have the potential to help small construction firms that operate on a limited safety budget to optimize the effectiveness of their current safety program.

CHAPTER 2

LITERATURE REVIEW

2.1 Preface

To accomplish the research objectives, the first step was to fully investigate previous research related to safety program elements and their effectiveness. This investigation provided a framework for establishing the importance of the research and identifying areas that need further exploration. The areas related to this study include safety program success and safety program elements and their effectiveness. This chapter provides a synopsis of these research study areas.

2.2 Safety Program Success

As a result of the regulations associated with the Occupational Safety and Health Act (OSHA) of 1970, safety has improved on construction sites; however, the industry still experiences a disproportionate number of injuries in comparison to other industries. Safety programs within construction have been given significantly more attention over the recent years because of the relatively poor safety record in the industry. There are many reasons for this disparity, but according to the Bureau of Labor Statistics (2009), the success of safety programs is hindered by the division of the design and construction phase.

Presently, the OSH Act puts the responsibility of work-site safety on the employer and unquestionably the employer has the most critical role in controlling job-site safety (Huang and Hinze 2006). Although, the safety of the work-site can be enhanced by getting involvement from other entities, that include the owner, subcontractor, and designer (Singh et al. 1999). In addition, in 1998, the American Society of Civil Engineers released a policy statement 350, that was aimed at improving construction site safety through the commitment from all roles. The following section will discuss how each role is important to a successful safety program.

2.2.1 Owner's Role

An owner of a construction project determines the needs and goals of the project, but research in their role towards construction site safety has only been explored since the early 1990's. Levitt and Samelson (1993) conducted one of the first studies and found that an owner can play a crucial role in the success of a safety program. This role that the owner plays can be broken into pre-construction and construction strategies. Some of the pre-construction strategies that Levitt and Samelson (1993) include:

- Investigate the contractors' safety performance from previous projects during bid selection.
- Supply the contractor with safety goals and guidelines to follow on the project.
- Incorporate safety guidelines into the owner-contractor contract.
    - This can include requiring an on-site safety manager that is employed by the contractor.
- Require that the contractor's workers complete safety training specific to the project being constructed.
- Emphasize the importance of safety to the contractor beginning during the notice for bid continuing through the construction phase.

Following the pre-construction phase, Levitt and Samelson (1993) found strategies that the owner can implement during construction and include:

- Perform safety inspections and safety audits when the owner is on-site.
- Hire a construction safety firm to keep an eye on the safety of the contractor.
- Record and keep safety performance statistics for the contractor
- Require all worker accidents or near misses to be reported immediately to the owner.
    - After the contractor reports an accident, investigate and disseminate the findings to the contractor.

The size of the project will dictate how many of these strategies will be implemented. On larger projects in the private sector the owner can play a more active role in safety. Hinze (1997) conducted a series of studies in the early 1990's to see if safety was becoming more important to owners of large projects. To quantify if there was a changing trend, the percentage of owners on large projects that reviewed contractors' safety records before allowing the contractor to bid was measured. The results from the study clearly showed that the owners were becoming more focused on safety in the bid selection process and forecasted that this trend is likely to continue into the future. Hinze (1997) also found that owners concerned with safety used the following strategies: Assigning an owner's representative for safety on every construction project; Participating in safety meetings with the contractor; Developing safety strategies and require the contractor to follow them; Providing safety training for the contractor; Requiring all contractors to attend a safety and health orientation prior to construction; Reviewing the safety program of the contractor prior to construction; Conducting periodic safety audits on the safety performance of the contractor and; Putting into practice safety incentive programs on all construction projects.

In addition to the strategies listed above, an active owner in safety will include provisions within the contract. Hinze (1997) found that some of these provisions included the following: Submitting a project-specific safety plan for owner review; Job hazard analyses; Regular safety meetings that include not only the workers, but also the supervisors; An appointed site-safety manager for the project; Reporting of any accidents, safety inspections, and safety meetings; Including subcontractors in the safety program; Conformity with the safety strategies that the owner develops in addition to the contractor's safety program and; Requiring and established safety and health orientation program developed by the contractor. Although many of these provisions may be required by OSHA, including the conditions in the contract will establish the owner's commitment to safety.

Research has found objective evidence that the owner's management commitment towards safety directly influences the successfulness of the project's safety program (Huang and Hinze 2006). Contracts between the Owner and General Contractor on safe construction projects generally include the following safety-related requirements: safe contractor selection criteria, safety requirements in the contract, owner's commitment and participation in safety over the course of the project and safety is included at all meetings, safety is stressed in the contract along with general safety guidelines, project specific goals towards safety, short-term permits required over broad project wide permits for hazardous activities, all project employees are required to do safety training, maintain records on contractor's safety performance, safety audits, 100% reporting including accident investigations, contractor employed site-safety coordinator, and compensate the contractor's project safety budget (Huang and Hinze 2006; Levitt and Samuelson 1993). In addition, owners can further enhance project safety by requiring the designer to address safety during planning and design (Gambatese 2000). These studies show that with an active participation in construction safety management in each stage of project execution, the owner can effectively promote and influence project safety performance.

2.2.2 Subcontractor's role

On construction projects, general contractors most often form a contract with many individual subcontractors. The owner usually does not have any involvement with the subcontractor selection and the general contractor selects who they want to complete the work. The contract that is formed with the general contractor and the subcontractor generally includes a provision that discusses safety. These provisions vary widely, but it is common for the subcontractors to be required to comply with OSHA regulations (Hinze 2006). Other provisions can go a step farther to include the contractors' right to stop any unsafe activity, in addition to hold-harmless clauses. The hold-harmless clause requires the subcontractor to accept any indebtedness to the general contractor due to any unsafe actions. The purpose of these provisions is to clearly identify who the responsible parties are.

It is important for the contract between the contractor and subcontractor to be clearly delineated towards safety. Unfortunately, addressing safety in the subcontract agreements is often directed in an artificial way (Hinze 2006). According to Hinze (2006), the purpose of this is to clearly separate the general contractor and subcontractor as distinct entities for liability purposes. By shifting liability from the general contractor to the subcontractor, the subcontractor will most likely have more concern towards safety because they have responsibility.

2.2.3 Designer's role

Designing for safety has gained momentum in recent years, even with the many perceived barriers to designing for safety. As more resources are becoming available it is likely to see a shift towards designers beginning to design for safety (Gambatese et al. 1997). A study conducted by Gambatese et. al (2005) found that 37% of designers accepted the concept of designing for safety and as more ideas and suggestions are complied and published for designers that percentage should increase. In addition, owners are becoming more safety conscience when selecting contractors and that will likely carry over into insisting that designers utilize the design for safety concept to improve the safety of the workers (Hinze 2006). For this study, the researchers' efforts were focused on the contractor's role towards safety and how to improve the effectiveness of the safety program's injury prevention strategies.

2.2.4 Contractor role

Research has found that the contractor has the most critical role in controlling job-site safety (Huang and Hinze 2006). The reason for this is two-fold, first the OSH Act places the responsibility of worker safety on the contractor, but also most construction contract general conditions maintain that the contractor has the main responsibility for worker safety (Toole 2002). As a result much of the safety research that is conducted focuses on the contractor's influence on safety. This section will review the root causes of construction accidents followed by the best practices that upper management can implement for achieving an excellent safety performance.

All accidents that happen can be linked to one or more root causes. These root causes have been studied by multiple authors and have came to similar results (Abdelhamid and Everett 2000; Suraji et al. 2001; Toole 2002). The root causes of construction accidents are given in Table 2.1.

Table 2.1 Root Causes of Construction Accidents (Toole 2002)

Root Cause	Description
Lack of proper training	A worker was not trained in recognizing and avoiding hazards on-site.
Deficient enforcement of safety	Upper management knew procedures were not being followed to avoid hazards, but did not enforce the safety standards.
Safe equipment not provided	A contractor does not provide a worker with proper equipment to minimize hazards.
Unsafe methods or sequencing	The normal sequencing of construction activities is not followed, resulting in a hazardous situation.
Unsafe site conditions	A site is more hazardous than typical construction sites.
Not using provided safety equipment	A worker has the proper equipment, but does not use it properly.
Poor attitude toward safety	A worker has a "tough-guy" attitude, is lazy, or does not follow safety precautions because it will take longer.
Isolated, sudden deviation from prescribed behavior	A normally competent worker performs an unsafe action because of fatigue, preoccupation, etc.

Out of the eight root causes that Toole (2002) described in Table 2.1, the first five stem from inadequate management towards safety. The remaining three root causes are a result of an unsafe act that is performed by the worker. Toole (2002) found that the factors needed to mitigate all the root causes of construction accidents include the following:

- Expertise in each task that is being performed
- Controlling the work occurring at the work-site
- Expertise in the safety requirements for each task
- Interaction with workers and ability to control their behavior
- Expertise in evaluation of the work and site conditions

These factors that have the ability to affect the root causes requiring total buy-in that begins at the management level (Hinze 2006). As a result, management commitment is a central element to the safety culture of the company (Zohar 1980). That centrality of upper management can have the ability to reduce construction injuries on the worksite. Levitt and Parker (1976) studied the role of upper management in reducing construction injuries and illness and found that:

- Contractors who had upper management speak about safety whey they were on job-sites had lower incident rates in comparison to other companies.
- Contractors with formal safety and health orientation programs had lower incident rates that companies that did not have an orientation program.
- Incentives that are centered on lost time accidents did not have any effect on improving the safety of the worksite.

Other studies have corroborated these initial findings of Levitt and Parker (1976) and upper management support towards safety continues to be critical for improving a contractor's safety performance.

2.3 Safety Program Elements

The responsibility of worker safety has been placed upon the employer by OSHA. Due to that legislation there has been much more research on contractor safety programs and the elements that comprise them. There are now, literally hundreds of injury prevention strategies, also termed safety program elements that are utilized in contractor safety programs (Rajendran 2007). Most often, contractors are not able to employ all of these safety elements within their respective safety program due to budget constraints (Hallowell and Gambatese 2007). Presently, the selection of safety program elements by contractors is informal and decisions are based on perception and peer suggestion (Hallowell and Gambatese 2007). This is unfortunate and an ineffective method because creating a successful safety program cannot be the adaptation of what safety program elements another company employs (Hinze 2006).

There are many safety program elements available to construction firms. During the literature review, seven publications were found that present effective safety program elements (Liska and Goodloe 1993; Meridian 1994; Jaselskis et al. 1996; Findley et al. 2004; Hill 2001; Hinze 2006; Hallowell and Gambatese 2009). Liska and Goodloe (1993) identified nine injury prevention strategies that when used properly will result in a successful safety record. In addition, the Meridian Research Group (1994) published a report documenting injury prevention strategies that lead to an effective construction safety program. Jaselskis et al. (1996) focused their research on identifying strategies for attaining a zero-accident construction safety performance and the methods to achieve that at the company and project level. Findley et al. (2004) focused their research on identifying which safety program elements were the most effective at preventing injuries while controlling workers' compensation costs. The results from that research found that implementing the strategies in Table 2.2 will lead to fewer fatalities and injuries for a contractor. Hill (2004) focused on identifying and defining the effective safety program elements that improve safety performance in the book, *Construction Safety Management Planning*. Hinze (2006) identified many elements that prevent injuries in safety programs and found that the elements must be tailored to the company and their specific goals, rather than utilizing another firm's existing safety program. The final study concerning effective safety program elements determined the relative effectiveness of injury prevention strategies through quantifying their individual ability to lessen risks associated with construction safety and health (Hallowell and Gambatese 2009). This most recent study identified 13 safety program elements as being essential to a construction safety program.

These publications identify twenty unique elements that are considered to be essential components of an effective safety program. Of these twenty elements, fifteen were mentioned by at least three of the seven publications. These fifteen elements, listed in Table 2.2, were the focal point of this study. It should also be noted that the number of elements was narrowed to fifteen because this number results in an appropriate scope (i.e., 210 pair wise ratings). These fifteen elements are listed and described in Table 2.3 using definitions provided in Construction Safety Management Planning (Hill 2004).

Table 2.2 Effective Safety Program Elements by Author

Safety Program Elements	Liska and Goodloe (1993)	Meridian (1994)	Jaselskis, et al (1996)	Findley et al. (2004)	Hill (2004)	Hinze (2006)	Hallowell and Gambatese (2009)	Total
Emergency response planning		x		x		x	x	4
First aid facilities		x		x		x		3
~~Flex and Stretch plan~~						x		~~1~~
Frequent Safety inspections	x	x	x	x	x	x	x	7
~~Insurance carrier selection~~						x		~~1~~
Job hazard analyses	x	x		x	x	x	x	6
Project based safety incentives	x				x	x		3
Record keeping and accident analyses	x	x		x	x	x	x	6
Safety and health committees		x		x		x	x	4
Safety and health orientation	x			x	x	x	x	5
~~Safety budgets~~			x			x		~~2~~
~~Safety bulletin board~~						x		~~1~~
Site-Safety Manager			x		x	x	x	4
Site-specific safety plan	x	x	x	x	x	x	x	7
Subcontractor selections and compliance		x		x	x	x	x	5
Substance abuse programs	x		x	x	x	x	x	6
Training and regular safety meetings	x	x	x	x	x	x	x	7
Upper management support	x	x	x	x	x	x	x	7
Worker Participation and Involvement		x		x	x	x	x	5
~~Work Permit system~~					x			~~1~~

Table 2.3 Critical elements to an effective construction safety program

Safety Program Element	Definition
Emergency response planning	Plans that include emergency response personnel, equipment, and procedures that cover emergency situations.
Frequent safety inspections	Regularly conducted safety inspections by safety manager or safety committee across the project site to identify hazardous exposures to workers
Job hazard analyses	Identification of specific safety hazards prior to a routine job, task, or process.
On-site first aid	Basic emergency treatment given to someone injured before medical services can arrive.
Project safety incentives	A tangible incentive given out on the project level for meeting a pre-specified outcome or level of performance.
Record keeping and accident analyses	The investigation, documentation, and reporting of accidents, near misses, first-aid cases, and other incidents.
Safety and health committees	A divers group of individuals on a specific project with the sole purpose of addressing safety and health on the worksite.
Safety and health orientation	Orientation and training sessions that focus on safe work practices and company safety policies for all new hires.
Site-safety manager	Full-time employment of a safety professional with formal safety experience and/or education that are charged with site safety.
Site-specific safety plan	A safety plan developed prior to construction commencing that is specific to a project that documents safety objectives, goals and methods for achieving success.

Subcontractor selections and compliance	Selection criteria and oversight of subcontractors to guarantee effective safety protection for all workers at the site.
Substance abuse programs	The identification and prevention of substance abuse in the workforce.
Training and regular safety meetings	Formal in informal safety and health training provided for managers, supervisors, and employees. Regular safety meetings are conducted to emphasize training and commitment to safety culture.
Upper Management Support	Upper management of an organization that acknowledges worker safety is a primary goal through motivation and resources to worker safety and health.
Worker participation an involvement	Worker involvement in the planning and operation of the safety and health program.

2.4 Safety Program Element Effectiveness

The effectiveness of safety program elements acting in isolation has been studied by several researchers over the years. Through the quantification of a safety program's effectiveness a contractor can use that information to select safety program elements in a more formal manner as opposed to how safety programs are traditionally pieced together through intuition and peer suggestion (Hallowell and Gambatese 2007). The results of these studies have found that some safety program elements are more effective than others. The following is a synthesis of the safety program effectiveness studies.

Workers' compensation insurance is a significant cost to construction companies and effective construction safety programs can reduce those costs considerably. This acts as an incentive for companies to employ effective construction safety programs. Insurance companies gauge the risk of construction companies by an experience modification rating (EMR), which is used to set the premium that the firm will pay. A firm with a poor safety record will have a higher modification rate resulting in a higher premium. There are many factors that figure into how the EMR is calculated, some of which include the injury frequency, injury severity, loss ratio, and many others. Hinze et al. (1995) found that injury frequency is counted more heavily than severity, although incidence rate alone is not the only factor. Another interesting finding, includes firms paying lower wages had a higher EMR than firms with higher wages even though their incidence rates were the same. While the various factors that figure into the EMR calculation are known, the magnitude of how the EMR is calculated from the factors is unknown (Hinze et al. 1995).

Jaselskis et al. (1996) compared safety inputs at the company and project level with varying levels of safety performance. The safety inputs showing a statistical significance for improving the recordable incidence rates at the company level include:

- Number of pates in the written safety plan
- Percent safety expenditures (safety $/billings)
- Safety training for part-time safety coordinator (hours per year)
- Meetings to discuss safety performance with field supervisors (number per month)
- Informal safety inspections on each project (number per month)
- Duration of safety training for new foreman (number of hours)

In addition the research looked to find the statistically significant differences in safety inputs for companies with lower EMRs in comparison to companies with higher EMRs. The safety inputs showing statistical significance for improved EMR that the researchers found were:

- Upper management support
- Company safety coordinator
- Field safety representatives
- Safety program
- Training and orientation specialty contractor safety management

In addition to the safety inputs at the company level, Jaselskis et al. (1996) found several factors associated with better project performance using the same subjective rating scale. The safety inputs showing statistical significance for improved project safety performance include:

- Upper management attitude towards safety
- Field safety representative
- Formal and informal safety meetings that include supervisors and subcontractors
- Informal site safety inspections
- Craft worker penalties assessed due to poor safety performance

The results from the research provide quantitative strategies to assist contractors institute effective safety programs to lower incident rates and EMRs. The limitations of the study include only investigating safety inputs with incident rates and EMR due to a lack of data concerning the incidence rates (i.e. severity and lost time) that was available to the researchers (Jaselskis et al. 1996).

Rajendran (2006) built upon this research by creating a rating system for projects based on the safety efforts of the owner, designer, subcontractor, and contractor. Using a Delphi panel, Rajendran (2006) considered the following questions for the study:

- What are the important safety program elements on projects to be included in the effectiveness rating system?
- What are the ratings for the effectiveness of the safety program elements?
- What is the framework of the effectiveness rating system?
- How can the ratings be calculated for the safety program elements being rated?
- Will it be feasible to use this rating system in the construction industry?

The rating system introduced by Rajendran (2006) organized safety program elements into 13 safety and health groups where credits can be assigned to evaluate all types of projects. Within the safety and health groups, there were 50 safety and health elements. The basis of the rating system is that a lower number of credits attained by a project would point to a higher possibility for construction worker injuries, illnesses, and fatalities. Rajendran (2006) found that the safety program groups and their total possible effectiveness rating credits are given in Table 2.4.

Table 2.4 Sustainable Construction Safety and Health Rating System (Rajendran 2006)

Sustainable Construction Safety and Health Rating Groups	Total Possible Effectiveness Credits within Group
Project team selection	6.6
Safety and health in contracts	5.5
Safety and health professionals	8.1
Safety commitment	4.3
Safety planning	27.8
Training and education	15.3
Safety resources	1.8
Drug and alcohol programs	1.8
Accident investigation and reporting	3.7
Employee involvement	4.2
Safety inspection	3.8
Safety accountability and performance measurement	8
Industrial hygiene practices	9.1

The findings from Rajendran (2006) introduced the first rating system that investigated the impact that different entities play in rating projects based on worker safety. In addition, an important result from this research defined relative ratings for safety program elements with regard to the overall safety of the project (Rajendran 2006).

More recently, Molenarr et al. (2009) conducted another study that calculated effectiveness ratings for selected safety program elements. The results created a set of best practices for corporate safety culture by evaluating five latent variables through a structural equations model. The latent variables and the best practices that Molenaar et al. (2009) found to have in influence on a company's EMR and are listed in order:

- Increase **safety commitment** through
    - Making safety a strategic concern
    - Assigning safety responsibilities at field levels
    - Frequent and effective inspections
    - Offering incentives for safety performance
- Offer **safety incentives** to personal
    - Allow workers to provide feedback
    - Build a culture that gives incentives for safety performance
    - Increase the value and frequency of the incentives
- Bring **subcontractor involvement** into the company's culture
    - Create long-term relationships with subcontractors
- Assign **safety accountability** and have field safety employees
    - Assign accountability for safety at all levels
    - Employ full-time on-site safety manager
    - Create a culture that gets on-site safety managers to buy into safety
- Use **disincentives** for unsafe behaviors consistently
    - Enforce safety at all times
    - Be consistent with disincentives for unsafe behavior
    - Punish worker only after review that allows feedback

This results from this study showed that company safety culture is linked to the effectiveness of the overall safety program. The limitations from this research come from only analyzing three companies, future research could look at more companies and compare to these findings.

Hallowell (2008) built upon existing studies by linking safety program elements to construction processes. The researchers found that safety program elements are selected informally across the industry. Through the study Hallowell (2008) introduced a formal method for selecting safety program elements that is built on their relative capability to alleviate risk. To construct the model the researchers first quantified the risk demand for a construction process by the following steps:

- Identify common safety risks
- Identify activities required for a construction process
- Identify and quantify the risks connected with each activity
- Add the quantified risks for each activity
- Add the risk values for all activities giving the total risk demand

The next step the researchers took was to quantify the capacity of a safety program to mitigate the risks. These steps were found to be:

- Identify common safety risks
- Identify practical safety program elements
- Identify and quantify the capacity of the safety program elements to mitigate the identified safety risks
- Add the capacity mitigation for each safety program element
- Add the capacity values for all of the safety program elements giving the total capacity

This model quantified the relative effectiveness for the safety program elements the researchers identified. This study found that subcontractor selection and management, upper management support and commitment and job hazard analyses are the most effective strategies.

Since these studies quantified the relative effectiveness on different scales, Hallowell (2010) combined four studies to find the average percent of maximum (POM) for each element. Finding the POM rating is important because each study is given equal weight and is accounted for in the effectiveness rating. The POM ratings are given in Table 2.5 and are applied to the results of this study for developing an overall decision support system for selecting safety program elements.

Table 2.5 Summary of effectiveness ratings (from Hallowell 2010)

	Sawacha et al. (1999)		Rajendran (2007)		Hallowell (2008)		Hallowell and Gambatese (in press)		
Element	Rating	POM	Rating	POM	Rating	POM	Rating	POM	Avg POM
Upper mgmt support	0.732	100%	2.3	96%	10	100%	144.2	100%	**99%**
Subcontractor mgmt	0.567	77%	2.3	96%	8	80%	133	92%	**86%**
Job hazard analyses	--	--	2.3	96%	8.5	85%	35.3	24%	**68%**
Written plan	0.713	97%	2.1	88%	8	80%	4	3%	**67%**
Training and regular mtgs	0.513	70%	2	83%	9.5	95%	27.2	19%	**67%**
Safety manager	0.582	80%	2.4	100%	7	70%	15.3	11%	**65%**
Employee involvement	--	--	1.9	79%	8	80%	43.4	30%	**63%**
Orientation and training	--	--	2	83%	9	90%	4.3	3%	**59%**
Inspections	--	--	2	83%	8	80%	15.8	11%	**58%**
Substance abuse programs	--	--	1.8	75%	8	80%	6.4	4%	**53%**
Committees	0.546	75%	1.9	79%	5.5	55%	5	3%	**53%**
Recordkeeping	--	--	2	83%	5	50%	0.04	0%	**44%**
Emergency response plan	--	--	--	--	5.5	55%	0.01	0%	**28%**

2.5 Chapter Summary

This chapter has provided background knowledge on the main areas of this research. The existing body of knowledge is organized into three sections including:

- Safety program success
- Safety program elements
- Safety program element effectiveness

Through the literature review it was found that there is a basic limitation in the existing literature concerning the interrelatedness of safety programs. Studies that have been completed in the past have quantified the effectiveness of safety program elements in isolation, but there has not been research that analyzes the impact that safety program elements have on one another. However, in practice, safety program elements interact to produce an effective and interconnected safety program. Furthermore, it is rare for elements to be implemented in isolation (Hallowell and Gambatese 2007). Thus, interdependencies among all elements must be taken into consideration when evaluating the overall effectiveness of safety programs. If these interactions are understood, than firms could select injury prevention strategies that are best suited for their current safety program using existing research that has quantified the elements independent effectiveness as well as how the elements interact with each other. This objective of this research is to identify and quantify the interrelationships among these safety program elements that have been identified as being highly effective for construction safety programs.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Preface

According to Songer (1992), general research methodologies include four main actions that include:

1. Research design
2. Data collection
3. Data analysis and results interpretation
4. Results validation

These actions are then adapted to the research problem that is being investigated and the objectives of the study.

In order to quantify the pair wise interactions among highly effective safety program elements, a cross-impact analysis was conducted using the Delphi method. The specific research design, justification of the selection of this research method, and methods implemented to minimize bias and enhance the validity and reliability of the results are described in detail in this chapter.

3.2 Cross-impact Analysis Selection

Researchers have used a number of methods to investigate the uncertainties that are connected with a particular event. In construction these methods have included the: analytical method, decision tree, influence diagram, Monte Carlo simulation, fuzzy set approach, neural network, Bayesian network, and the multi-attribute hierarchy method (Han and Diekmann 2004). Unfortunately, these methods of analysis require a significant amount of data to implement and are not tailored to construction processes that are implicitly related but have conditional probabilities that are difficult to explicitly quantify. Due to these reasons, the cross-impact analysis method was selected for this research design.

3.2.1 History of Cross-impact Analyses

Cross-impact analyses were first introduced as a tool for long range forecasting by Helmer and Gordon for Kaiser-Aluminium at the RAND Corporation (Bradfield et al. 2005). Gordon and Hayward further refined the technique by considering all potential relationships and the possibility of mutually reinforcing or mutually exclusive interactions (Gordon and Hayward 1968). Since that time, there have been many forms of cross-impact analyses that have been applied to different research studies. Cross-impact analyses have been adapted to many areas that include economics, history, law, physics, biology, engineering, and many other fields. Within construction, Han and Diekmann (2004) used a cross-impact analysis for the purpose of estimating interactions among events or elements that were previously considered independent of one another. One of the strengths of cross-impact analyses are they bring attention to chains of causality.

3.2.2 Causality

Causality is the relationship between two events, where one is a cause and the other is an effect. These relationships can be connected to a number of events that include: objects, elements, variables, processes, facts, properties, and states of affairs (Lewis 1973). Born (1949) described three assumptions for defining causality which are stated below:

- Causality assumes that there are laws that govern the occurrence of an event X that depends on the occurrence of a different event Y meaning X is called the cause and Y the effect.
- The cause must be before or at least occur at the same time as the effect.
- The cause and effect must be in contact or connected together by a chain of intermediaries in contact.

Since being introduced, these assumptions have been disproved concerning quantum mechanics, but they remain valid at the level of human experience (Lewis 1973).

3.2.3 Cross-impact Analysis Application

In general, cross-impact analyses are performed by quantitatively predicting the impact that each element of interest has on each of the other elements of interest (Blanning and Reinig 1999). This results in the quantification of pair-wise interactions occurring among the elements. One way to carry out such a task is to engage experts within the field of interest to use their knowledge to develop pair wise estimates among the elements. This quantification results in a matrix of conditional probabilities or percent impacts on a particular performance metric

(Mitchell and Tydemann 1978). Although, there are drawbacks to quantifying these impacts that can be explained by human behavior. Dawes (1998) draws attention to three common violations:

- Overestimating the probability of an interaction between two elements.
- Underestimating the probability of a disjunction between two elements.
- Overestimating the probability of personally desirable outcomes.

The Delphi method was used in this research study to eliminate these violations. The Delphi method by nature gives the researcher the ability to obtain consistent, valid, and reliable results (Hellmer 1972; Turoff 1972; Ezner 1972).

The cross-impact method is effective for describing subjective conditional relationships that do not have necessarily objective data that can be found through experimentation. According to Hellmer (1977), the major steps required to perform a cross-impact analysis are as follows:

1. Define the elements to be included in the analysis
2. Define the interdependencies through matrices
3. Define how the interactions or interdependencies will be measured
4. Estimate the number of interrelationships in the matrix
5. Perform the cross-impact analysis
6. Evaluate results

The following sections related to the cross-impact method will discuss the details behind each step related to this research study.

3.2.3.1 Elements of the Analysis

The elements for this analysis consist of injury prevention strategies also termed safety program elements. How these elements were selected is defined thoroughly in section 2.3. The elements that were found to be highly effective to a safety program are listed in Table 3.1. These elements were used in the cross-impact analysis.

Table 3.1 Critical elements of an effective construction safety program

Safety Program Element
Emergency response planning
Frequent safety inspections
Job hazard analyses
On-site first aid
Project safety incentives
Record keeping and accident analyses
Safety and health committees
Safety and health orientation
Site-safety manager
Site-specific safety plan
Subcontractor selections and compliance
Substance abuse programs
Training and regular safety meetings
Upper Management Support
Worker participation an involvement

3.2.3.2 Cross-impact analysis matrix

Cross-impact analyses identify the relations that variables have with each other. The presence of a link represents a relationship or interaction and that interaction can be positive or negative. These relationships have the possibility of going two-ways, meaning an element X can affect another element Y and vice versa. These relationships are mapped using a matrix. An example of a cross-impact matrix is included in Figure 3.1.

Variables	A	B	C	D	E
A					
B					
C					
D					
E					

Figure 3.1 Cross-impact relationship matrix

The variables of the analysis are seen on the horizontal and vertical axis and are denoted as A through E. The link or causal relationship would be recorded in the cell. For instance, if this example was looking at probabilities, the research question would be what is the probability that B (horizontal) occurs given A (vertical). Meaning A (vertical) is the cause and B (horizontal) is the effect. That probability would be recorded in the corresponding cell. The darkened cells represent an element that cannot have a recordable effect on itself.

This research study is concerned with finding the percent increase (or decrease) that a safety program element A has on the effectiveness of safety program element B. This can be represented by the following Table 3.2. The impact OF variables on the left-side of the matrix represents the cause and the impact ON variables on the top indicates the corresponding effect.

Table 3.2. Cross-impact matrix of highly-effective safety program elements

Impact ON

Percent increase or decrease in effectiveness

Impact OF	Emergency Response Plan	Frequent Inspections	Job Hazard Analyses	On-site first aid	Project safety incentives	Record Keeping & Accident Analyses	Safety & Health Committee	Safety & Health Orientation	Site-Safety Manager	Site-Specific Safety Plan	Subcontractor Management	Substance Abuse Programs	Training & Regular Safety Meetings	Upper Management Support	Worker Involvement
Emergency Response Plan															
Frequent Inspections															
Job Hazard Analyses															
On-site first aid															
Project safety incentives															
Record Keeping & Accident Analyses															
Safety & Health Committee															
Safety & Health Orientation															
Site-Safety Manager															
Site-Specific Safety Plan															
Subcontractor Management															
Substance Abuse Programs															
Training & Regular Safety Meetings															
Upper Management Support															
Worker Involvement															

3.2.3.3 Measurement of Interactions

The basic measurement of a cross-impact relationship between two variables or events communicates how the initial probability of an effected variable will increase or decrease in the event of a causation variable being present. Different methods of measurement have been established depending on the research that is being conducted. One common method was introduced by Alarcon (1992) to depict cross-impact relational patterns. This technique classifies the interactional patterns in a general nature and is given in Table 3.3.

Table 3.3 Cross-Impact Relation Patterns Developed by Alarcon (1992)

Designation	Definition	Index
SIG+	Significantly in the same direction	+3
SIG-	Significantly in the opposite direction	-3
MOD+	Moderately in the same direction	+2
MOD-	Moderately in the opposite direction	-2
SLI+	Slightly in the same direction	+1
SLI-	Slightly in the opposite direction	-1

Gordon and Hayward (1968) introduced another method to quantify the probabilities for the purpose of developing forecasts. This method begins by defining the probability that a development will occur. The example that the researchers use is related to crops. The following developments and there probability of occurring is seen in Table 3.4.

Table 3.4 Probability that the development will occur (from Gordon and Hayward 1968)

D	Development D	Probability P
D_1	One-month reliable weather forecasts	0.4
D_2	Feasibility of limited weather control	0.2
D_3	General biochemical immunization	0.5
D_4	Crop damage from adverse weather eliminated	0.5

Once these probabilities are quantified, the next step is to ask, “If the probability that D occurs is 100%, are the probabilities of the other developments affected?” In the event that there is a cross-impact, it can either be in a positive or negative direction. The researchers depict this occurrence with an arrow that is pointed up or down. These arrows would be placed in the matrix corresponding to the cause and effect. For example, in Table 3.5 if $D_1(P_{D1}=100\%)$ were to occur and there is a positive cross impact influence on D_3, this would be depicted with an arrow pointing up. If there is a negative cross impact that would be depicted with a down arrow and finally if there was not a relationship the cell in the matrix would be left blank or a horizontal line used for the non-occurrence.

Table 3.5 Forecasting cause and effect relationships in a cross-impact matrix (from Gordon and Hayward 1968)

	Then the probability of			
If this development occurs:	D_1	D_2	D_3	D_4
D_1	■	--	--	↑
D_2	↑	■	--	↑
D_3	--	--	■	--
D_4	--	--	--	■

This research will use a similar approach to the Gordon and Hayward (1968) method for their forecasting measurement of interactions. But instead of forecasting and having initial probabilities of whether the development will occur, there will be an assumption that the safety program element is implemented and the measurement of the interactions that element has on the other highly-effective safety program elements will be measured in a percent increase or decrease in effectiveness. An example of the cross-impact interaction measurement is given in Figure 3.2. This survey sheet represents the effects that one element (cause) has on the other elements. The element represented as the cause is a site-safety manager.

Figure 3.2 Example of measurement of interactions

DIRECTIONS: Put an "**X**" in the box that indicates the percent increase that a **SITE-SAFETY MANAGER** has on the effectiveness of each safety program elements listed.

Safety Program Element	Negative Influence	**Percent increase that a SITE-SAFETY MANAGER has on the effectiveness of the indicated safety program element**											
		0	10	20	30	40	50	60	70	80	90	100	>100
Project Safety Incentives													
Site-Specific Safety Plan													
Substance Abuse Programs													
Safety and Health Committees													
Training and Regular Safety Meetings													
Worker Participation and Involvement													
On-site First Aid													
Safety and Health Orientation													
Job Hazard Analyses													
Subcontractor Selections and Compliance													
Record Keeping and Accident Analyses													
Emergency Response Planning													
Upper Management Support													
Frequent Safety Inspections													

The scale used for this research has the potential to increase the effectiveness of another element by greater than 100% and also this can go in the negative direction. Since these possibilities have the potential to be undefined, a column is used for the authors to define how much greater than 100% the element contributes to the others' effectiveness. This is also done for the other direction, in the event the element has a negative influence on the effectiveness of the other elements. In addition, there is the possibility of no interaction between the safety program elements and that was defined as 0%.

3.2.3.4 Cross-Impact Summary

Cross-impact analyses are a method for estimating interactions between events or elements and are often used when objective data is not available. The steps to perform a cross-impact analysis have been found to include: define the elements to be included in the matrix, create cross-impact matrices to define the interrelationships between the elements, define how the interactions or interdependencies will be measured, estimate the entries in the matrix, i.e., the impact of that each element has on the effectiveness of all other elements, perform the cross-impact analysis, and evaluate the quantified results. The following section will describe the Delphi method and how it was used in conjunction with the cross-impact analyses to quantify the interactions between the elements of a highly-effective construction safety program.

3.3 Delphi Method

The Delphi method was developed by a group of researchers working for the RAND Corporation in the mid 1950's within the field of forecasting and planning (Dalkey and Helmer 1963). Since that time, the Delphi method has been applied in numerous research areas that have included: transportation, real estate, finance, environmental, health care, academia, construction, and many more (Gupta and Clarke 1996). The method has proven useful in these fields when objective data is not feasible, experimental research is impossible, or empirical evidence is deficient (Hallowell and Gambatese 2010). This is especially true for construction engineering and management research and specifically applies to this study. Hallowell (2009) describes many challenges to safety and health risk management research. The following Table 3.6 is modified from Hallowell (2009) and demonstrates the challenges and how the Delphi method can be used to address each challenge for this study.

Table 3.6 Applicability of the Delphi method to safety and health research (from Hallowell 2009)

Characteristics of Safety and Health Research	Applicability of the Delphi Method
Archival data is incomplete	Delphi offers an alternative judgment-based method of obtaining highly-reliable data
Experiments are unethical and unrealistic	Delphi typically requires no input of experimental data and relies only on judgment of experts
Incidents exist on a relatively long timeline	The judgments of expert participants utilize years of professional and academic experience
The field of study is complex and involves many confounding factors	The use of judgment from expert panelists allow researchers to separate the effects of desired factors from confounding factors in a properly designed survey
Expert knowledge of the topic required to accurately rate the interrelationship	Delphi is characterized by the use of a prequalified group of experts in an effort to achieve consensus of opinion
Broad topics and number of ratings are outside the scope of one expert	Delphi studies typically involve 8-12 highly qualified individuals that have met a minimum level of expertise
Experts are geographically dispersed and funding for research is limited	Anonymity and the use of e-mail allows any expert with internet access or a mailing address to participate from their location
The impact of research on human welfare may be significant	Delphi is highly-rigorous and preferred over all other judgment-based techniques

3.3.1 Characteristics of the Delphi Method

The purpose of the Delphi method is to extract unbiased information that deals with complex problems on uncertain issues (Linstone and Turoff 1975). The unbiased information is gathered from a formalized method of communication that is characteristic of anonymity, iteration with controlled feedback, and statistical response around a panel of independent experts to gain a reliable consensus (Dickey and Watts 1978). The following will discuss the nature of these characteristics of the Delphi method.

Anonymity

During a Delphi study all experts maintain their anonymity from the other participants (Linstone and Turoff 1975). The purpose of this prevents a dominating effect that some participants may exhibit as a personality trait or through authority. For example if anonymity is not followed, a leading researcher may use their authority that they have in the field to influence other panelist responses. Anonymity will also allow the experts to freely express their opinions, while encouraging an open forum to voice opinions (Dickey and Watts 1978).

Iteration with Controlled Feedback

According to Linstone and Turoff (1975), the Delphi method consists of several iterations of surveys that are also termed rounds. The purpose of the iterations with controlled feedback is to inform the experts about the opinion of the other experts. Through these rounds the experts are able to change their opinion or provide justification as to why they differ from the others. Through these iterations the facilitator aims to bring the group to a pre-established targeted consensus rate (Dickey and Watts 1978).

Statistical Response

Through the iterations with controlled feedback while conducting a Delphi survey will usually result in a great deal of statistical data. This statistical data can be represented and presented to the expert panel in a number of ways. The purpose of the statistical response is to aggregate the responses and compare each individual response to the group. This individual feedback is presented to the expert in subsequent rounds. The statistical measures used have included reporting the mean or median (Dickey and Watts 1978).

According to Hallowell and Gambatese (2010), a difficult aspect of the Delphi technique is selecting how this statistical response will be aggregated. For this study, the absolute deviation was used as a statistical measure over standard deviation. By selecting the absolute deviation, the variability of the response was about the median rather than the mean. The absolute deviation is the absolute difference between that element and a given point. The given point for this study was the median of the group. The purpose of selecting the median was to minimize the effect of biased responses and outliers (Hallowell and Gambatese 2010).

3.3.2 Application of the Delphi Method in CEM research

Hallowell and Gambatese (2010) identified seven research studies that have used the Delphi method on a construction related study (Arditi and Gunaydin 1999; del Cano and de la Crux 2002; de la Cruz and del Cano 2006; Gunhan and Arditi 2005a; Gunhan and Arditi 2005b; Hyun et al. 2008; Robinson 1991). From that study, the researchers found widespread variability with how the Delphi method was implemented. Hallowell and Gambatese (2010) found the variations to include:

- Differing requirements of what an “expert” is
- Appropriate methods for data collection was not selected
- Differing strategies with feedback that occurs with the expert panel

- Number of rounds completed
- Inconsistent consensus measures

Prior to applying the Delphi method to this study, a detailed literature review was completed to avoid these variations that have resulted in criticism towards the Delphi method in the past. Through that review, an article was found by Hallowell and Gambatese (2010) who suggested a procedure for conducting a Delphi study when conducting CEM research. The procedure that was followed for this study is given in Figure 3.3 from Hallowell and Gambatese (2010).

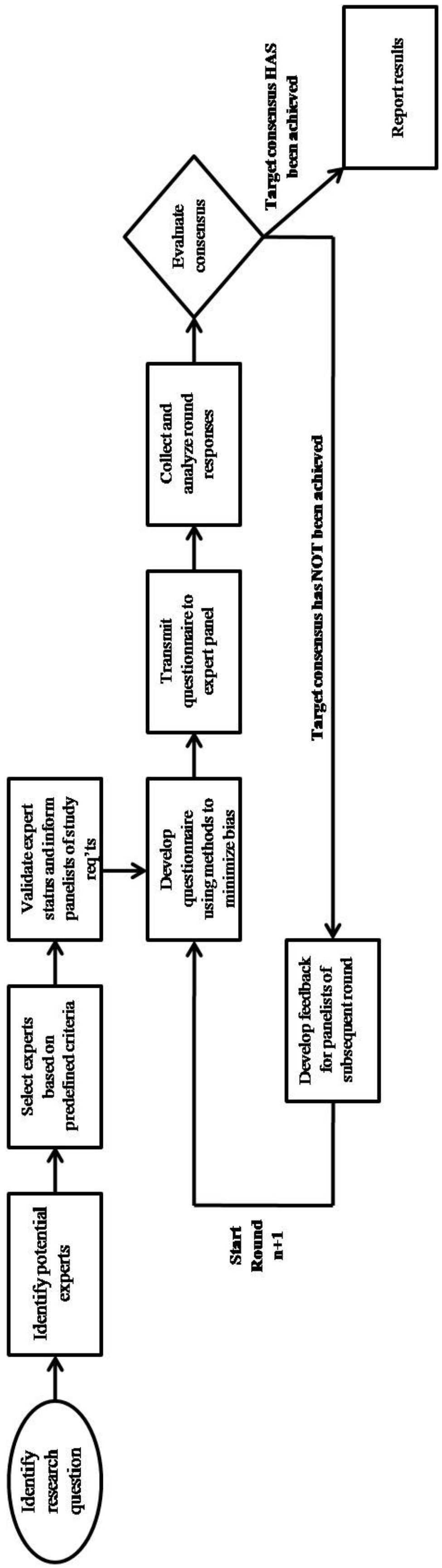

Figure 3.3 Suggested Delphi procedure (from Hallowell and Gambatese 2010)

The Delphi method has been criticized by some due to the short-cuts and modification to the prescribed research method (Sackman 1974; Armstrong 1978). To avoid that criticism for this study, the following sections present how the research design for this study was modeled after specific guidelines developed by Hallowell and Gambatese (2010) for construction engineering and management research. These specific guidelines developed by Hallowell and Gambatese (2010) include the following headings that will be discussed in the next sections:

- Minimization of bias
- Expertise requirements
- Number of panelists
- Number of rounds and feedback provided
- Target consensus
- Survey design

3.3.3 Minimizing Bias

Minimizing biases are vital for any research method that is being employed for a study. If these biases are not considered, the researcher brings into question the accuracy of the results that were found. In particular, minimizing biases is important when conducting a Delphi study because it offers the researcher the ability to obtain consistent, valid, and reliable results (Hellmer 1972; Turoff 1972; Ezner 1972). Due to a handful of researchers not taking this into account, the Delphi method has received criticism in the past for allowing significant bias and calling into question the validity of the study. This can be avoided by understanding the judgment based biases that are present and eliminating or at the very least minimizing them through the research design. Hallowell (2009) compiled the judgment-based biases when using the Delphi method and the applicable biases to this research study are presented in Table 3.7.

Table 3.7 Judgment-Based Biases (from Hallowell 2009)

Bias	Source(s)	Description
Collective unconscious	Durkheim (1982)	The theory of collective unconscious (i.e., the bandwagon effect), states that decision makers tend to join a popular trend. In other words, individuals are likely to unconsciously feel pressure to conform to the common or standard beliefs within a particular group.
Contrast effect	Bjarnason and Jonsson (2005)	The contrast effect occurs when the perception of a given subject is enhanced or diminished by the value of the immediately preceding subject. In theory, the contrast effect can cause significant bias, especially when individuals are asked to rate back-to-back factors.
Von Restorff effect	Restorff (1933); Krimsky and Golding (1992)	The Von Restorff Effect was first introduced to the field of psychology when subjects were found to recognize and remember relatively extreme events more often and more accurately than less extreme events. In theory, individuals are more likely to remember events associated with severe outcomes thereby distorting the perception of probability. This effectively creates an artificially inflated risk score for potential events associated with a higher level of severity.
Recency effect		The recency effect occurs when subjects are more likely to artificially inflate risk ratings because similar incidents have recently occurred in their personal lives (i.e., recent events are given inappropriate levels of salience in relation to others). The effect of recency is relatively common.
Primacy Effect		The primacy effect results from the unconscious assignment of importance to initial questions, observations, or other stimuli. The theory states that individuals are inherently more concerned with initial stimuli.
Dominance	Linstone and Turoff (1975)	Dominance occurs when one, usually very vocal group member, exhibits great control over the ratings of the other members. This common source of bias is typical in studies that attempt to gather group opinion such as the Nominal Group Technique or focus groups.
Myside bias	Perkins (1989); Baron (2003)	Myside bias occurs when an individual generates arguments only on one side of an issue. Participants can be easily prompted for additional arguments on the other side, although this is usually ineffective due to the person's opinion that may or may not be based on fact.

After identifying the judgment based biases related to this study, the researchers minimized or controlled the potential effects through implementing a set of techniques presented by Hallowell (2009). These techniques used for this study include:

Randomization of questions in the survey

Randomization is the foremost way to minimize bias by guaranteeing that every element has an equal chance of being selected. For this study, a random number generator was used in Microsoft Excel to individualize each survey for each expert on the panel. This method was used for randomizing two variables. First, for each cross-impact analysis, the causes were randomized so the order of cross-impact analyses was different for all. Secondly, the effects for each cross-impact analysis were also randomized. This randomization was conducted for the first round of surveys and then each individual survey order was used for the subsequent rounds. Through randomizing the order of the causes and effects, the contrast and primacy biases were effectively eliminated (Hallowell 2009).

Include reasons in controlled feedback

Including reasons in controlled feedback is a necessary characteristic of the Delphi method according to Linstone and Turoff (1975). In addition, Best (1974) conducted a study that found Delphi studies that included feedback with reasons in addition to statistical response had significantly more precise results than studies that just used statistical response as feedback. By using this technique, the Von Restorff effect, myside bias, and the collective unconscious.

Conduct multiple rounds of surveys

Iteration is a critical characteristic of the Delphi method noted by Linstone and Turoff (1975) because through each round the group can be brought to a consensus. By using iteration and anonymity, dominance bias can be eliminated while minimizing the Von Restorff effect (Hallowell 2009).

Identify individuals that have experienced recent or relevant events

During the qualification of the expert panel, each panelist was asked if they had any recent experience that would inhibit them participating on the panel. Out of the thirteen initial panelists that were qualified, none indicated any experience that would hinder their participation. By asking this up front, the potential consequence of the recency effect was eliminated (Hallowell 2009).

Report results as medians rather than means

It has been stated previously that reporting results as medians rather than means because the outlier responses have little or no impact on the absolute deviation. In addition, by using this method, all types of biases can be minimized.

3.3.4 Expert Requirements

In order to be considered a Delphi study the panelists must be qualified as experts using objective criteria prior to initiating the first round of data collection. As is customary, the demographic data that was used to qualify individuals as experts was obtained during an introductory survey. Rogers and Lopez (2002) suggest that each expert panelist meet two of the following requirements:

1. Authorship
2. Conference presenter
3. Member or chair of a relevant committee
4. Employed in the relevant industry with at least five years experience
5. Employed as a faculty member that has done research in the relevant area.

In another study, Veltri (1985) suggests a more subjective selection process that requires the participants to meet four requirements that include:

1. Have a quality performance record in the relevant area
2. Have the ability to devote the time necessary for the study
3. Hold a level of objectivity within the relevant field
4. Have the time and energy to be fully dedicated to the research at hand

According to Hallowell and Gambatese (2010), the subjective nature of these guidelines will qualify many participants, but the validity of the results may be given up.

Rajendran and Gamabatese (2009) and Hallowell and Gambatese (2009) created a more stringent procedure in selecting experts to enhance the validity of the results. This procedure required every panelist to meet at least four of the following eight characteristics related to the construction safety management in order to qualify as an expert for this study:

1. Primary or secondary author of at least three peer-reviewed journal articles on the topic of injury prevention in construction;
2. At least three presentations on a safety-related topic at a national conference;
3. Member of a national construction safety committee (e.g., ASCE site safety, CII Safety Community of Practice);

4. At least 5 years of professional experience in the construction industry with safety management responsibilities;
5. Faculty member at an accredited institution of higher learning with a research or teaching focus on injury prevention in construction;
6. Author or editor of a book or book chapter on the topic of injury prevention in construction;
7. Advanced degree in the field of civil engineering, construction engineering, occupational safety and health, or other fields directly related to this study, from an institution of higher learning (minimum of a BS); and
8. Designation as a Professional Engineer (PE), Certified Safety Professional (CSP), Associated Risk Manager (ARM), or a Licensed Architect (AIA).

The Delphi panel formed for this study was extremely well qualified to address this research topic. The panel included a mix of six academics (i.e., professors of full-time researchers in academic institutions) and four professionals (i.e., safety managers from large construction organizations and professional researchers). The education of the panel included seven panelists with a terminal degree of a PhD, two with an MS degree, and one with a BS all in related fields. Additionally, the collective panel authored 204 peer-reviewed journal papers, 13 books or book chapters, 348 peer-reviewed conference proceedings, and 49 trade publications on the topic of construction safety and health. While the majority of the panelists were employed at academic institutions during the study, the panel also had a wealth of professional experience including a collective 108 years of professional experience related to construction safety. Furthermore, five of the panelists were registered as Professional Engineers and three were Certified Safety Professionals. Finally, all panel members were actively participating on at least one national construction safety committee associated with the American Society of Civil Engineers (ASCE), the International Council for Research and Innovation in Building and Construction (CIB), or the Constriction Industry Institute (CII). These qualifications are summarized in Delphi summary as Table 3.8.

3.3.5 Number of Panelists

Delphi studies have had a large spectrum in the number of expert panelists involved and have ranged from less than 10 into the hundreds. Generally, the number of panelists depends on the number of experts available on the particular topic, the expected volume of data and time requirements, and the ability and sophistication of the facilitator. Brockhoff (1975) and Boje and Murnighan (1982) studied the impact of the number of panelists on the level of accuracy of the Delphi method and concluded that the appropriate number of panelists for the typical Delphi study ranges from 8 to 15. For the present study the authors targeted an initial group of 15 experts in the case that one or more of the panelists defaulted during the series of survey rounds. Of the fifteen participants who were targeted, 10 agreed to participate and successfully completed all survey rounds.

3.3.6 Number of Rounds and Feedback Provided

The Delphi method is characterized in part by the use of multiple rounds and feedback provided between rounds. Most literature indicates that the Delphi process should continue for as many rounds as it takes to achieve the desired consensus. However, other literature indicates that Delphi results are most accurate after rounds two and three and become less accurate as a result of additional rounds (Dalkey et al. 1972). Hallowell and Gambatese (2010) suggest three rounds because this tends to be adequate for achieving consensus and implementing the controls to minimize bias. In this study the authors elected to conduct three rounds of surveys with detailed feedback provided at the beginning of rounds two and three.

Providing adequate and strategic feedback allows expert panelists to anonymously consider the opinions and experiences of other members without being subjected to time consuming discussions, which are also prone to dominance, myside, and collective unconscious biases. Feedback is usually provided in terms of written feedback and quantitative statistics from previous rounds (Linstone and Turoff 1972). To ensure adequate feedback that would promote consensus, this study involved controlled feedback at the beginning of rounds two and three. In round two the median interaction ratings from the previous round were provided to all panelists in addition to their personal rating from the previous round. During round two, panelists were asked to provide reasons if they believed that the true value for a particular rating deviated more than 10% from the group median from round 1. In round three the panelists were provided with the median ratings from the second round, their personal rating from the second round, and the reasons provided by all panelists for outlying responses.

3.3.7 Format of Delphi rounds

The Delphi study was conducted over a four month period with approximately one month dedicated to each survey round and one month for the initial expert qualification. The expert qualification was completed with a two page questionnaire that was emailed to any respondents that agreed to participate. The intention of this survey was to identify the potential participants personal, academic, and professional information related to safety and health in the construction industry. The introductory survey has been included as Appendix A.

The length of each Delphi round consisted of a month in duration. This was deemed necessary because each panelist was asked to provide 210 ratings per round for all three rounds. For each of these rounds, an individualized survey was made for each of the participants to minimize the biases that were discussed in the previous chapter. Once the surveys were created they were emailed to all participants with the exception of one that was mailed due to their remote location. An example of one survey has been included in Appendix B.

As previously stated in Chapter 3, one of the characteristics of the Delphi panel is statistical response and feedback. The statistical response and feedback for this study included the participants' previous ratings, along with the group median for each relationship. The statistical response was aggregated after round 1 and presented in the individualized survey for round 2. This was also done after round 2 and in the event the participant deviated from the median by 10% above or below the median, they were asked to provide justification for their outlying response. These responses were also presented in round 3 for all the participants to consider. This justification for outlying responses was also a criterion in the final round of the study. The final results from round 3 were also aggregated, but not presented to the participants since the study had concluded. An example of how the statistical response and feedback were presented to the panelists is included in Appendix C. In Appendix D, this is followed by a round 3 survey that shows how the respondent's feedback was provided for all participants to consider.

3.3.8 Target Consensus

The primary objective of any Delphi study is to achieve consensus in opinion among a qualified group of experts with regard to a specific area. This means that measuring consensus is an integral component of the Delphi process. Most quantitative studies use standard deviation of absolute deviation to measure consensus depending on whether the facilitator elects to report the results in terms of median or mean responses (Hallowell 2009). In the present study the researchers set the goal of achieving an ultimate absolute deviation (i.e., average deviation from the median) of < 0.10 or less than 10%. At the end of round three, the consensus was calculated to be 11.99%, which was nearly 2% more than the target consensus. Another round was deemed unnecessary because less than 5% of the median scores had changed from the second to the third round. Although the target consensus was not reached, the validity of the results was still kept since reaching the target consensus would have little effect on the medians.

3.3.9 Survey Design

As indicated, the Delphi panelists were asked to rate the interactions among safety program elements as measured by a percent increase or decrease in effectiveness. Each pair wise interaction was considered independently. Furthermore, the interactions were considered to be two-way interactions. For example, the impact that a safety manager has on the effectiveness of job hazard analyses was considered independently from the impact that job hazard analyses have on the effectiveness of safety managers. For clarity an example survey sheet from round 1 of the Delphi process has been provided and discussed as Figure 3.2 in the cross-impact analysis section.

The first round of the Delphi survey was an emailed survey representing a cross-impact analysis of 15 highly effective safety program elements. During this round of the Delphi survey, the expert panel members were asked to rate the influence that each construction safety program element has on the effectiveness of the other elements in percent increase or decrease.

In round two of the Delphi method, the medians of the group were presented to each expert on a survey with their response. Each panelist was encouraged to review the medians of the group and consider revising their previous response. In the event that their rating was two or more standard deviations from the median of the group, the panelist was asked to provide a reason for their response. The goal of this round was to decrease the variability of the responses and achieve a group consensus about the correct value (Linestone and Turoff, 1975)

The third round was similar in nature to the second and the medians from the second round were presented to the panelists and were encouraged to re-evaluate their score based on the consensus of the group. In the event the expert's response still varied from the rest of the experts, they were again asked to provide a reason to justify and support their response.

3.3.10 Delphi method Summary

The Delphi method was deemed to be the most applicable methodology for quantifying the interactions between the fifteen highly-effective safety program elements that have were identified through previous studies. Ten experts that completed the Delphi rounds were qualified to participate in this study. The Delphi panel was highly qualified and the characteristics of the group are presented in Table 3.8.

Table 3.8 Summary of Delphi panel characteristics

Panel characteristics related to construction safety	
Number working in Academia	6
Number working in Industry	4
Panelists holding a BS	10
Panelists holding a MS	8
Panelists holding a PhD	7
Number of peer-reviewed journals	204
Number of books or chapters	13
Number of conference proceedings	348
Number of trade publications	49
Number of years industry experience	108
Number of Professional Engineers	5
Number of Certified Safety Professionals	3
Chair or member of a committee	10

The following chapter will present the results and consensus for this study by this Delphi panel.

CHAPTER 4

RESULTS

4.1 Preface

The main objective of this study was to quantify the interrelationships among highly effective safety program elements in the construction industry. To fulfill this objective, the research question developed and considered by the Delphi panel in the analysis was:

- What is the increase or decrease in effectiveness that each safety program element has on the others. This was completed for the 15 elements discussed previously.

This chapter is divided into five main parts. First, the discussion begins with the overall contribution of the research study. This section is followed by the characteristics of the initial Delphi panel and is followed by how the results were collected from the participants. The third section describes how the expert panel consensus evolved throughout the study. Finally, the chapter concludes with the results gathered from the expert panel and identifies the critical interactions experienced in a safety program.

4.2 Overall Contribution

The overall contribution, after the expert panel quantified the interrelationships of the elements, was a cross impact matrix of each highly-effective safety program elements. Through the cross-impact analysis, the most significant interrelationships of construction safety program elements were identified. Finally, the measures of impact of each element on the overall effectiveness of the safety program were identified by total contribution received from the other elements and the total contribution made to the other elements is given. These data has the potential to help small construction firms that operate on a limited safety budget to optimize the effectiveness of their current safety program.

4.3 Characteristics of Panelists

A large factor in the success of a Delphi study is the quality of the experts (Linstone and Turoff 1975). For this study, 13 participants were qualified as experts within the field of construction safety. Of the 13 participants that agreed to participate eight (62%) are academics in the construction discipline and have a research focus in the field of health and safety and five (38%) professionals that have had experience as safety managers for large construction companies and professional researchers.

The initial Delphi panel consisted of a diverse group of experts. Three countries and ten U.S. States were represented as locations where the experts work within the construction field. Out of these thirteen panelists, ten (77%) fully completed the study. The reasons that the three panelists defaulted included:

- “I was unaware of the time commitment that this study required and I have too many obligations at this time to fully participate.”
- “I have worked my way up from safety into upper management and I have been away from the field too long to effectively rate these relationships.”

- “I have done research in the field of safety, but I do not have the experience to complete this survey.”

All of the defaulting respondents declined to participate during the first round of the study; therefore no data from those participants were used for any of the statistical response. The validity of results is elevated if all of the panelists that submit responses continue through until the final round of the study (Linstone and Turoff 1975).

The results collection went through three rounds of the Delphi method. Ten of the original thirteen panelists completed all three survey rounds resulting in 630 ratings per expert and a total of 6,300 ratings were gathered from the expert panel over four months.

4.4 Consensus through Delphi Method

As previously indicated, one of the benefits of the Delphi method is the ability to achieve consensus within a group. After the first round, the absolute deviation of all the medians, also termed the average of the absolute deviation, for the safety program elements among the group resulted in a total consensus of 25.90%. Following the second round, the absolute deviation was 19.40% and after the third round the absolute deviation was 11.99%. The absolute deviation by safety program elements through the three rounds is given in Table 4.1 and shows how the group came closer to consensus through the course of the study.

Table 4.1 Absolute deviation by safety program elements

Safety Program Element	Absolute Deviation (%) Round 1	Round 2	Round 3
Emergency Response Plan	20.79	13.54	5.45
Frequent Inspections	27.36	18.14	10.71
Job Hazard Analyses	24.57	18.43	11.89
On-site first aid	18.14	13.64	5.61
Project safety incentives	26.14	18.75	11.36
Record Keeping & Accident Analyses	27.86	22.00	9.07
Safety & Health Committee	28.64	22.82	18.25
Safety & Health Orientation	27.43	21.18	8.52
Site-Safety Manager	21.21	14.75	11.48
Site-Specific Safety Plan	30.50	23.89	19.13
Subcontractor Management	29.43	24.07	14.71
Substance Abuse Programs	23.43	17.00	8.86
Training & Regular Safety Meetings	29.29	23.29	16.48
Upper Management Support	22.86	17.61	13.50
Worker Involvement	30.86	21.96	14.77
Average of the Absolute Deviations	**25.90**	**19.40**	**11.99**

Although the group did not come to the target consensus of 10%, a fourth round of surveys was deemed to be unnecessary because 95% of the medians remained unchanged between rounds two and three. In addition, each Delphi panelist had already produced 630 ratings (210 ratings per round) and had provided a significant time contribution to this study. The final reason a fourth round was not employed was due to Dalkey et al. (1972), who found that Delphi studies become increasing less accurate after the third round.

4.5 Delphi Panel Results

Once the acceptable consensus was reached among the ten panelists, the median ratings for the group were calculated and are presented in Table 4.2. As one can see from this table, all of the cross-impacts are positive. In other words, the results indicate that all of the injury prevention strategies have a positive relationship with one another. Only one interaction, the impact of recordkeeping and accident analyses on substance abuse programs, resulted in a 0 percent impact. The majority of the interactions resulted in cross-impact ratings of between 30 and 60 percent. These ratings will be discussed further in chapter 5.

The deviations for each interaction were averaged among all the panelists and are presented in Table 4.3. As one can see from this table, the deviations from the median vary from 0 percent deviation to 28. The low of 0, indicates that all experts agreed that an emergency response plan can increase the effectiveness of a substance abuse program by 30%. The larger deviations indicate there was more disagreement among the experts. The highest deviation was the impact that training and regular safety meetings have on the effectiveness of the safety and health orientation. The potential explanation for this will be discussed in chapter 5.

Table 4.2 – Pair wise cross impacts of construction safety program elements

Impact OF \ Impact ON (Percent increase in effectiveness)	Emergency Response Plan	Frequent Inspections	Job Hazard Analyses	On-site First Aid	Project Safety Incentives	Record Keeping	Safety & Health Committee	Safety & Health Orientation	Site-Safety Manager	Site-Specific Safety Plan	Subcontractor Management	Substance Abuse Programs	Training & Regular Safety Meetings	Upper Management Support	Worker Involvement
Emergency Response Plan		5	18	23	0	8	25	8	16	25	25	30	16	20	30
Frequent Inspections	13		70	15	38	48	55	23	75	51	33	10	55	33	55
Job Hazard Analyses	25	65		10	10	30	25	15	60	79	25	5	35	50	55
On-site First Aid	30	5	10		0	10	0	0	10	15	3	0	5	0	13
Project Safety Incentives	0	35	30	0		0	18	10	38	16	10	40	16	40	70
Record Keeping	15	30	28	10	20		30	20	46	20	30	0	20	50	30
Safety & Health Committee	30	54	45	13	55	40		40	53	60	33	33	60	50	80
Safety & Health Orientation	20	30	28	20	20	35	28		33	30	10	30	40	13	43
Site-Safety Manager	50	90	80	45	50	60	45	75		85	50	60	85	53	85
Site-Specific Safety Plan	40	60	60	26	25	34	53	50	50		40	50	50	35	55
Subcontractor Management	25	45	48	19	18	35	30	25	40	41		25	28	30	41
Substance Abuse Programs	5	18	23	5	8	25	8	16	25	25	30		16	20	30
Training & Safety Meetings	46	63	65	10	15	35	38	48	50	50	13	35		13	78
Upper Management Support	55	64	50	29	70	65	79	58	80	80	80	70	66		70
Worker Involvement	46	39	65	30	45	55	70	55	45	60	13	45	65	20	

Table 4.3 Average deviations from the medians for each pair wise cross impact studied of the safety program elements

Impact OF \ Impact ON (Average deviations from medians)	Emergency Response Plan	Frequent Inspections	Job Hazard Analyses	On-site First Aid	Project Safety Incentives	Record Keeping	Safety & Health Committee	Safety & Health Orientation	Site-Safety Manager	Site-Specific Safety Plan	Subcontractor Management	Substance Abuse Programs	Training & Safety Meetings	Upper Management Support	Worker Involvement
Emergency Response Plan		7	7	11	1	14	3	2	8	7	4	0	5	5	4
Frequent Inspections	7		7	14	22	15	10	14	12	9	4	7	11	11	9
Job Hazard Analyses	14	16		9	4	17	6	13	20	9	9	11	10	11	19
On-site First Aid	12	4	6		2	6	4	1	6	12	3	6	7	2	8
Project Safety Incentives	8	15	15	3		5	14	12	9	10	12	16	10	14	17
Record Keeping	8	9	10	7	8		9	8	12	6	8	4	12	10	16
Safety & Health Committee	24	14	20	14	22	19		19	13	18	20	21	15	25	14
Safety & Health Orientation	13	5	10	7	11	8	9		9	9	7	11	7	6	9
Site-Safety Manager	12	11	13	14	15	12	11	11		10	9	10	10	11	13
Site-Specific Safety Plan	17	18	24	20	16	24	22	18	14		17	23	17	20	20
Subcontractor Management	13	13	20	6	19	16	11	16	15	19		18	13	14	16
Substance Abuse Programs	5	7	14	6	10	12	7	9	7	13	9		11	6	11
Training & Safety Meetings	18	19	21	5	9	20	17	28	13	21	16	21		13	12
Upper Management Support	16	14	15	18	14	13	14	10	10	9	13	19	12		14
Worker Involvement	12	10	20	13	20	15	15	18	9	14	12	18	17	16	

Table 4.4 and 4.5 were produced to visually highlight the cross-impact relationships that are most and least significant to a construction safety program. As one can see, a site safety manager plays a central role in enhancing the effectiveness of inspections, safety plans, safety training, worker participation, and job hazard analyses. Additionally, upper management support and commitment was found to significantly increase the effectiveness of the site safety manager,

safety plan, subcontractor safety management, and safety and health committees. These results may not be surprising because effective executives and safety managers tend to be well-educated, have a job function that involves integrating and involving multiple organizational units, and are ultimately responsible for implementing and managing safety-related activities within the organization. Conversely, in Table 4.5 the contributing elements of on-site first aid, substance abuse programs, and project safety incentives have little or no impact on increasing the effectiveness of other elements that include: safety and health committees, safety and health orientation, substance abuse programs, project safety incentives, emergency response plan, on-site first aid, and record keeping and accident analyses. The potential causes for this will also be discussed in chapter 5.

Table 4.4 Most significant interactions that increase the receiving elements by 75% or more

Contributing Element	Receiving Element	Receiving Element's Potential Percent Increase in Effectiveness
Site-Safety Manager	Frequent Inspections	90
Site-Safety Manager	Site-Specific Safety Plan	85
Site-Safety Manager	Training & Regular Safety Meetings	85
Site-Safety Manager	Worker Involvement	85
Safety & Health Committee	Worker Involvement	80
Site-Safety Manager	Job Hazard Analyses	80
Upper Management Support	Site-Safety Manager	80
Upper Management Support	Site-Specific Safety Plan	80
Upper Management Support	Subcontractor Management	80
Job Hazard Analyses	Site-Specific Safety Plan	79
Upper Management Support	Safety & Health Committee	79
Training & Regular Safety Meetings	Worker Involvement	78
Frequent Inspections	Site-Safety Manager	75
Site-Safety Manager	Safety & Health Orientation	75

Table 4.5 Relationships among construction safety program elements that do not contribute to the receiving element

Contributing Element	Receiving Element	Receiving Element's Potential Percent Increase in Effectiveness
Emergency Response Plan	Project Safety Incentives	0
On-site First Aid	Project Safety Incentives	0
On-site First Aid	Safety & Health Committee	0
On-site First Aid	Safety & Health Orientation	0
On-site First Aid	Substance Abuse Programs	0
On-site First Aid	Upper Management Support	0
Project Safety Incentives	Emergency Response Plan	0
Project Safety Incentives	On-site First Aid	0
Project Safety Incentives	Record Keeping & Accident Analyses	0
Record Keeping & Accident Analyses	Substance Abuse Programs	0

4.6 Conclusion

The purpose of this section was to illustrate the results of the Delphi method. The Delphi panel consisted of ten participants who successfully completed the whole Delphi procedure with each panelist providing 630 ratings for a total of 6,300 ratings, while reaching an overall consensus of 11.99%. It was found that the most significant contributing elements are site-safety managers, worker participation and involvement, and upper management support. These three elements have the potential to increase the effectiveness of other elements considerably and in some cases over 75%, the increases in effectiveness have been presented in Table 4.2. The elements that the Delphi panel quantified to have the least significance in contributing to the effectiveness of the other elements were found to include on-site first aid, project safety incentives, and substance abuse programs. The contributions that these elements provide are minimal and in some cases do not interact with the effectiveness of other elements. These relationships that do not interact are presented in Table 4.5. The next chapter will discuss the possible reasons for these findings.

CHAPTER 5
ANALYSIS

5.1 Preface

The objective of this chapter is to highlight three measures that can be used to identify the relative increase in effectiveness that a safety program will see by the inclusion of an element. These three measures are analyzed by the total contribution made and received by the other elements and used to calculate the total level of centrality of each element. To conclude the analysis, the total average deviations from the medians among the panelists' scores are calculated for each interaction and then averaged for each element. The purpose of this calculation is to show the level of consensus among the panelists for each interaction. The chapter concludes by identifying the safety program elements that are the most and least central to a safety program.

5.2 Overall Effectiveness

In the results section, the pair wise interactions among injury prevention strategies were highlighted. For the analysis, those pair wise interactions were analyzed to determine the degree to which specific elements contribute to the overall effectiveness of the safety program. It has been previously stated that elements can have a cause or effect on one another. The cause can also be thought of as the contribution made to another element, while the effect would be the contribution received from another element. Once these two contributions are quantified, the overall contribution or centrality can be calculated. Table 5.1 includes these three measures , which are defined as:

1. Total contribution ***received*** from the other fourteen elements measured as the sum of all impacts on a particular element (i.e., sum of the columns in Table 4.2);
2. Total contribution ***made*** to the other fourteen elements measured as the sum of all impacts made by a particular element (i.e., sum of the rows in Table 4.2);
3. The total level of centrality of a particular element as measured by the sum of the contributions made to and contributions received from the other elements.

These three measures are unit-less, but provide relative scores that indicate the contributing impact, receiving impact, and overall centrality. This analysis uses the sum of both the impact that a particular element has on the others and the amount that the element is impacted by others as a measure of centrality because it represents the relative increase in effectiveness that the inclusion of the element would have on the overall effectiveness of the safety program.

It should be noted that these three measures provide an indication of the impact that each element would have if integrated into a safety program that includes the remaining fourteen elements highlighted in this study. These values would change, however, if one or more elements were omitted from a program but could be simply calculated by summing the rows and columns of the remaining matrix.

From Table 5.1, the elements most central to the safety program are site safety manager, worker participation and involvement, and upper management support and commitment. This is understandable because these safety program elements are dynamic and involve human interactions through the implementation of each strategy. In addition, these findings further support previous research that has also found upper management support and commitment, safety managers, and worker participation and involvement are essential elements of an effective injury prevention program.

The elements that are least central to a safety program are on-site first aid, emergency response planning, and substance abuse programs. These findings are also logical because these safety program elements are applied to workers, but do not interact with the workers. The nature of this research looked at the interactions and therefore it is not a surprise that these elements were found to be the least central to the overall effectiveness of a construction safety program.

Table 5.1 – Measures of synergistic impact of each element on the overall effectiveness of the safety program

Safety Program Element	Total Contribution Received from Other Elements (Relative Unitless Score)	Total Contribution Made to Other Elements (Relative Unitless Score)	Sum
Site-Safety Manager	621	913	1534
Worker Involvement	735	653	1388
Upper Management Support	427	916	1343
Site-Specific Safety Plan	637	628	1266
Frequent Inspections	603	574	1177
Safety & Health Committee	504	646	1149
Training & Regular Safety Meetings	557	559	1116
Job Hazard Analyses	620	489	1109
Subcontractor Management	395	449	844
Record Keeping & Accident Analyses	480	349	829
Safety & Health Orientation	443	380	823
Project Safety Incentives	373	323	695
Substance Abuse Programs	433	254	687
Emergency Response Plan	400	249	649
On-site First Aid	254	100	354

5.3 Safety program element consensus

As previously stated, the overall consensus from the Delphi panel reached an absolute deviation rate of 11.99%. The consensus was calculated using the total average deviations that each participant had from the medians for each pair-wise interaction. These average deviations ranged from a high of 28% to a low of 0% and represent the level of consensus that the Delphi panel had for each interaction. The safety program elements that had the greatest and least consensus are presented in Table 5.2. The procedure for calculating these findings was similar to the previous section, in that the elements average deviations are found for both the contributions received and made. The relative unit-less columns from Table 5.2 are found in the following ways.

1. Total average deviations for contributions ***received*** from the other fourteen elements measured as the sum of all the average deviations on a particular element (i.e., sum of the columns in Table 4.2);
2. Total average deviations for contributions ***made*** from the other fourteen elements measured as the sum of all the average deviations on a particular element (i.e., sum of the rows in Table 4.2);
3. The total level of agreement for a particular element as measured by the sum of the contributions made to and contributions received from the other elements.

Table 5.2 – Safety program elements that had the largest difference in opinion

Safety Program Element	Total Average Deviations for Contribution Received from Other Elements (Relative Unitless Score)	Total Average Deviations for Contribution Made to Other Elements (Relative Unitless Score)	Sum
Site-Specific Safety Plan	165	268	432
Safety & Health Committee	150	256	405
Training & Regular Safety Meetings	155	231	386
Worker Involvement	179	207	386
Job Hazard Analyses	201	167	367
Upper Management Support	163	189	352
Subcontractor Management	141	206	347
Project Safety Incentives	171	159	330
Record Keeping & Accident Analyses	193	127	320
Site-Safety Manager	155	161	316
Frequent Inspections	161	150	311
Substance Abuse Programs	184	124	308
Safety & Health Orientation	178	119	298
Emergency Response Plan	177	76	253
On-site First Aid	145	79	223

The lower the sum implies the Delphi panel had a higher level of agreement. There was a high level relative agreement among the Delphi panel on the effectiveness of on-site first aid, emergency response planning, and safety and health orientation. In contrast, the site-specific safety plan, safety and health committee, and training and regular safety meetings had more disagreement amongst the Delphi panel on the contributions made and received for those respective elements. This disagreement can be translated into uncertainty. It is important to note that this uncertainty will be amplified if it is multiplied by another effectiveness rating.

5.4 Conclusion

From this analysis, the elements that are most and least central to an effective safety program were found. This was found by calculating the overall contributions received and made. The elements most central to a safety program were found to be site-safety manager, worker participation and involvement, and upper management support. On the other hand, the elements that are least central were found to be on-site first aid, emergency response plan, and substance abuse programs. Interestingly, there was relatively a high level agreement amongst the Delphi panel on the interrelationships of these elements that were the found to be the least central. The elements that were found to have the highest level of disagreement amongst the Delphi panel include: site-specific safety plan, safety and health committees, and training and regular safety meetings. The next section will introduce the validation method used for this study for the purpose of confirming these findings. The validation panel used for this study was completely independent from the participants of the Delphi panel.

CHAPTER 6
VALIDATION

6.1 Preface

The previous sections have presented the results of a cross-impact analysis that have quantified the synergistic effects between safety program elements relating to effectiveness. These interactions were then validated using individual structured interviews with the purpose of verifying the findings from the Delphi panel. This is an important and necessary step when conducting a research study because it verifies if the findings of a study are reliable or need further research. This chapter will discuss the methodology for conducting the validation interviews, followed by the validation panel characteristics, in addition to the validation design, and finally the findings from the validation participants are presented.

6.2 Validation Methodology

To verify the results from the Delphi panel, the researchers considered different research methodologies to use for validation. Due to the in-depth nature of the original Delphi results, phone interviews were elected as the best method to validate the findings. The phone interviews were structured with questions that will be defined in the validation design section. To validate the findings, it is important to note that the validation panelists were different participants than the Delphi panel.

There are many techniques that could have been used for the validation collection, but the advantages of structured interviews outweighed the other methods. Due to the dispersed geographical nature of the validation panelists, phone interviews were chosen as opposed to face-to-face. The advantages of conducting phone interviews allowed the researchers to dialogue with experts across the U.S. In addition, phone interviews allowed the researchers to "control" the questioning and structure the queries around the results from the Delphi panel for the purpose of extracting the necessary information while keeping the participants on-track.

There are limitations to all types of data collection techniques and phone interviews are no different. According to Creswell (2003), the limitations of phone interviews include the following:

- Indirect information is filtered through the views of interviewees
- Information is not gathered in the natural setting
- Interviewees may exhibit bias due to the presence of the interviewer
- Interviewees communication skills vary

These are all valid points and require discussion in relation to this research study. The discussion will begin with the first point that interviews provide "indirect" information.

The nature of the results for this study is subjective and based on opinion, which is why only experts were qualified to participate in the Delphi and validation panels. The construction safety management experience that the interviewees have related to safety element program effectiveness was critical to discover and document for this study. These views may be filtered through the eyes of the interviewees, but employing multiple interviews with different participants provided the opportunity to triangulate the results and arrive at a group consensus.

The second limitation Creswell (2003) identifies is concerned with the location of the interview. For this study the interviews were conducted over the phone. Although, the interviews were not conducted on a construction site, it was deemed unnecessary due to the extensive years of experience that the interviewees held. Although, the interviewees knowledge was attained from being on-site over many years of projects that will not be set aside once they go home for the day. Do to this it was not necessary to conduct the interviews on a construction site.

The third limitation that Creswell states implies that the researcher's presence may produce bias. To eliminate that limitation, the researchers provided the interview questions beforehand to provide time for the interviewees to consider prior to the interview. That way the unbiased opinions of the interviewees could be learned before presenting the results of the Delphi panel. In addition, many of these interviewees have over thirty years in the construction industry and it is unlikely that the presence of a construction graduate student will influence the responses of these construction safety veterans.

The final limitation concerning interviews has to do with the interviewees not being equally articulate and perceptive. This is definitely true and everyone is unique with different capabilities for voicing their opinion. To minimize this limitation, the questions for the interviewees were structured as opposed to being open-ended. In addition, these questions were given to the interviewees prior to the phone interview for the purpose of allowing time for the participants to formulate their thoughts fully.

In conclusion, although phone interviews have limitations, the researchers selected this methodology as the most effective way to validate the findings from the Delphi panel. To minimize the limitations of phone interviews, the validation design and expert qualification were structured around this goal. The following sections will discuss how the Delphi panel results were validated using qualified experts around a structured interview process.

6.3 Expert Characteristics

While the initial Delphi panel consisted of both academic and industry professionals, the validation panel was made up of entirely experts that were actively managing safety in the construction industry. These individuals who participated in the validation phone interviews were not part of the initial Delphi panel and consisted of eight construction safety experts. Collectively, these eight industry experts had a total of 320 years experience in the construction industry and were all members of the ASCE Site-Safety Committee or representatives from the Occupational Safety and Health Administration. To minimize bias, potential participants were randomly selected from both contact lists. Unpredictably, all eight individuals initially contacted agreed to participate in the validation effort resulting in a response rate of 100 percent.

6.4 Validation Design

To ensure consistency, each interviewee was supplied with the list of validation questions and the list of the safety program elements under investigation prior to the interview date. The validation questions included the following three questions:

1. Of the thirteen injury prevention strategies listed, which five are impacted the most by the other elements?
2. Of the thirteen injury prevention strategies, which five contribute the most to the effectiveness other elements?
3. Of the thirteen injury prevention strategies, which five pair-wise safety program element interactions are most significant?

6.5 Validation Results

Each phone interview was conducted one-on-one in a one-hour session. When appropriate, the questions were clarified to ensure proper validation. It should be noted that the results of the initial Delphi study were not discussed with the interviewees until after responses to the initial questions had been provided. Table 6.1 summarizes the responses from the validation interviews for validation question 1 and compares the responses of the interviewees with the initial Delphi results. Specifically, Table 6.1 shows the number of interviewees that selected each element as one of the top five elements that receive support from the other elements (question 1).

Table 6.1 – Comparison of validation results with initial Delphi results for elements impacted the most (Validation Question 1)

	Receiving Elements	
Safety Program Element	**Number of validation interviewees including element in top five (Q1)**	**Rank from initial Delphi (See Table 4)**
Frequent Inspections	7	5
Site-Specific Safety Plan	6	2
Training & Regular Safety Meetings	6	6
Worker Participation and Involvement	5	1
Job Hazard Analyses	5	4
Site-Safety Manager	3	3
Safety & Health Committee	2	7
Subcontractor Selections & Compliance	2	13
Record Keeping & Accident Analyses	2	8
Safety & Health Orientation	1	9
On-site First Aid	1	15
Upper Management Support	0	11
Substance Abuse Programs	0	10
Emergency Response Plan	0	12
Project Safety Incentives	0	14

Table 6.2 summarizes the responses from the validation interviews for validation question 2 and compares the responses of the interviewees with the initial Delphi results. Specifically, Table 6.2 shows the number of interviewees that selected each element as one of the top five elements that contribute the most to the effectiveness of the other elements (question

2). It is important to note that site-safety manager was identified as a top five receiver by the Delphi panel, but was ranked six by the validation panel. Instead the validation panel considered training and regular safety meetings as being impacted more. Interviewees believed that training and regular safety meetings can be impacted by a higher degree than a site-safety manager who is more of a contributor to the effectiveness of other elements.

Table 6.2 – Comparison of validation results with initial Delphi results for elements that contribute the most (Validation Question 2)

	Contributing Elements	
Safety Program Element	**Number of validation interviewees including element in top five (Q2)**	**Rank from initial Delphi (See Table 4)**
Site-Safety Manager	7	2
Upper Management Support	7	1
Site-Specific Safety Plan	6	5
Worker Participation and Involvement	6	3
Frequent Inspections	5	6
Training & Regular Safety Meetings	4	7
Job Hazard Analyses	2	8
Safety & Health Orientation	2	10
On-site First Aid	1	15
Safety & Health Committee	0	4
Subcontractor Selections & Compliance	0	9
Record Keeping & Accident Analyses	0	11
Substance Abuse Programs	0	13
Emergency Response Plan	0	14
Project Safety Incentives	0	12

As one can see from the comparison between the initial Delphi results and the results of the validation interviews, there was a great deal of consistency. In fact, five elements that receive the most support from the other elements identified through the Delphi analysis were also four of the top five elements identified in the validation interviews. Similarly, four of the five elements initially identified as the top contributing elements were also ranked in the top five in the validation interviews.

One will note that safety and health committee was identified as a top five contributor in the analysis of the original Delphi data, but was not ranked in the top five of the interviews. Rather, the validation interview panel identified site-specific safety plan as a top five contributor. Interviewees believed that safety and health committees tend to lose effectiveness for small projects, while a site-specific safety plan helps to establish a culture of safety at the initiation of every project. Despite these two conflicts, the overall, the responses to the first two questions provided very strong validation evidence for the relative rankings.

The objective of question three was to validate the synergistic interactions that were identified as the most significant to a construction safety program. A higher degree of variability was expected in the responses because the validation interviewees were asked to identify the top five interactions out of a possible 210 pair-wise interactions. Although there was a high degree of possibilities, 7 of the 10 most significant interrelationships were identified by 25% or more of the validation panel. Table 6.3 summarizes the results of the validation interviews and compares the results with the initial Delphi analysis.

Table 6.3 –Pair wise interactions ranked in the top five interactions by two or more validation interviewees

Contributing Element	Receiving Element	Number of experts that selected interrelationship as significant	Rank in initial Delphi analysis (out of 210 interactions)*
Upper Management Support	Site-Safety Manager	4	5
Site-Safety Manager	Job Hazard Analyses	3	5
Site-Safety Manager	Training & Regular Safety Meetings	3	2
Site-Safety Manager	Site-Specific Safety Plan	3	2
Training & Regular Safety Meetings	Worker Participation & Involvement	3	12
Site-Safety Manager	Frequent Inspections	2	1
Frequent Inspections	Job Hazard Analyses	2	14
Upper Management Support	Site-Specific Safety Plan	2	5

In the final step of the interview, the panelists were presented with the results from the Delphi panel. Upon looking at the Delphi panel results, the validation experts agreed with the overall findings of the study, while bringing up two important considerations. These two comments involved location and project size. Depending on these factors, one validation participant felt that there is a possibility that worker participation & involvement may be inhibited in some locations with the presence of unions. In addition, another validation panelist felt that some of the safety program elements are ineffective on smaller projects. Aside from those comments, the validation panel agreed with the results of the Delphi panel and there was not any major disagreement.

6.5 Conclusion

In conclusion, the Delphi panel results were validated using eight construction safety experts that had a collective total of 320 years of experience in the industry. The researchers conducted structured phone interviews with the validation participants who identified the top five elements that contribute and receive the most towards the effectiveness of the safety program. In each case, the validation panel identified four of the five elements that the Delphi panel also found. Finally, 25% or more of the participants validated seven out of the ten most significant pair wise safety element interactions that were identified by the Delphi panel.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Preface

Recent research has begun to introduce effectiveness rating systems with the purpose of being used to select the most effective injury prevention strategy to improve construction safety programs. This trend will likely improve the dismal safety record of the construction industry in the future by giving firms an objective way to select safety program elements as opposed to the present strategy of intuition and peer suggestion. The purpose of this study was to build upon these previous studies that have developed effectiveness rating systems for highly-effective injury prevention strategies. These rating systems have analyzed the safety program elements in isolation, but have not looked at the synergistic effects that these elements have on one another. This chapter will show how the results from this study can be used in conjunction with previous studies to develop a decision support system that is based on objective data that has been quantified. In addition, the chapter will conclude with limitations of this study and future recommendations.

7.2 Conclusion

The purpose of this study was to quantify the interrelationships between highly effective safety program elements using a Delphi panel of experts and to validate the findings with interviews of an independent panel of practicing professionals. Through this process 6,300 ratings were collected and analyzed with the experts coming to a consensus that the site-safety manager, worker participation and involvement, upper management support and commitment, and a site-specific safety plan play a central role in a highly effective safety program. The findings of this study are unique in that they quantify the contributions made and received by each safety program element rather than investigating the effectiveness of injury prevention strategies in isolation.

Safety decision support systems in the construction industry are becoming more common. The advent of these systems was for the purpose of helping contractors to not have to rely on informal methods when developing a safety program. Through this study the 2-way interrelationships between the effectiveness of fifteen highly effective injury prevention strategies was added to the existing body of knowledge. Previously there have been only research studies that have formulated the effectiveness of highly-effective injury prevention strategies acting in isolation.

7.2 Application

These results can be used to enhance safety programs by clarifying the significant interrelationships that have a higher probability of increasing the effectiveness of other elements within a safety program. The authors suggest that the findings be used by practicing professionals when selecting specific injury prevention strategies for potential integration into an existing safety program as elements that would contribute the most to the existing program.

As discussed in the literature review, other authors have published effectiveness ratings for safety program elements in isolation. These ratings can combined to find the average percent of maximum (POM) among all studies. This compilation of average POM ratings can be combined with the quantified interactions of this study to aid safety program element selection. Finding and comparing these contributions can be easily identified with a simple analysis where the percent increase in effectiveness for the addition of a new safety program element can be found by summing all of the average POM ratings that have been multiplied by the interaction (percent increase in effectiveness) for all of the existing elements that are present in the current safety program. The formula to find the percent increase in effectiveness (Eff_j) for adding a new safety program element to an existing safety program is as follows:

$$Eff_j = \sum[(A_j)(X_{ji})+(A_i)(X_{ij})]$$

Where:

A_j = Average POM rating for j

X_{ji} = Percent increase in effectiveness that j has on i

A_i = Average POM rating for i

X_{ji} = Percent increase in effectiveness that i has on j

An example of this simple analysis is presented in Table 7.1. This example uses the average POM ratings for safety program elements in isolation presented in Table 2.5. This example illustrates the increase in effectiveness of the overall safety program when combined with upper management support by each element. These percent increases are based on the POM ratings and the interactions quantified by this research for each element. This example shows that the greatest increase in the effectiveness that the overall safety program could experience is 171% if a site-safety manager is combined with upper management support. It is important to note that although this study analyzed the interactions among fifteen safety program elements, only the elements that have average POM ratings are listed in Table 7.1.

Table 7.1 Percent increase in effectiveness if combined with Upper Management Support

Safety Program Element		
Emergency Response Plan	=	(0.99(1+0.20))+(0.28(1+0.55)) = 1.622 - 0.99 = 0.632 / 0.99 * 100 = 64
Frequent Jobsite Inspections	=	(0.99(1+0.33))+(0.58(1+0.64)) = 2.268 - 0.99 = 1.278 / 0.99 * 100 = 129
Job Hazard Analyses	=	(0.99(1+0.50))+(0.68(1+0.50)) = 2.505 - 0.99 = 1.515 / 0.99 * 100 = 153
Record Keeping	=	(0.99(1+0.50))+(0.44(1+0.65)) = 2.211 - 0.99 = 1.221 / 0.99 * 100 = 123
Safety & Health Committee	=	(0.99(1+0.50))+(0.53(1+0.79)) = 2.434 - 0.99 = 1.444 / 0.99 * 100 = 146
Safety & Health Orientation	=	(0.99(1+0.13))+(0.59(1+0.58)) = 2.051 - 0.99 = 1.061 / 0.99 * 100 = 107
Site-Safety Manager	=	(0.99(1+0.53))+(0.65(1+0.80)) = 2.685 - 0.99 = 1.695 / 0.99 * 100 = 171
Site-Specific Safety Plan	=	(0.99(1+0.35))+(0.67(1+0.80)) = 2.543 - 0.99 = 1.553 / 0.99 * 100 = 157
Subcontractor Management	=	(0.99(1+0.30))+(0.65(1+0.80)) = 2.457 - 0.99 = 1.467 / 0.99 * 100 = 148
Substance Abuse Programs	=	(0.99(1+0.20))+(0.53(1+0.70)) = 2.089 - 0.99 = 1.099 / 0.99 * 100 = 111
Training & Safety Meetings	=	(0.99(1+0.13))+(0.67(1+0.58)) = 2.177 - 0.99 = 1.187 / 0.99 * 100 = 120
Worker Participation	=	(0.99(1+0.20))+(0.63(1+0.70)) = 2.259 - 0.99 = 1.269 / 0.99 * 100 = 128

This example uses an existing safety program that utilizes upper management support. Unfortunately, in most cases construction safety programs employ more injury prevention strategies and as a result, calculating the increase in effectiveness becomes increasingly more complex as more elements are considered. In addition, these values are relative percentages and perhaps a more intuitive way to view them would be through ranges.

An interesting conclusion of this study is that many of the injury prevention strategies that have been found to be effective in isolation (e.g., upper management support and site safety manager), also provide a high level of synergistic effect that enhances the effectiveness of other elements. Additionally, it should be noted that this study shows that an elements' impact on the effectiveness of an overall program depends more on synergistic effects than base-level effectiveness previously studies by researchers.

7.3 Limitations

Several limitations of this study should be noted. First, this study operated under the assumption that all safety program elements are being used consistently and effectively. However, in practice there are many approaches to implementing each strategy. Additionally, a second assumption was that the interactions are cumulative and that there are no diminishing returns as safety programs become more complex. This assumption may reduce the reliability of the results if diminishing returns do exist. Also, the study only focused on fifteen elements already identified by previous literature that is now nearly five years old. Therefore, the potential contributions of new safety management techniques and emerging technologies are not included in this analysis. Finally, the research methodology used for this study depended on expert opinion and is subjective in nature. Although, the biases that are inherent in this type of research were minimized, there still may be disagreement depending on the experiences of other experts within the field of construction safety. As a result, the exact percent increases that were quantified through this study should be evaluated as a range rather than the precise percent increase.

7.4 Recommendations

In concluding this study, there are a few recommendations for future research to build on these results from this study. First, future research may improve the quality of these finding through investigating these and new injury prevention strategies and to combine and analyze with this study to determine a perimeter around the most influential safety program elements. In addition, the findings of this research combined with previous effectiveness ratings for safety program elements in isolation can be complied into a decision support system to give firms a simple tool that helps them select the next most effective injury prevention strategy to add to their current safety program. Finally, cost data for each safety program element per project scope dollars can be combined with this decision support system for the purpose of selecting the most cost-effective element to add to a firm's current safety program. The authors predict that this simple tool will significantly help construction firms select safety program elements and eliminate the need to rely on the current method of intuition and peer suggestion for deciding what injury prevention strategies to join with their current construction safety program.

BIBLIOGRAPHY

Alarcon, L.F. (1992). “Project performance modeling: A methodology for evaluating project execution strategies.” Doctoral dissertation, University of California, Berkeley, California.

Best, R.J. (1974). “An experiment in Delphi estimation in marketing decision making.” Journal of Marketing Research, 11(1), 448-452.

BLS. (2008). "Bureau of Labor Statistics." Retrieved December 1, 2008, from http://www.bls.gov/iif/oshwc/cfoi/cfch0006.pdf.

Born, M. (1949). *Natural Philosophy of Cause and Chance*, Dover Publications, New York.

Bryman, A. (1996) *Quantity and Quality in Social Research*, Routledge, London.

Behm, Michael (2005). Linking Fatalities to the Design for Construction Safety Concept. *Safety Science*, 43(8): 589-611.

Best, R.J. (1974). “An experiment in Delphi estimation in marketing decision making.” *Journal of Marketing Research* 11:448-452.

Bradfield, r., Wright, G., Burt, G., Cairns, G., and Van Der Heijden, K. (2005). “The origins and evolution of scenario techniques in long range business planning.” *Futures* 37: 795-812.

Dalkey, N.C., and Helmer, O. (1963). “An experimental application of the Delphi method to the use of experts.” *Management Science*, (9):458-467.

Dalkey, N.C. (1972). The Delphi method: an experimental application of group opinion. In Dalkey, D.L. Rourke, r. Lewis, & D. Snyder (Eds.) Studies in the quality of life. Lexington, MA: Lexington Books.

Dickey, J. and Watts, T. (1978) *Analytic Techniques in Urban and Regional Planning*. McGraw-Hill, New York.

European Foundation for the Improvement of Living and Working Conditions (1991). From Drawing Board to Building Site (EF/88/17/FR). European Foundation for the Improvement of Living and Working Conditions, Dublin.

Everett, J. and Thompson, W. (1995). *Experience Modification Rating for Workers' Compensation Insurance*. Journal of Construction Engineering and Management, ASCE, 121(10: 66-79.

Findley, M., et al. (2004). "Safety Program Elements in Construction: Which ones best prevent injuries and control related workers' compensation costs?" *Professional Safety*, ASSE 49(2): 14-20.

Hallowell, M. R. and J.A. Gambatese (2009). "Construction safety risk mitigation." *Journal of Construction Engineering and Management*, ASCE Pre-Press.

Gambatese, J., Hinze, J., and Haas, C. (1997). "A Tool to Design for Construction Worker Safety." *Journal of Architectural Engineering*, ASCE, 3(1): 32-41.

Gambatese, J. (1998). "Liability in Designing for Construction Worker Safety." *Journal of Architectural Engineering*, ASCE 4(3): 107-112.

Gambatese, J. (2000). "Owner Involvement in Construction Site Safety." *Construction Congress VI: Building Together for a Better Tomorrow in an Increasingly Complex World*, sponsored by the American Society of Civil Engineers, Orlando, FL, February 20-22, 2000.

Gambatese, J., Behm, M., and Hinze, J. (2005). Viability of Designing for Construction Worker Safety. *Journal of Construction Engineering and Management*. 131(9): 1029-1036.

Gibb, A., Haslam, R., Hide, S., and Gyi, D., (2004). The role of design in accident causality. In: Hecker, S., Gammbatese, J., Weinstein, M., Designing for safety and health in construction: Proceedings from a Research and Practice Symposium, September 15-16, Portland, OR, USA, pp. 44-57.

Gordon, T.J. and Hayward, H. (1968). "Initial experiments with the cross impact matrix method of forecasting." *Future*s 1:110-116.

Gupta, U.G. and Clarke, R.E. (1996). "Theory and applications of the Delphi technique: a bibliography (1975-1994)." *Technological Forecasting & Social Change*, 53(2), 185-211.

Hallowell, M. R. and Gambatese, J.A. (2007). “A Formal Model of Construction Safety Risk Management.” *2007 Construction and Building Research Conference (COBRA)*, sponsored by the Royal Institution of Chartered Surveyors and Georgia Tech University, Atlanta, GA, September 6-7, 2007.

Hallowell, M.R. and Gambatese, J.A. (2010). “Qualitative Research: Application of the Delphi method to CEM research.” *Journal of Construction Engineering and Management*. 136(1): 99-107.

Hallowell, M.R. (2008). “A formal model of construction safety and health risk management.” Ph.D. Dissertation, Oregon State University, Corvallis, OR.

Hallowell, M.R. (2009). “Techniques to minimize bias when using the Delphi Method to quantify construction safety and health risks.” Construction Research

Congress, 339(151): 1489-98.

Hallowell, M.R. (2010). “Cost-effectiveness of construction safety programme elements.” *Construction Management and Economics*. 28:25.34.

Han, S.H. and Diekmann, J. (2004). "Judgment Based Cross-Impact Method for

Predicting Cost Variance for Highly Uncertain Projects." *Journal of Construction Research*, 5(2): 171-192.

Hill, D. C. (2004). *Construction Safety Management Planning,* American Society of Safety Engineers, Des Plaines, IA.

Hinze, J. (2002). Safety Incentives: Do They Reduce Injuries? Practice Periodical on Structural Design and Construction, ASCE 7(2): 81-84.

Hinze, J. (2006). *Construction Safety,* Second ed., Prentice Hall, Englewood Cliffs, NJ.

Huang, X. and Hinze, J. (2006). *Owner’s Role in Construction Safety*. Journal of Construction Engineering and Management, ASCE 132(2): 164-173.

Jaselskis, E.J., et al. (1996) *Strategies for Achieving Excellence in Construction Safety Performance*. Journal of Construction Engineering and Management, ASCE 122: 61-70.

Levitt, R. and Parker, H. (1976). *Reducing Construction Accidents-Top Management's Role*. Journal of Construction Division, ASCE 102(3), 465-478.

Levitt, R. and Samelson, N. (1993). *Construction safety management*, 2nd Ed., Wiley, New York.

Lewis, D. (1973). "Causality." *The Journal of Philosophy*, 70:556-567.

Linestone, H. and Turoff, M. (1975) *The Delphi Method: Techniques and Applications*, Addison Wesley, Reading, MA pp 3-12.

Liska, R. and Goodloe, S. (1993) *Zero Accident Techniques: A Report to the Construction Industry Institute*. Source Document #86, Austin, TX: University of Texas.

Meridian Research (1994). "Worker Protection Programs in Construction: Final Report." Silver Spring, MD; Meridian Research.

Molenaar, K.R., Park, J. and Washington, S. (2009). "Framework for measuring corporate safety culture and its impact on construction safety performance." *Journal of Construction Engineering and Management*, 135(6), 488-96.

National Occupational Research Agenda. (2008). "National Construction Agenda." Retrieved December 1, 2008, from

http://www.cdc.gov/niosh/NORA/comment/agendas/construction/pdfs/ConstOct2008.pdf

Singh, A., Hinze, J., and Coble R. (1999). *Implementation of Safety and Health on Construction Sites*. Balkema, Rotterdam. Netherlands.

Rajendran, S. (2006). Sustainable Construction Safety and Health Rating System. Civil Construction and Environmental Engineering. Corvallis, Oregon State University. Doctorate.

Rajendran, S. and Gambatese, J.A. (2009). "Development and initial validation of sustainable construction safety and health rating system." *Journal of Construction Engineering and Management*, 135(10), 1067-75.

Reed, J. and Roskell, V. (1997). “Focus groups: issues of analysis and interpretation.” Journal of Advanced Nursing, 26, 765-771.

Rogers, M.R. and Lopez, E.C. (2002). “Identifying critical cross-cultural school psychology competencies.” Journal of school psychology, 40(2) 115-141.

Sackman, H. (1974). “Delphi assessment: expert opinion, forecasting, and group process.” Rand, santa Monica, California

Toole, T. (2002). “Construction site safety roles”, Journal of Construction Engineering and Management, 128(3), 203-210.

Veltri, A.T. (2006). Analyzing failures to protect and use a firm’s resources productively: an analytical sequence model. OSU. Corvallis, OR.

U.S. Census Bureau. (2006). “United States Census Bureau.” Retrieved December 1, 2008, from http://www.census.gov/econ/census02/guide/INDRPT23.HTM

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

APPENDIX

List of Appendices

APPENDIX A

INTRODUCTORY SURVEY

The purpose of this 10-15 minute introductory survey is to objectively confirm your status as an expert in the field of construction safety based on your academic and/or professional experience and achievements. All responses will be anonymous and all members will be treated equally.

Directions: Please answer the following questions by typing in or placing an "X" when denoted, fields that require a response are shaded. When you have finished answering all of the questions please email your response to Matthew.Calhoun@colorado.edu

PERSONAL INFORMATION

Name	
Current Employer	
Position	
City	
State	
Country	

ACADEMIC INFORMATION

Please list the degrees that you have earned from accredited institutions of higher education

None	
Associates	
Bachelors	
Masters	
Doctorate	

Please show your approximate number of years in academia

Position	**Approximate Number of Years**
No position in academia	
Lecturer	
Assistant Professor	
Associate Professor	
Professor	
Other (please specify)	

Please indicate your publishing and conference activity in the field of safety

Activity	**Approximate Number**
Publications in peer-reviewed journals	

Books or book chapters	
Conference presentations	
Trade Publications	
Other (Please specify)	

PROFESSIONAL EXPERIENCE

Please show your approximate number of years experience in the construction industry

Position	**Approximate Number of Years**
Laborer	
Foreman	
Superintendent	
Safety and Health Management	
Upper Management (GC, CM or Sub)	
Project Engineer	
Architect	
Other (please specify)	

Please indicate any professional licensure/certification

Licensure or certification	**Please place an "X" where appropriate**
Professional Engineer (PE)	
Certified Safety Professional (CSP)	
Certified Industrial Hygienist (CIH)	
Associated Risk Manager (ARM)	
Licensed Architect (AIA)	
Other (please specify)	

Please list any safety or health committees that you have been or are a member of such as the CIB W099 Technical and Scientific Committee.

Committee Name	**Chair (past or present) of this committee? (if yes, please indicate with an "X")**

If there is an element of your academic or professional experience that helps to qualify or would disqualify you as an expert that cannot be classified in a previous category, please briefly describe it here.

APPENDIX B

ROUND 1 – DELPHI SURVEY

Thank you for taking the time to complete Round 1 of this Delphi survey. This survey is intended to take approximately 20 minutes. When you have finished answering all of the questions, please email your response to Matthew.Calhoun@colorado.edu by Friday, March 13.

INSTRUCTIONS: Please answer all of the following questions to the best of your ability using your experience and judgment. Indicate your response by placing an "X" in the appropriate boxes. The survey requests that you indicate the percent increase in effectiveness that Safety Program Element X has on Safety Program Element Y. There are fifteen safety program elements that are defined below using the text(s): Construction Safety Management and Engineering, edited by D. Hill and Construction Safety, by J. Hinze.

Emergency Response Planning: Plans that include emergency response personnel, equipment, and procedures that cover emergency situations.

Frequent Safety Inspections: Regularly conducted safety inspections by safety manager or safety committee across the project site to identify hazardous exposures to workers.

Job Hazard Analyses: Identification of specific safety hazards prior to a routine job, task, or process.

On-site First Aid: Basic emergency treatment given to someone injured before medical services can arrive.

Project Safety Incentives: A tangible incentive given out on the project level for meeting a pre-specified outcome or level of performance.

Record Keeping and Accident Analyses: The investigation, documentation, and reporting of accidents, near-misses, first-aid cases, and other incidents.

Safety and Health Committees: A diverse group of individuals on a specific project with the sole purpose of addressing safety and health on the worksite.

Safety and Health Orientation: Orientation and training sessions that focus on safe work practices and company safety policies for all new hires.

Site-Safety Manager: Full-time employment of a safety professional with formal safety experience and/or education that is charged with site safety.

Site-Specific Safety Plan: A safety plan developed prior to construction commencing that is specific to a project that documents safety objectives, goals and methods for achieving success.

Subcontractor Selections and Compliance: The selection and oversight of subcontractors to ensure effective safety protection for all workers at the site.

Substance Abuse Programs: The identification and prevention of substance abuse in the workforce. Drug testing programs intended to reduce safety incidents and improve productivity.

Training and Regular Safety Meetings: Formal and informal safety and health training provided for managers, supervisors, and employees. Regular safety meetings are conducted to emphasize training and commitment to safety culture.

Upper Management Support: Upper management of an organization that acknowledges worker safety is a primary goal through motivation and resources to worker safety and health.

Worker Participation and Involvement: Worker involvement in the planning and operation of the Safety and Health program.

DIRECTIONS: Put an "**X**" in the box that indicates the percent increase that **SAFETY AND HEALTH ORIENTATION** has on the effectiveness of each safety program elements listed.

Safety Program Element	Negative Influence	Percent increase that SAFETY AND HEALTH ORIENTATION has on the effectiveness of the indicated safety program element — % Increase in Effectiveness: 0	10	20	30	40	50	60	70	80	90	100	>100
Site-Specific Safety Plan													
Upper Management Support													
Job Hazard Analyses													
Substance Abuse Programs													
Safety and Health Committees													
Site-Safety Manager													
Training and Regular Safety Meetings													
Project Safety Incentives													
Worker Participation and Involvement													
Emergency Response Planning													
On-site First Aid													
Record Keeping and Accident Analyses													
Subcontractor Selections and Compliance													
Frequent Safety Inspections													

DIRECTIONS: Put an "**X**" in the box that indicates the percent increase that a **SITE-SAFETY MANAGER** has on the effectiveness of each safety program elements listed.

Safety Program Element	Negative Influence	Percent increase that a SITE-SAFETY MANAGER has on the effectiveness of the indicated safety program element — % Increase in Effectiveness: 0	10	20	30	40	50	60	70	80	90	100	>100
Project Safety Incentives													
Site-Specific Safety Plan													
Substance Abuse Programs													
Safety and Health Committees													
Training and Regular Safety Meetings													
Worker Participation and Involvement													
On-site First Aid													
Safety and Health Orientation													
Job Hazard Analyses													
Subcontractor Selections and Compliance													
Record Keeping and Accident Analyses													
Emergency Response Planning													
Upper Management Support													
Frequent Safety Inspections													

DIRECTIONS: Put an "**X**" in the box that indicates the percent increase that **PROJECT SAFETY INCENTIVES** have on the effectiveness of each safety program elements listed.

Safety Program Element	Negative Influence	Percent increase that PROJECT SAFETY INCENTIVES have on the effectiveness of the indicated safety program element: % Increase in Effectiveness											
		0	10	20	30	40	50	60	70	80	90	100	>100
Subcontractor Selections and Compliance													
On-site First Aid													
Job Hazard Analyses													
Emergency Response Planning													
Upper Management Support													
Worker Participation and Involvement													
Site-Safety Manager													
Safety and Health Orientation													
Site-Specific Safety Plan													
Substance Abuse Programs													
Frequent Safety Inspections													
Training and Regular Safety Meetings													
Safety and Health Committees													
Record Keeping and Accident Analyses													

DIRECTIONS: Put an "**X**" in the box that indicates the percent increase that **SUBCONTRACTOR SELECTIONS AND COMPLIANCE** has on the effectiveness of each safety program element.

Safety Program Element	Negative Influence	Percent increase that SUBCONTRACTOR SELECTIONS AND COMPLIANCE has on the effectiveness of the indicated safety program element: % Increase in Effectiveness											
		0	10	20	30	40	50	60	70	80	90	100	>100
Job Hazard Analyses													
Frequent Safety Inspections													
Emergency Response Planning													
Worker Participation and Involvement													
Safety and Health Committees													
Project Safety Incentives													
Training and Regular Safety Meetings													
Safety and Health Orientation													
Site-Specific Safety Plan													
On-site First Aid													
Record Keeping and Accident Analyses													
Substance Abuse Programs													
Site-Safety Manager													
Upper Management Support													

DIRECTIONS: Put an "**X**" in the box that indicates the percent increase that **WORKER PARTICIPATION AND INVOLVEMENT** has on the effectiveness of each safety program elements listed.

		Percent increase that WORKER PARTICIPATION AND INVOLVEMENT has on the effectiveness of the indicated safety program element											
		% Increase in Effectiveness											
Safety Program Element	Negative Influence	0	10	20	30	40	50	60	70	80	90	100	>100
Site-Safety Manager													
Safety and Health Committees													
Safety and Health Orientation													
Emergency Response Planning													
Subcontractor Selections and Compliance													
On-site First Aid													
Frequent Safety Inspections													
Substance Abuse Programs													
Site-Specific Safety Plan													
Upper Management Support													
Project Safety Incentives													
Record Keeping and Accident Analyses													
Job Hazard Analyses													
Training and Regular Safety Meetings													

DIRECTIONS: Put an "**X**" in the box that indicates the percent increase that **FREQUENT SAFETY INSPECTIONS** have on the effectiveness of each safety program elements listed.

		Percent increase that FREQUENT SAFETY INSPECTIONS have on the effectiveness of the indicated safety program element											
		% Increase in Effectiveness											
Safety Program Element	Negative Influence	0	10	20	30	40	50	60	70	80	90	100	>100
Subcontractor Selections and Compliance													
Training and Regular Safety Meetings													
Substance Abuse Programs													
Record Keeping and Accident Analyses													
Safety and Health Committees													
Upper Management Support													
Safety and Health Orientation													
Worker Participation and Involvement													
On-site First Aid													
Job Hazard Analyses													
Project Safety Incentives													
Emergency Response Planning													
Site-Safety Manager													
Site-Specific Safety Plan													

DIRECTIONS: Put an "**X**" in the box that indicates the percent increase that **SITE-SPECIFIC SAFETY PLANS** have on the effectiveness of each safety program elements listed.

		Percent increase that SITE-SPECIFIC SAFETY PLANS have on the effectiveness of the indicated safety program element											
		% Increase in Effectiveness											
Safety Program Element	Negative Influence	0	10	20	30	40	50	60	70	80	90	100	>100
Project Safety Incentives													
Frequent Safety Inspections													
On-site First Aid													
Safety and Health Committees													
Emergency Response Planning													
Subcontractor Selections and Compliance													
Substance Abuse Programs													
Job Hazard Analyses													
Training and Regular Safety Meetings													
Worker Participation and Involvement													
Site-Safety Manager													
Safety and Health Orientation													
Upper Management Support													
Record Keeping and Accident Analyses													

DIRECTIONS: Put an "**X**" in the box that indicates the percent increase that **TRAINING AND REGULAR SAFETY MEETINGS** have on the effectiveness of each safety program elements listed.

		Percent increase that TRAINING AND REGULAR SAFETY MEETINGS have on the effectiveness of the indicated safety program element											
		% Increase in Effectiveness											
Safety Program Element	Negative Influence	0	10	20	30	40	50	60	70	80	90	100	>100
Safety and Health Committees													
Substance Abuse Programs													
Site-Specific Safety Plan													
Safety and Health Orientation													
Worker Participation and Involvement													
Upper Management Support													
Job Hazard Analyses													
Emergency Response Planning													
Record Keeping and Accident Analyses													
Project Safety Incentives													
Subcontractor Selections and Compliance													
Frequent Safety Inspections													
On-site First Aid													
Site-Safety Manager													

DIRECTIONS: Put an "**X**" in the box that indicates the percent increase that **UPPER MANAGEMENT SUPPORT** has on the effectiveness of each safety program elements listed.

Safety Program Element	Negative Influence	**Percent increase that UPPER MANAGEMENT SUPPORT has on the effectiveness of the indicated safety program element** — % Increase in Effectiveness: 0	10	20	30	40	50	60	70	80	90	100	>100
Substance Abuse Programs													
Emergency Response Planning													
Frequent Safety Inspections													
Safety and Health Orientation													
Site-Specific Safety Plan													
Record Keeping and Accident Analyses													
Training and Regular Safety Meetings													
Job Hazard Analyses													
Subcontractor Selections and Compliance													
Worker Participation and Involvement													
Project Safety Incentives													
Site-Safety Manager													
On-site First Aid													
Safety and Health Committees													

DIRECTIONS: Put an "**X**" in the box that indicates the percent increase that **ON-SITE FIRST AID** has on the effectiveness of each safety program elements listed.

Safety Program Element	Negative Influence	**Percent increase that ON-SITE FIRST AID has on the effectiveness of the indicated safety program element** — % Increase in Effectiveness: 0	10	20	30	40	50	60	70	80	90	100	>100
Site-Safety Manager													
Safety and Health Committees													
Emergency Response Planning													
Record Keeping and Accident Analyses													
Job Hazard Analyses													
Substance Abuse Programs													
Safety and Health Orientation													
Project Safety Incentives													
Subcontractor Selections and Compliance													
Site-Specific Safety Plan													
Frequent Safety Inspections													
Worker Participation and Involvement													
Upper Management Support													
Training and Regular Safety Meetings													

DIRECTIONS: Put an "**X**" in the box that indicates the percent increase that **SAFETY AND HEALTH COMMITTEES** have on the effectiveness of each safety program elements listed.

		Percent increase that SAFETY AND HEALTH COMMITTEES have on the effectiveness of the indicated safety program element											
		% Increase in Effectiveness											
Safety Program Element	Negative Influence	0	10	20	30	40	50	60	70	80	90	100	>100
Frequent Safety Inspections													
Safety and Health Orientation													
On-site First Aid													
Project Safety Incentives													
Job Hazard Analyses													
Record Keeping and Accident Analyses													
Site-Specific Safety Plan													
Substance Abuse Programs													
Upper Management Support													
Training and Regular Safety Meetings													
Subcontractor Selections and Compliance													
Site-Safety Manager													
Worker Participation and Involvement													
Emergency Response Planning													

DIRECTIONS: Put an "**X**" in the box that indicates the percent increase that **EMERGENCY RESPONSE PLANNING** has on the effectiveness of each safety program elements listed.

		Percent increase that EMERGENCY RESPONSE PLANNING has on the effectiveness of the indicated safety program element											
		% Increase in Effectiveness											
Safety Program Element	Negative Influence	0	10	20	30	40	50	60	70	80	90	100	>100
Substance Abuse Programs													
Site-Safety Manager													
Job Hazard Analyses													
Safety and Health Committees													
Subcontractor Selections and Compliance													
Frequent Safety Inspections													
Site-Specific Safety Plan													
Training and Regular Safety Meetings													
Record Keeping and Accident Analyses													
Upper Management Support													
Safety and Health Orientation													
Worker Participation and Involvement													
On-site First Aid													
Project Safety Incentives													

DIRECTIONS: Put an "**X**" in the box that indicates the percent increase that **RECORD KEEPING AND ACCIDENT ANALYSES** have on the effectiveness of each safety program elements listed.

		Percent increase that RECORD KEEPING AND ACCIDENT ANALYSES have on the effectiveness of the indicated safety program element											
		% Increase in Effectiveness											
Safety Program Element	Negative Influence	0	10	20	30	40	50	60	70	80	90	100	>100
Site-Specific Safety Plan													
Safety and Health Orientation													
Substance Abuse Programs													
Training and Regular Safety Meetings													
Project Safety Incentives													
On-site First Aid													
Site-Safety Manager													
Upper Management Support													
Emergency Response Planning													
Safety and Health Committees													
Worker Participation and Involvement													
Job Hazard Analyses													
Subcontractor Selections and Compliance													
Frequent Safety Inspections													

DIRECTIONS: Put an "**X**" in the box that indicates the percent increase that **JOB HAZARD ANALYSES** have on the effectiveness of each safety program elements listed.

		Percent increase that JOB HAZARD ANALYSES have on the effectiveness of the indicated safety program element											
		% Increase in Effectiveness											
Safety Program Element	Negative Influence	0	10	20	30	40	50	60	70	80	90	100	>100
Emergency Response Planning													
Safety and Health Committees													
Substance Abuse Programs													
Safety and Health Orientation													
Frequent Safety Inspections													
On-site First Aid													
Upper Management Support													
Site-Safety Manager													
Training and Regular Safety Meetings													
Worker Participation and Involvement													
Project Safety Incentives													
Site-Specific Safety Plan													
Record Keeping and Accident Analyses													
Subcontractor Selections and Compliance													

DIRECTIONS: Put an "**X**" in the box that indicates the percent increase that **SUBSTANCE ABUSE PROGRAMS** have on the effectiveness of each safety program elements listed.

		Percent increase that SUBSTANCE ABUSE PROGRAMS have on the effectiveness of the indicated safety program element											
		% Increase in Effectiveness											
Safety Program Element	Negative Influence	0	10	20	30	40	50	60	70	80	90	100	>100
Record Keeping and Accident Analyses													
Safety and Health Committees													
Upper Management Support													
Training and Regular Safety Meetings													
Worker Participation and Involvement													
Job Hazard Analyses													
Subcontractor Selections and Compliance													
Safety and Health Orientation													
On-site First Aid													
Site-Safety Manager													
Site-Specific Safety Plan													
Frequent Safety Inspections													
Project Safety Incentives													
Emergency Response Planning													

Thank you for completing Round 1 of the Delphi Survey. Your survey responses can be emailed to Matthew.Calhoun@colorado.edu or printed and mailed to:

University of Colorado at Boulder
Dept. of Civil, Environmental, and Architectural Engineering
Construction Engineering and Management Program
Attn: Matt Calhoun (Graduate Student)
1111 Engineering Drive, ECOT 440
Boulder, CO 80309-0428 USA

After all Delphi participants have completed the Round 1 survey, the results will be reported to you with the median response and range. In Round 2 you will be given the opportunity to change your response. Round 2 is scheduled to start March 23, 2009. Thank you again for your time in this study.

APPENDIX C

ROUND 2 – DELPHI SURVEY

Thank you for taking completing the Round 1 Delphi survey. I recognize that the survey required a significant time investment. I appreciate your time and effort. This Round 2 survey continues the Delphi process for this study. The purpose of Round 2 is to provide you with the opportunity to change your response, if desired, given the median group response for each category.

This survey is intended to take approximately 20 minutes as you are only being asked to review your previous responses given the collective group median. When you have finished answering all of the questions, please email your response to Matthew.Calhoun@colorado.edu by Friday, April 10.

INSTRUCTIONS: For each safety element you will see 2 values: your response from the Round 1 survey (indicated with a highlighted box), and the group median from the Round 1 survey indicated in the column to the far right hand of each table. Please take one of the following three actions for each category:

1. **Accept the group median response by leaving the field completely unchanged.**
2. **Maintain your original response by placing an 'X' in the highlighted field*.**
3. **Indicate a new response by placing an 'X' in the appropriate field*.**

*If your response is more than ten percent above or below the group median please provide a reason for you outlying response in the field provided.

The Round 1 survey provided you with the definitions of fifteen construction safety program elements. If at any time you would like to review these definitions, you will find them at the end of this survey.

DIRECTIONS: Please do one of the following: **(1)**accept the group median response by leaving the field completely unchanged, **(2)**maintain your original response by placing an 'X' in the highlighted field*, **(3)**indicate a new response by placing an 'X' in the appropriate field*.

*If your response is more than 10 percent above or below the group median please provide a reason for you outlying response in the field provided.

Safety Program Element	Negative Influence	Percent increase that TRAINING AND REGULAR SAFETY MEETINGS have on the effectiveness of the indicated safety program element: % Increase in Effectiveness												Median
		0	10	20	30	40	50	60	70	80	90	100	>100	
Project Safety Incentives														15
Worker Participation and Involvement														75
Safety and Health Orientation														50
Upper Management Support														15
Safety and Health Committees														35
Site-Safety Manager														50
Emergency Response Planning														45
On-site First Aid														10
Subcontractor Selections and Compliance														15
Frequent Safety Inspections														60
Site-Specific Safety Plan														50
Record Keeping and Accident Analyses														35
Substance Abuse Programs														35
Job Hazard Analyses														60

Reason(s) for outlying response(s):

Safety Program Element	Negative Influence	Percent increase that PROJECT SAFETY INCENTIVES have on the effectiveness of the indicated safety program element: % Increase in Effectiveness												Median
		0	10	20	30	40	50	60	70	80	90	100	>100	
Job Hazard Analyses														40
Worker Participation and Involvement														70
Safety and Health Orientation														10
Frequent Safety Inspections														30
Substance Abuse Programs														35
On-site First Aid														0
Safety and Health Committees														15
Emergency Response Planning														0
Record Keeping and Accident Analyses														0
Upper Management Support														40
Site-Specific Safety Plan														15
Training and Regular Safety Meetings														15
Subcontractor Selections and Compliance														5
Site-Safety Manager														35

Reason(s) for outlying response(s):

Safety Program Element	Negative Influence	Percent increase that JOB HAZARD ANALYSES have on the effectiveness of the indicated safety program element: % Increase in Effectiveness												Median
		0	10	20	30	40	50	60	70	80	90	100	>100	
Site-Safety Manager														60
Safety and Health Committees														15
Frequent Safety Inspections														70
On-site First Aid														10
Safety and Health Orientation														10
Project Safety Incentives														10
Worker Participation and Involvement														55
Subcontractor Selections and Compliance														25
Site-Specific Safety Plan														75
Record Keeping and Accident Analyses														30
Upper Management Support														50
Training and Regular Safety Meetings														30
Substance Abuse Programs														5
Emergency Response Planning														25

Reason(s) for outlying response(s):

Safety Program Element	Negative Influence	Percent increase that SUBCONTRACTOR SELECTIONS AND COMPLIANCE has on the effectiveness of the indicated safety program element: % Increase in Effectiveness												Median
		0	10	20	30	40	50	60	70	80	90	100	>100	
Upper Management Support														30
Worker Participation and Involvement														45
Site-Safety Manager														40
Emergency Response Planning														25
Safety and Health Orientation														25
On-site First Aid														15
Substance Abuse Programs														25
Job Hazard Analyses														40
Project Safety Incentives														15
Frequent Safety Inspections														40
Training and Regular Safety Meetings														25
Safety and Health Committees														30
Site-Specific Safety Plan														45
Record Keeping and Accident Analyses														30

Reason(s) for outlying response(s):

APPENDIX D

ROUND 3 – DELPHI SURVEY

Thank you for completing the Round 2 Delphi survey. We appreciate your time and effort. This Round 3 survey concludes the Delphi process for this study. The purpose of Round 3 is to provide you with a final opportunity to change your response, if desired, given the median group response and reasons for outlying responses for each safety element.

This survey is intended to take approximately 20 minutes as you are only being asked to review your previous responses given the collective group median. When you have finished answering all of the questions, please email your response to Matthew.Calhoun@colorado.edu by Friday, May 15.

INSTRUCTIONS: The instructions for this survey are nearly identical to that of the Round 2 survey. The only difference between this survey and the Round 2 survey is the reasons provided at the end of each page. In Round 2 all panelists were asked to provide reasons if their responses were more than ten percent from the median. Please review the reasons provided by other expert panelists and consider them in your final response.

For each safety element you will see 2 values: your response from the Round 2 survey (indicated with a yellow highlighted box), and the group median from the Round 2 survey indicated in the column to the far right hand of each table. Please take one of the following three actions for each category:

4. **Accept the group median response by leaving all fields completely unchanged.**
5. **Maintain your original response by placing an 'X' in the highlighted field*.**
6. **Indicate a new response by placing an 'X' in the appropriate field*.**

*If your final response is more than ten percent above or below the group median please provide a reason for your outlying response in the field provided if you have not done so already.

*If your response is >100% or a negative influence, please quantify how many percent.

We **URGE** you to review and consider the median and the responses provided by the other expert panelists when considering your final responses for each element.

		Percent increase that TRAINING AND REGULAR SAFETY MEETINGS have on the effectiveness of the indicated safety program element												
		% Increase in Effectiveness												
Safety Program Element	Negative Influence	0	10	20	30	40	50	60	70	80	90	100	>100	Median
Project Safety Incentives														15
Worker Participation and Involvement														77.5
Safety and Health Orientation														45
Upper Management Support														12.5
Safety and Health Committees														37.5
Site-Safety Manager														50
Emergency Response Planning														47.5
On-site First Aid														10
Subcontractor Selections and Compliance														12.5
Frequent Safety Inspections														65
Site-Specific Safety Plan														50
Record Keeping and Accident Analyses														35
Substance Abuse Programs														35
Job Hazard Analyses														65

Reason(s) for outlying response(s):

- Training and regular safety meetings were not appear to increase the effectiveness of orientation, as orientation is for workers who have not yet received training.
- Similarly emergency response planning should occur prior to the commencement of construction activities, so there will not be any benefit from the training, except for education others about the response plan. Depends on what is covered in the training and safety meetings.
- The effectiveness of safety inspections might be enhanced slightly but it depends on the individual making the inspections. The results of safety inspections might be better as a result of training, but the effectiveness of the inspections is more difficult to assess. Assumptions have to be made throughout concerning the effectiveness.

Safety Program Element	Negative Influence	Percent increase that PROJECT SAFETY INCENTIVES have on the effectiveness of the indicated safety program element: % Increase in Effectiveness												Median
		0	10	20	30	40	50	60	70	80	90	100	>100	
Job Hazard Analyses														30
Worker Participation and Involvement														70
Safety and Health Orientation														10
Frequent Safety Inspections														35
Substance Abuse Programs														42.5
On-site First Aid														0
Safety and Health Committees														17.5
Emergency Response Planning														0
Record Keeping and Accident Analyses														0
Upper Management Support														40
Site-Specific Safety Plan			15											17.5
Training and Regular Safety Meetings			15											17.5
Subcontractor Selections and Compliance		5												7.5
Site-Safety Manager					35									37.5

Reason(s) for outlying response(s):

- Incentives are seldom used properly and typically promote injury hiding, which is information hiding.
- Project incentives have a great impact on workers participation and morale and will help better safety. I am not sure it will help with other elements except for committees which will increase participation.
- Worker Participation and Involvement is not a good thing for project safety incentives, it yields underreporting.
- Safety incentives will vary in their effectiveness depending on whether they are based on not having injuries or if they are designed to reward safe work behavior. If based on not having injuries, incentives will result in some injuries not being reported, so a negative percentage might be more appropriate.
- Job hazard analyses are prepared before the work takes place. Safety incentives relate to performance on the site during construction. There is no connection between these two elements.

		Percent increase that JOB HAZARD ANALYSES have on the effectiveness of the indicated safety program element											
		% Increase in Effectiveness											
Safety Program Element	Negative Influence	0	10	20	30	40	50	60	70	80	90	100	>100	Median
Site-Safety Manager														60
Safety and Health Committees														25
Frequent Safety Inspections														65
On-site First Aid														10
Safety and Health Orientation														15
Project Safety Incentives														10
Worker Participation and Involvement														55
Subcontractor Selections and Compliance														25
Site-Specific Safety Plan														77.5
Record Keeping and Accident Analyses														30
Upper Management Support														50
Training and Regular Safety Meetings														35
Substance Abuse Programs														5
Emergency Response Planning														25

Reason(s) for outlying response(s):

- JHAs are the first line of defense against injuries. Its value increased when used during accident analyses to verify whether JHA was performed correctly. It's a great help for safety professionals and is a great tool for inspections.
- Frequent Safety Inspections requires Job Hazard Analyses.
- JHAs should help to identify safety and health issues on the project and this should help overall project safety. This would not be expected to influence safety incentives or recordkeeping, even if there are fewer accidents to investigate.

APPENDIX E

Research objective: To quantify the percent increase in effectiveness that one safety program element has on another safety program element using an expert panel. Fifteen safety program elements were studied and are presented in the cross-impact table below (results not included).
Validation: The expert panel came to a consensus and these findings now need to be validated. I have three questions to present to you:

- Which 5 safety program elements contribute the most to the other elements?
- Which 5 safety program elements are impacted the most by the other elements?
- Which 5 pair wise safety program element interactions are most significant (i.e. have the greatest percent increase in effectiveness?)

Table 1 - Pair wise cross impacts of construction safety program elements (Results will be presented after the interview)

Impact ON

Percent increase in effectiveness

Impact OF	Emergency Response Plan	Frequent Inspections	Job Hazard Analyses	On-Site First Aid	Project Safety Incentives	Record Keeping & Accident Invstg.	Safety & Health Committee	Safety & Health Orientation	Site-Safety Manager	Site-Specific Safety Plan	Subcontractor Management	Substance Abuse Programs	Training & Regular Safety Meetings	Upper Management Support	Worker Involvement
Emergency Response Plan															
Frequent Inspections															
Job Hazard Analyses															
On-Site First Aid															
Project Safety Incentives															
Record Keeping & Accident Analyses															
Safety & Health Committee															
Safety & Health Orientation															
Site-Safety Manager															
Site-Specific Safety Plan															
Subcontractor Management															
Substance Abuse Programs															
Training & Regular Safety Meetings															
Upper Management Support															
Worker Involvement															